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# UDAAN

## PRELIMS WALLAH (STATIC)

## PRELIMS 2025

# PHYSICAL GEOGRAPHY

QUICK AND COMPREHENSIVE REVISION SERIES

# CONTENTS

# 1 The Origin, Evolution and Geodesy of Earth

## THEORIES OF EARTH'S ORIGIN

### Early Theories

- **Nebular Hypothesis**
  - **Proposed by:** Immanuel Kant (1755) and later revised by Pierre-Simon Laplace (1796).
  - **Concept:** The theory suggests that the Sun and planets formed from a large, slowly rotating cloud of gas and dust (solar nebula). Over time, this cloud contracted due to gravity, flattened into a disk, and began spinning faster. The Sun formed at the center, and the leftover material formed planets.
  - **Supporting Evidence:**
    - Similar disk-like structures are observed around young stars, supporting the idea of disk formation leading to planetary systems.
    - The **conservation of angular momentum** explains the increase in spinning speed as the nebula contracted.
  - **Challenges:**
    - This model does not explain the detailed mechanisms for planet formation, particularly how the initial dust particles grew into larger planetary bodies.
- **Revised Nebular Hypothesis**
  - **Proposed by:** Otto Schmidt (Russia) and Carl Weizascar (Germany).
  - **Concept:** This theory expanded on the original Nebular Hypothesis by adding details about how planets formed. The solar system started as a large cloud of gas (mostly hydrogen and helium) mixed with dust. Through the process of **accretion**, dust particles collided and stuck together to form larger bodies. Eventually, these formed planets, moons, and other celestial objects.
  - **Supporting Evidence:**
    - Accretion processes are seen in modern astronomy, where small dust grains stick together to form larger clumps.
    - Dust clouds around stars are observed in space, suggesting this process occurs in other solar systems.
  - **Challenges:**
    - It does not fully explain the observed distribution of angular momentum in the solar system, as the Sun has very little compared to the planets.
- **Planetesimal Hypothesis**
  - **Proposed by:** Thomas Chamberlain and Forest Moulton (1900), later supported by Sir James Jeans and Sir Harold Jeffrey.
  - **Concept:** This theory suggests that a large star passed near the Sun, pulling off material due to gravitational forces. This material cooled and condensed into planetesimals (small, solid bodies), which later grew into planets through accretion.
  - **Supporting Evidence:**
    - The hypothesis was developed before modern understanding of nuclear fusion and the Sun's heat. It attempted to explain how solid materials could form into planets.
    - The idea of gravitational influence from passing stars is supported by gravitational tidal forces seen in cosmic interactions today.
  - **Challenges:**
    - This theory fell out of favor due to its reliance on a close encounter with another star, a rare event.

### Modern Theories

- **Big Bang Theory (Expanding Universe Hypothesis)**
  - **Proposed by:** Georges Lemaitre (1927) and strengthened by Edwin Hubble's observations (1929).

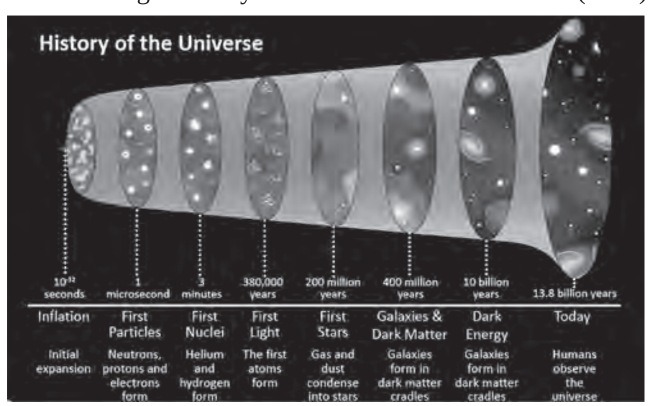



**Fig.** Big Bang Theory

- **Concept:** According to this theory, around 13.7 billion years ago, the universe began from a singular, extremely dense and hot point (referred to as a "tiny ball"). This point exploded in an event known as the **Big Bang**, causing the universe to expand rapidly. As the universe expanded, it cooled, allowing energy to convert into matter. Over time, galaxies, stars, and planets formed.
- **Supporting Evidence:**
  - **Redshift of Galaxies:** Hubble observed that galaxies are moving away from us, implying the universe is expanding. This is seen through the redshift of light from distant galaxies.
  - **Cosmic Microwave Background Radiation (CMB):** Discovered by Penzias and Wilson, this faint radiation is the remnant heat from the early universe, providing strong evidence for the Big Bang.
  - **Abundance of Light Elements:** The Big Bang model predicts the relative amounts of hydrogen, helium, and lithium in the universe, matching observed quantities.
- **Challenges:**
  - While it explains the large-scale structure of the universe, the Big Bang does not account for what happened before the explosion or why the universe's expansion is accelerating (which is attributed to dark energy).

- **Steady State Theory**
  - **Proposed by:** Fred Hoyle (1948).
  - **Concept:** In contrast to the Big Bang, this theory suggests that the universe has always existed in its current state. It is infinite in both time and space, with matter continuously being created to maintain a constant density as the universe expands.
  - **Supporting Evidence:**
    - At the time, it was appealing because it avoided questions about the universe's origin and why an explosion would occur.
    - The idea that the universe is eternal and unchanging is philosophically attractive to some.
  - **Challenges:**
    - The discovery of the CMB and observations of an evolving universe over time (such as the formation of galaxies and stars) contradicted the steady-state model. As a result, this theory has largely been abandoned.

## STAR FORMATION

- **Initial Universe and Density Differences:** After the Big Bang, matter and energy were not evenly distributed. These small density variations led to regions where gravitational forces were stronger, pulling nearby matter toward these areas. This process was the foundation for the creation of galaxies.
- **Nebula and Galaxy Formation:** A nebula is a large cloud of hydrogen gas, which acts as the birthplace of stars and galaxies. Galaxies begin to form as hydrogen gas accumulates into these large clouds. Over time, localized areas within the nebula grow denser, eventually leading to the formation of clumps of gas.

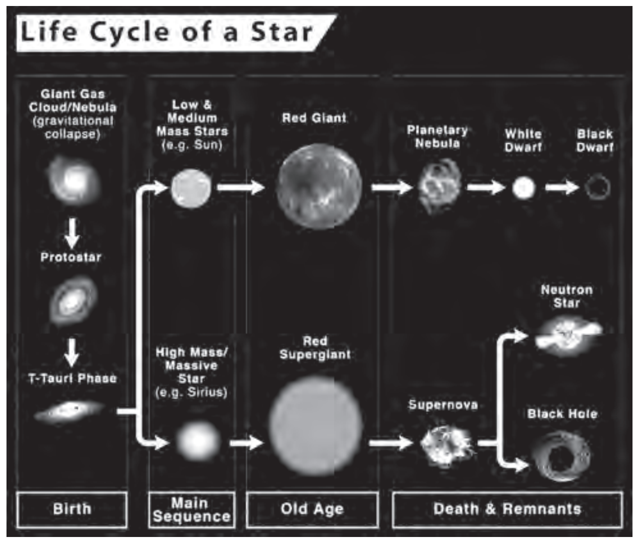



**Fig.** Life Cycle of Star

- **Birth of Stars:** These gas clumps continue to gather more material, becoming even denser. As the gravitational forces increase, the core temperature rises until nuclear fusion ignites in the center. This process marks the formation of a star. Over millions of years, more stars form within the galaxy.

### Formation of Planets

- **Formation of Stars within a Nebula:** Stars are essentially large lumps of gas formed inside a nebula. When a star forms, it creates a core within a dense gas cloud. Around this core, a rotating disc of gas and dust develops.
- **Development of Planetesimals:** As the gas surrounding the core starts condensing, smaller rounded objects begin to form through cohesion. These smaller objects are called planetesimals. Over time, these planetesimals start to collide and stick together due to gravitational attraction.

- **Planet Formation:** The planetesimals continue to merge and accrete, eventually forming fewer but larger bodies that develop into planets. This process is driven by both collisions and the gravitational pull of nearby objects.
- **Accretion Process:** The term *accretion* refers to the gradual accumulation of matter to form larger bodies. This process continues over millions of years, eventually leading to the creation of full-sized planets that orbit their parent star.

## Timeline of Earth's Evolution

- **13.7 Billion Years Ago - Big Bang**
  - The universe originated from a singularity, leading to the formation of galaxies, including the Milky Way, which hosts our solar system.
- **5-6 Billion Years Ago - Formation of Stars**
  - Within galaxies, stars formed from clouds of gas and dust due to gravitational forces, leading to the creation of various stellar bodies.
- **4.6 Billion Years Ago - Formation of Planets**
  - The solar system began to take shape as particles in a rotating disk around the young Sun collided and coalesced, forming the planets, including Earth.
- **4.4 Billion Years Ago - Formation of the Moon**
  - A significant impact event involving a Mars-sized body led to debris that eventually coalesced to form the Moon, influencing Earth's tides and axial tilt.
- **4 Billion Years Ago - Formation of Oceans**
  - As the Earth cooled, water vapor condensed and accumulated, forming oceans. This process was vital for developing the planet's climate and supporting life.
- **3.8 Billion Years Ago - Life Begins to Evolve** **[UPSC 2018]**
  - Simple life forms, likely prokaryotic microbes, emerged in the oceans, marking the beginning of biological evolution on Earth.
- **2.5-3 Billion Years Ago - Evolution of Photosynthesis**
  - Photosynthetic organisms, particularly cyanobacteria, began converting sunlight into energy, releasing oxygen as a byproduct. This process drastically altered Earth's atmosphere and paved the way for more complex life forms.

## GEOLOGICAL TIMESCALE

- **Definition:** A system of chronological dating used to describe Earth's history, dividing it into eons, eras, periods, epochs, and ages.
- **Major Divisions:**
  - **Eons** (largest): *Hadean, Archean, Proterozoic, Phanerozoic*.
  - **Eras** (within Phanerozoic): *Paleozoic, Mesozoic, Cenozoic*.
  - **Periods**: Examples include *Cambrian, Jurassic, Quaternary*.
  - **Epochs** (within Cenozoic): *Pleistocene, Holocene*.
- **Time Span:** Spans approximately 4.6 billion years, from Earth's formation to the present.
- **Key Events:**
  - **Precambrian** (4.6 billion to 541 million years ago): Formation of Earth and early life (unicellular organisms).
  - **Paleozoic Era:** Explosion of marine life, first land plants, and reptiles.
  - **Mesozoic Era:** Age of dinosaurs and first mammals.
  - **Cenozoic Era:** Rise of mammals and humans.
- **Current Epoch:** *Holocene*, beginning around 11,700 years ago, marked by human civilization.
- **Importance:** Helps scientists understand Earth's evolution, climate changes, and life forms over time.

## Geological Time Scale

| Relative Duration of Eons | Era | Period | Epoch | Age (Millions of Years Ago) | Some Important Events in the History of Life |
|---|---|---|---|---|---|
| Phanerozoic | Cenozoic | Quaternary | Holocene | 0.01 | Historical time |
| | | | Pleistocene | 1.8 | Ice ages; Origin of genus Homo |
| | | Neogene | Pliocene | 5.3 | Appearance of bipedal human ancestors. |
| | | | Miocene | 23 | Continued radiation of mammals and angiosperms; earliest direct humans ancestors |
| Proterozoic | | Paleogene | Oligocene | 33.9 | Origins of many primate group |
| | | | Eocene | 55.8 | Angiosperm dominance increases; continued radiation of most modern mammalian orders |
| | | | Paleocene | 65.5 | Major radiation of mammals, birds and pollinating insects |
| | Mesozoic | Cretaceous | | 145.5 | Flowering plants (angiosperms) appear, many groups of organisms, including most dinosaurs, become extinct at end of period |
| | | Jurassic | | 199.6 | Gymnosperms continue as dominant plants; dinosaurs abundant and diverse |
| | | Triassic | | 251 | Cone-bearing plants (gymnosperms) dominate landscape; radiation of dinosaurs; origin of mammal |
| | Paleozoic | Permian | | 299 | Radiation of reptiles; origin of most present-day groups of insects; extinction of marine and terrestrial organisms many at end of period |
| Archaean | | Carboniferous | | 359.2 | Extensive forests of vascular plants; first seed plants appear, origin of reptiles; amphibians dominant |
| | | Devonian | | 416 | Diversification of bony fishes; first tetrapods and insects appear |
| | | Silurian | | 443.7 | Diversification of early vascular plants |
| | | Ordovician | | 488.3 | Marine algae abundant; colonization of land by diverse fungi, plants and arthropods |
| | | Cambrian | | 542 | Sudden increase in diversity of many animal phyla (Cambrian explosion) |
| | | Ediacaran | | 600 | Diverse algae and soft-bodied invertebrate animals |
| | | | | 2,100-2500 | Oldest fossils of eukaryotic cells |
| | | | | 2,700 | Concentration of atmospheric oxygen begins to increase |
| | | | | 3,500 | Oldest fossils of cells (prokaryotes) appear |
| | | | | 3,800 | Oldest known rocks on Earth's surface |
| | | | | App. 4,600 | Origin of Earth |

## Our Solar System

| Parameter | Description |
|---|---|
| **Solar System** | A celestial system including the Sun, planets, asteroids, comets, dust, and gases. |
| **Location** | Orbits in the Milky Way's outer spiral arm (Orion arm). |
| **Inner/Terrestrial Planets** | High density, smaller size, solid rocky surfaces due to intense solar winds. Examples: **Mercury, Venus, Earth, Mars.** |
| **Outer/Jovian Planets** | Low density, larger size, gaseous surfaces due to weak solar winds. Examples: **Jupiter, Saturn, Uranus, Neptune.** |
| **Total Planets** | 8 (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune) |
| **Mercury** | Smallest and nearest to the Sun. |
| **Venus** | Earth's twin; hottest planet due to carbon dioxide atmosphere and sulfuric acid clouds. |
| **Jupiter** | Largest planet with hydrogen, helium, methane, and ammonia atmosphere. |
| **Axis Tilt** | Venus and Uranus rotate opposite to other planets due to extreme axial tilt. |

## Overview of Planets

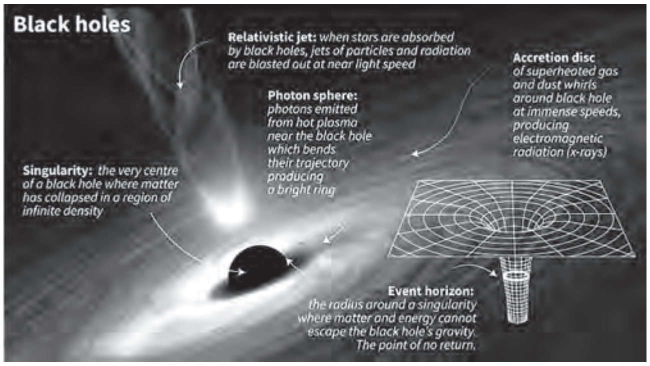
| Planet | Type | Time of Rotation | Axial Tilt (°) | Composition | Distance from Sun (AU) | Key Features |
|---|---|---|---|---|---|---|
| **Mercury** | Terrestrial | 59 Earth days | 0.03 | Rocky, metallic core | 0.39 | Closest to Sun, no atmosphere, extreme temperature fluctuations. |
| **Venus** | Terrestrial | -243 Earth days (retrograde) | 177.4 | Rocky, dense $CO_2$ atmosphere | 0.72 | Hottest planet due to greenhouse effect; rotates in opposite direction. |
| **Earth** | Terrestrial | 24 hours | 23.5 | Rocky, water on surface, $N_2$-$O_2$ atmosphere | 1 | Only planet with liquid water and life; located in the Goldilocks zone. |
| **Mars** | Terrestrial | 24.6 hours | 25.2 | Rocky, thin $CO_2$ atmosphere | 1.52 | Known as the "Red Planet"; has the largest volcano (Olympus Mons) in the Solar System. |
| **Jupiter** | Jovian (Gas Giant) | 9.9 hours | 3.1 | Hydrogen, helium, ammonia, methane | 5.2 | Largest planet; Great Red Spot (a massive storm); faint ring system. |
| **Saturn** | Jovian (Gas Giant) | 10.7 hours | 26.7 | Hydrogen, helium, methane | 9.539 | Iconic ring system; low density (could float in water). |
| **Uranus** | Jovian (Ice Giant) | -17.2 hours (retrograde) | 97.8 | Hydrogen, helium, methane, water, ammonia | 19.2 | Spins on its side due to extreme axial tilt; pale blue-green color due to methane. |
| **Neptune** | Jovian (Ice Giant) | 16.1 hours | 28.3 | Hydrogen, helium, methane | 30.05 | Deep blue color; fastest winds in the Solar System; has faint rings. |

# OVERVIEW OF ASTRONOMICAL OBJECTS AND CONCEPTS

## Key Celestial Objects

- **Exoplanets**
  - Planets orbiting stars outside our Solar System.
  - Discovered using methods like radial velocity and transit photometry. Example: Proxima Centauri b.
- **Dwarf Planets**
  - Celestial bodies that orbit the Sun, have enough mass for a nearly round shape, but haven't cleared their orbital paths.
  - Examples: Pluto, Eris, Haumea, Makemake, Ceres.
- **White Dwarfs**
  - Remnants of stars like the Sun after exhausting their nuclear fuel.
- **Comets**
  - Icy bodies from regions like the Kuiper Belt or Oort Cloud.
  - Develop tails (gas and dust) when near the Sun due to sublimation.
- **Asteroids**
  - Rocky remnants from the Solar System's formation, mostly located in the Asteroid Belt.

- **Black Holes**
  - Regions of spacetime with gravitational forces so strong that not even light can escape.
  - **Event Horizon:** Boundary beyond which nothing escapes.
  - Formed from collapsing massive stars beyond the **Chandrasekhar Limit** (~1.4 solar masses).




- **Pulsars**
  - Highly magnetized, rotating neutron stars emitting beams of electromagnetic radiation.
  - Detected as regular pulses when the beam aligns with Earth.
- **Supernovae**
  - Explosions marking the death of massive stars, dispersing elements into space and forming neutron stars or black holes.
- **Neutron Stars**
  - Compact remnants of massive stars that exploded as supernovae. Composed mostly of neutrons.
- **Quasars**
  - Extremely bright and energetic centers of distant galaxies, powered by supermassive black holes.
  - Emit vast amounts of radiation as matter spirals into the black hole.

## Advanced Concepts

- **Gravitational Lensing**
  The bending of light from distant objects by a massive intervening object, as predicted by Einstein's **General Relativity**.
  - Used to detect dark matter and distant galaxies.

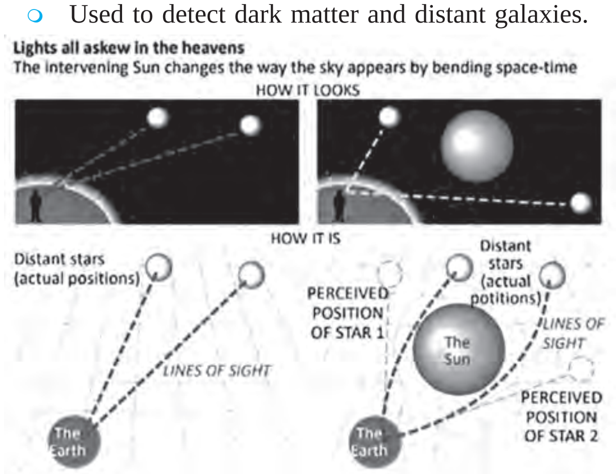



**Fig.** Gravitational Lensing

- **General Relativity**
  - Einstein's theory describing gravity as the warping of spacetime by mass and energy.
  - Predicts phenomena like gravitational waves and time dilation near massive objects.
- **Chandrasekhar Limit**
  - Maximum mass (~1.4 solar masses) a white dwarf can have before collapsing into a neutron star or black hole.
- **Event Horizon**
  - A boundary around a black hole where escape velocity equals the speed of light.

## Other Celestial Phenomena

- **Meteoroids, Meteors, and Meteorites**
  - **Meteoroid:** Small rocky or metallic body in space.
  - **Meteor:** A meteoroid entering Earth's atmosphere, producing a bright streak.
  - **Meteorite:** A meteoroid that survives its journey and lands on Earth.
- **Oort Cloud**
  - Hypothetical outermost boundary of the Solar System, source of long-period comets.
- **Planetary Nebulae**
  - Clouds of gas ejected by dying stars, often forming beautiful, colorful structures.
- **Supernovae**
  - Explosions marking the death of massive stars, dispersing elements into space and forming neutron stars or black holes.
- **Interstellar Medium**
  - The gas and dust filling the space between stars, crucial for star formation.
- **Dark Matter and Dark Energy**
  - **Dark Matter:** Unseen matter influencing galaxy rotation and structure.
  - **Dark Energy:** Mysterious force driving the accelerated expansion of the Universe.

## THE MOON: EARTH'S NATURAL SATELLITE

- **Basic Facts**
  - The Moon is the only natural satellite of Earth, with a diameter approximately one-quarter that of Earth.
- **Tidal Locking**
  - The Moon is tidally locked to Earth, meaning it takes about **27 days** to complete both its orbit around Earth and its rotation on its axis. As a result, only one side of the Moon is visible from Earth.
- **Formation**
  - The prevailing theory regarding the Moon's formation is the **giant impact hypothesis**, also known as the "big splat." This theory suggests that the Moon formed from the debris resulting from a collision between a Mars-sized body and the early Earth.

- **Super Moon**
  - A **Super Moon** occurs when the Moon is at its closest distance to Earth (known as **perigee**) during a full moon. During this event, the Moon can appear **14% larger** and **30% brighter** than usual, making it a spectacular sight.

### Moons of Various Planets

| Planet | Number of Moons | Notable Moons | Key Features |
|---|---|---|---|
| Mercury | 0 | None | - |
| Venus | 0 | None | - |
| Earth | 1 | Moon | Influences tides; stabilizes axial tilt. |
| Mars | 2 | Phobos, Deimos | Phobos: irregular, spiraling inward; Deimos: smaller, distant. |
| Jupiter | 80 | Io, Europa, Ganymede, Callisto | Io: volcanically active; Europa: potential ocean; Ganymede: largest moon; Callisto: heavily cratered. |
| Saturn | 80+ | Titan, Rhea, Lapetus | Titan: thick atmosphere, methane lakes; Rhea: icy surface; Iapetus: two-tone coloration. |
| Uranus | 27 | Titania, Oberon, Miranda | Titania: largest moon; Oberon: heavily cratered; Miranda: unique surface features. |
| Neptune | 14 | Triton | Triton: retrograde orbit, geologically active. |

## RETROGRADE AND PROGRADE MOTION AND ROTATION

- **Prograde Motion**
  - **Definition:** The apparent eastward motion of a planet against the background of stars as observed from Earth. It is the usual, counterclockwise orbital motion of planets around the Sun (when viewed from above the Sun's north pole).
  - **Cause:** Planets orbit the Sun in nearly the same plane and direction due to the conservation of angular momentum from the rotating disk of gas and dust that formed the Solar System.
- **Retrograde Motion**
  - **Definition:** The apparent westward motion of a planet against the backdrop of stars as seen from Earth.
  - **Cause:** Retrograde motion is an optical illusion caused by the relative positions and motions of Earth and the other planets. When Earth overtakes a slower-moving outer planet (like Mars), that planet appears to move backward temporarily in the sky.

### Key Differences Between Retrograde Motion and Rotation

- **Retrograde Motion:** Apparent backward movement in the sky, observed due to relative orbital dynamics (optical illusion).
- **Retrograde Rotation:** Physical spinning or axial rotation of a planet in the opposite direction of most planets in the Solar System.

### Retrograde Rotation of Venus and Uranus

**Venus (Retrograde Rotation):** Venus rotates backward (clockwise) compared to its orbit around the Sun, with a very slow rotation period of 243 Earth days.

- **Reasons:**
  1. **Giant Impact Hypothesis:** A massive collision early in Venus's history might have reversed its spin direction.
  2. **Atmospheric Effects:** Venus's thick atmosphere might have interacted with its surface through tidal friction, contributing to the reversal over millions of years.

### Uranus (Axial Tilt and Retrograde-like Rotation)

- **Axial Tilt:** Uranus has an extreme tilt of about 98 degrees, causing it to essentially "roll" along its orbit. This results in retrograde-like rotation relative to the Sun.
- **Reasons:**
  1. **Massive Collisions:** Multiple or a single catastrophic impact with a large proto-planet during the formation of the Solar System likely knocked Uranus onto its side.
  2. **Gravitational Interactions:** Strong interactions with massive bodies during the early stages of Solar System development could have altered its axial tilt.

## EARTH : GOLDILOCKS ZONE, LATITUDE AND LONGITUDE

**Earth** is the fifth largest planet in the Solar system; also called Blue Planet as two-thirds surface is covered by water.

- **Shape: Geoid** (oblate spheroid) - slightly flattened at the Poles and bulging at the Equator.
- Earth lies in the **Goldilocks Zone** - water can exist in a liquid state.
- **Densest** planet in the solar system.(**About 5.513 g/cm$^3$**)
- Speed of rotation around the axis is maximum at the equator and decreases poleward.
- The **axis of the earth,** which is an imaginary line, **makes an angle of 66½°** with its orbital plane.

> **Polestar** **[UPSC-2012]**
>
> A **pole star** is a visible star nearly aligned with the rotational axis of an astronomical body. For Earth, Polaris marks the North.
>
> If a person in a desert needs to walk 5 km **east** to reach their village and can locate the **polestar**, they should walk in a direction **keeping the polestar to their left**, as this will align them with the **eastward direction**.

## Goldilocks Zone

The **Goldilocks Zone**, or **habitable zone**, is the region around a star where conditions are just right for liquid water, essential for life.

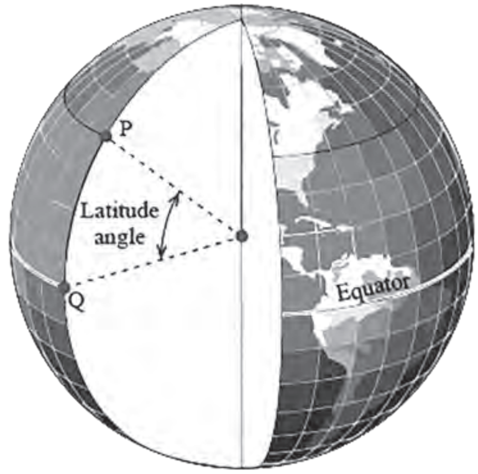
- **Temperature Range**
  - This zone allows water to remain liquid; too close to a star results in evaporation (too hot), while too far leads to freezing (too cold).
- **Influencing Factors**
  - The size and brightness of a star determine the Goldilocks Zone's boundaries. Larger or hotter stars have habitable zones farther out.
- **Earth as a Reference**
  - Earth lies within the Sun's Goldilocks Zone, enabling it to support life due to favorable average temperatures for liquid water.
- **Exoplanets**
  - An **exoplanet** (or **extrasolar planet**) is a planet that orbits a star outside our solar system.
  - **Proxima Centauri b:** Closest known exoplanet to Earth, located in the habitable zone of Proxima Centauri.
  - **TRAPPIST-1 System:** Contains seven Earth-sized planets, with three in the habitable zone.
  - **Kepler-186f:** The first Earth-sized exoplanet found in the habitable zone of its star.

### Importance

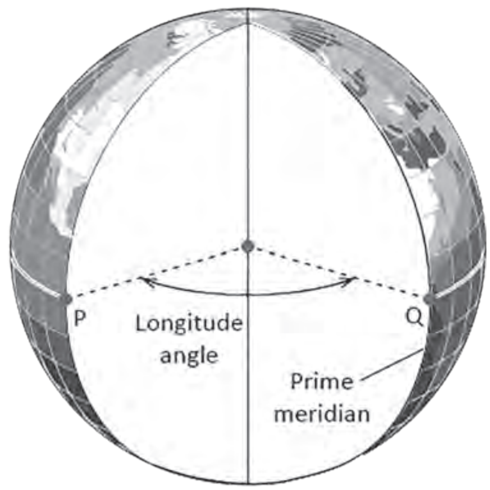
The Goldilocks Zone is crucial in astrobiology, guiding the search for extraterrestrial life by identifying where habitable worlds might exist.

## Latitude and Longitude

- **Latitude:** Angular distance from the Earth's centre, measured in degrees. Parallels of latitude are parallel to the equator.
  - **Distance:** Each degree of latitude is about 69 miles (111 km).




**Latitude:** The latitude of a parallel is the angle between a point on the parallel (P) and a point on the Equator at the same meridian (Q), as measured from the Earth's center.




**Longitude:** The longitude of a meridian is the angle between a point on the meridian at the Equator (P) at a point on the prime meridian at the Equator (Q), as measured at the Earth's center.

- **Longitude:** Angular distance east or west of the Prime Meridian (0°). Measured in degrees from 0° to 180°.
  - **Prime Meridian:** Passes through the UK, France, Algeria, and Antarctica.
  - **International Date Line:** Located at 180°, it alters date and time across the Pacific. It is not a straight line to avoid dividing the same landmass in two dates.
  - **Distance:** Between longitudes decreases from the equator to the poles, converging at the poles.

- **Standard Time:**
  - **Indian Standard Time (IST):** Based on the **82½° E** meridian, passing through Uttar Pradesh, Chhattisgarh, Odisha, Madhya Pradesh, and Andhra Pradesh.
    - **Important Cities:** Kanpur, Raipur, Bhubaneswar, Bhopal, Vijayawada.
  - **Time Difference:** IST is **5 hours and 30 minutes** ahead of GMT.
- **Great Circle:** A great circle is the intersection of a sphere (like Earth) with a plane that passes through its centre. It represents the shortest path between two points on the surface of the sphere.
  - The **Equator** (0° latitude) is a great circle because it divides the Earth into two equal hemispheres (Northern and Southern). Other latitudes are not Great circles.
  - All **meridians** (lines of longitude) are considered great circles when paired with their antipodal (opposite) meridians. For example, the line at 0° (Prime Meridian) and its opposite at 180° create a great circle.
  - **Navigation and Great Circles**
    - **Shortest Path:** When navigating long distances, pilots and sailors often use great circles to determine the shortest route between two points. This is crucial for saving time and fuel.
    - For example, a flight from New York to Tokyo typically follows a great circle route, appearing as a curve on a flat map.

**Major Latitudes of Earth**

| Latitude | Name | Countries |
|---|---|---|
| 0° | Equator | **Africa:** Gabon, Republic of the Congo, Democratic Republic of the Congo, Uganda, Kenya, Somalia<br>**Asia:** Indonesia, Maldives<br>**South America:** Ecuador, Colombia, Brazil, São Tomé and Príncipe |
| 23½° N | Tropic of Cancer | **North America:** Mexico, Bahamas<br>**Africa:** Egypt, Libya, Niger, Algeria, Mali, Mauritania<br>**Asia:** Taiwan, China, Myanmar, Bangladesh, India, Oman, UAE, Saudi Arabia |
| 23½° S | Tropic of Capricorn | **South America:** Argentina, Brazil, Chile, Paraguay<br>**Africa:** Namibia, Botswana, South Africa, Mozambique, Madagascar<br>**Australia:** Australia |
| 66½° N | Arctic Circle | **Europe:** Norway, Sweden, Finland<br>**Asia:** Russia<br>**North America:** United States (Alaska)<br>**North America:** Canada<br>**Oceania:** Greenland (Denmark), Iceland |
| 66½° S | Antarctic Circle | **Antarctica:** Antarctica |

## EARTH'S GEOMAGNETIC FIELD

It is the field of a **magnetic dipole** currently tilted at an angle of about 11 degrees with respect to Earth's rotational axis, as if there were a bar magnet placed at that angle at the centre of the Earth.

- The geomagnetic field is a **dynamic field** and it changes across geological time scale.
- Study of this magnetic field and its variations gives us a better **understanding about the metallic core of the Earth**.
- The intensity of the geomagnetic field is greatest near the poles and weaker near the Equator.

### Causes of Geomagnetic Field

The magnetic field of the Earth is generated by the **motion of molten iron alloys** in the **Earth's liquid outer core**.

- Differences in temperature, pressure and composition within the core cause **convection currents in the molten metal**.
- This flow of liquid iron generates **electric currents**, which in turn produce **magnetic fields**. This effect is known as **Dynamo Effect**.

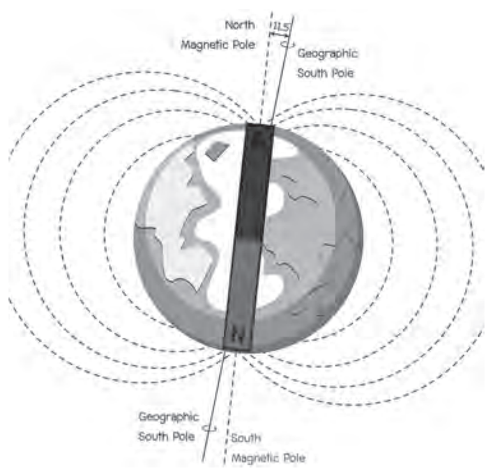



**Fig.** Geo-magnetic Field

### Geomagnetic Reversal

A geomagnetic reversal is a change in a planet's magnetic field such that the **positions of magnetic north and magnetic south are interchanged**. This happens in a cycle of a few hundred thousand years.

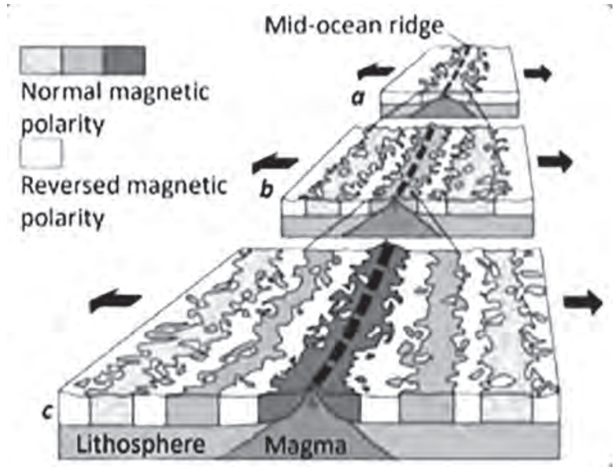



**Fig.** Geomagnetic Reversal recorded along mid-Oceanic Ridges (Sea Floor Spreading Theory)

### Geomagnetic Poles

The Geomagnetic poles are the intersections of the Earth's surface and the axis of a bar magnet hypothetically placed at the centre of the Earth.

- If the Earth's magnetic field were a perfect dipole, the field lines would be vertical to the surface at the Geomagnetic Poles, and they would coincide with the North and South magnetic poles.
- However, the approximation is imperfect, and so the Magnetic and Geomagnetic Poles lie some distance apart.

### Significance Of Geomagnetic Field

- This field acts as a **shield** that **blocks the solar winds** emanating from the sun, consisting of energetically electrically charged particles which can severely damage life on the planet. **[UPSC-2012]**
- Some particles manage to enter our planet, being directed by the magnetic field towards the poles, and excite the molecules of nitrogen and oxygen in the atmosphere. These excited molecules produce light seen as **Auroras**. In Northern Hemisphere: **Aurora Borealis** and in Southern Hemisphere: **Aurora Australis.**
- Helps in **navigation** by use of compass.
- **Magneto-Perception:** Some **animals** can use this magnetic field to navigate while migrating over long distances.
- The study of paleo-magnetism provides us with information about the past record of geomagnetism and the age of rocks on the surface of the planet.
- It also helped in developing the theories of **Seafloor spreading and Plate Tectonics**.
- Geomagnetic field is the cause of the formation of the magnetosphere around the Earth.

### Magnetosphere

A magnetosphere is a region of space surrounding the Earth (or any other planet or star) that is affected by the geomagnetic field (or magnetic field of that body).

- It traps charged particles from the solar winds (ions and electrons emitted by the Sun) and funnels them into a plasma.

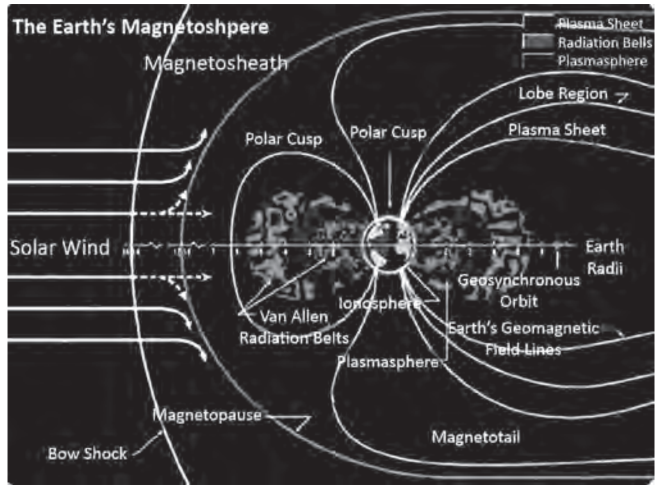



**Fig.** Magnetosphere and Magnetotail

- **Magnetotail:** It **extends up to 60,000 km** on the side **facing the Sun** and to a **greater extent on the opposite side which is called Magnetotail.**
- Its boundary is known as **Magnetopause**, outside which is a turbulent magnetic region known as magneto-sheath.
- It contains the **Van Allen radiation belts,** which contain high energy charged particles.
    - The lower belt contains electrons and protons extending from 1000 to 5000 km above the Earth's equator.
    - The upper belt has mainly electrons extending from 15000 to 25000 km above the equator.

### Magnetic Storm

When the **strong gusts of solar wind collide with the magnetosphere of the Earth**, resulting in rapid magnetic field variation, this is known as magnetic storm.

- This results in generation of electric currents in near earth space, which can **harm our artificial satellites** (eg. GPS) and **long-range radio communication**.
- Magnetic storms are known as **Ring currents** and they are **mostly concentrated over the equator**.

## HEAT ZONES OF EARTH

The Earth has three primary heat zones based on the Sun's rays:

- **Torrid Zone (Tropical Zone)**

  Located between the Tropics of Cancer and Capricorn, this is the hottest region. It receives direct sunlight year-round, leading to high temperatures and abundant rainfall. Examples include the Amazon and Congo Basins.

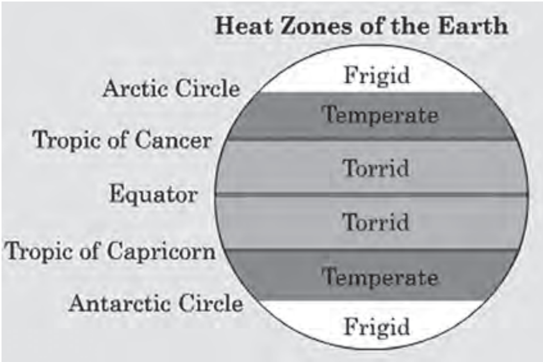
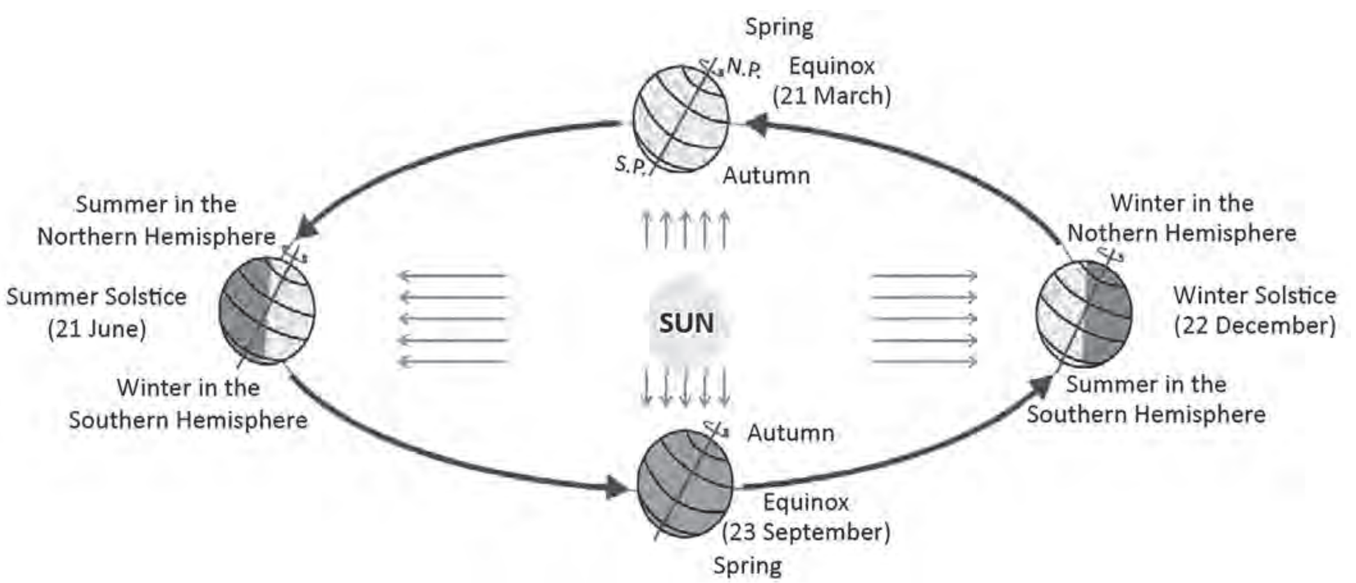



**Fig.** Heat Zones of Earth

- **Temperate Zone**
  Found between the tropics and polar circles, this zone has moderate temperatures with four seasons. Sunlight is slanted, resulting in diverse climates. Examples are Europe and North America.
- **Frigid Zone (Polar Zone)**
  Located between the polar circles and the poles, it experiences extreme cold with slanted sunlight. Long winters and harsh conditions are typical. Examples include Antarctica and Greenland.

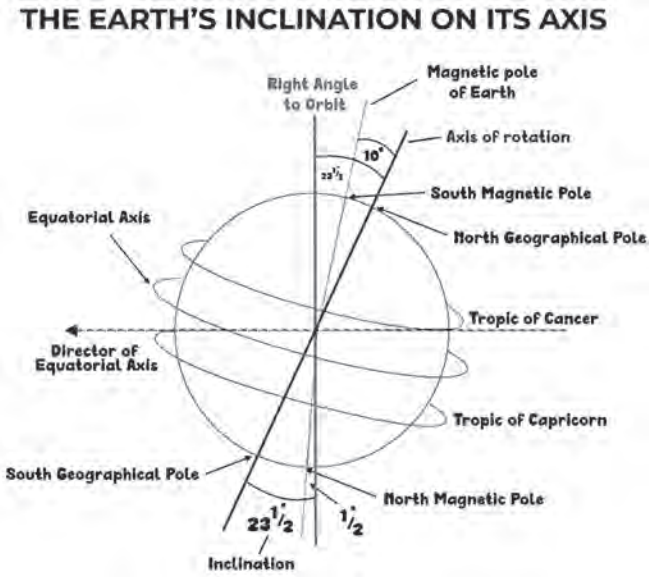
## EARTH'S MOVEMENTS AND CYCLES

- **Rotation of the Earth**
  - **Definition:** The Earth rotates around its axis from west to east.
  - **Speed:** Rotation is fastest at the equator (about 1670 km/h) and decreases toward the poles.
  - **Effects:**
    - **Day & Night:** Alternating periods of daylight and darkness across the globe.
    - **Coriolis Force:** Deflects wind and ocean currents, causing clockwise circulation in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.
- **Revolution of the Earth**
  - **Definition:** Earth revolves around the Sun in an elliptical orbit.
  - **Perihelion and Aphelion**:
    - **Perihelion** (closest to the Sun): January 3rd.
    - **Aphelion** (farthest from the Sun): July 4th.
  - **Effects:**
    - **Seasons:** Seasonal changes occur due to Earth's axial tilt (23.5°) and its changing position around the Sun. **[UPSC 2013]**
    - **Daylight Variations:** The length of day and night varies throughout the year, with regions near the poles experiencing continuous daylight or darkness for months.




- **Earth's Axial Tilt and Precession**
  - **Axial Tilt (Obliquity):** Earth's axis is tilted at 23.5° relative to its orbit around the Sun, which causes the seasonal variation.
  - **Cycle of Tilt:** Over 41,000 years, the tilt varies between 22.1° and 24.5°, affecting the intensity of the seasons.
  - **Axial Precession:** The slow wobbling of Earth's axis (like a spinning top) completes one cycle every 26,000 years. This influences the timing of the seasons relative to Earth's orbit.

- **Milankovitch Cycles**
  These are long-term cycles that influence Earth's climate and seasons:




- **Eccentricity:** The shape of Earth's orbit fluctuates between more circular and more elliptical over a 100,000-year cycle. A more elliptical orbit increases temperature extremes between seasons.
- **Obliquity (Axial Tilt):** As Earth's tilt changes over a 41,000-year cycle, it affects the strength of seasonal variations.
- **Precession (Axial Wobble):** Over 26,000 years, the direction of Earth's tilt changes, shifting the timing of seasons.
- **Magnetic Axis and Magnetic Pole Reversal**
  - **Magnetic Axis:** Earth's magnetic field is generated by its liquid outer core and is tilted about 11° from the rotational axis.
  - **Wobble of the Magnetic Axis:** The magnetic poles slowly drift due to changes in the outer core. This movement is gradual but significant for navigation and geophysics.
  - **Magnetic Reversals:** Earth's magnetic field reverses periodically, with the North and South magnetic poles switching places. These reversals occur over tens of thousands to millions of years and are detected through magnetic patterns in rocks.
- **Other Cycles and Influences**
  - **Chandler Wobble:** A small, irregular movement of Earth's poles with a period of about 433 days. This wobble affects Earth's rotation slightly.
  - **Solar Activity Cycles:** The Sun undergoes cycles of increased and decreased solar activity, approximately every 11 years, which affects solar radiation reaching Earth and influences climate patterns.

## Solstice and Equinoxes

**Solstice:** The point during Earth's orbit where the Sun reaches its highest or lowest point in the sky at noon, resulting in the longest or shortest day of the year.

**[UPSC 2024, 2022 and 2019]**

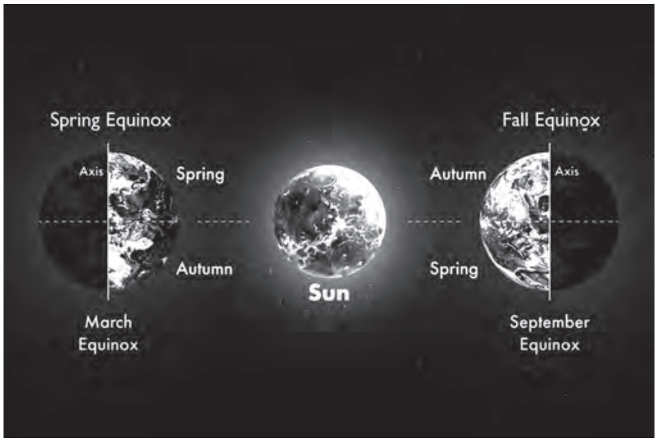



**Fig.** Equinox

**Equinox:** The time when day and night are of approximately equal length, occurring when the Sun is directly over the equator.

### Solstices and Equinoxes

| Event | Date (Approximate) | Daylight in Northern Hemisphere | Daylight in Southern Hemisphere | Arctic Circle (66.5°N) | Antarctic Circle (66.5°S) |
|---|---|---|---|---|---|
| Summer Solstice | June 21 | Longest day (most daylight) | Shortest day (least daylight) | 24 hours of daylight | 24 hours of darkness |
| Winter Solstice | December 22 | Shortest day (least daylight) | Longest day (most daylight) | 24 hours of darkness | 24 hours of daylight |
| Spring Equinox | March 21 | Equal day and night (12 hours) | Equal day and night (12 hours) | 12 hours of daylight | 12 hours of daylight |
| Autumn Equinox | September 23 | Equal day and night (12 hours) | Equal day and night (12 hours) | 12 hours of daylight | 12 hours of daylight |

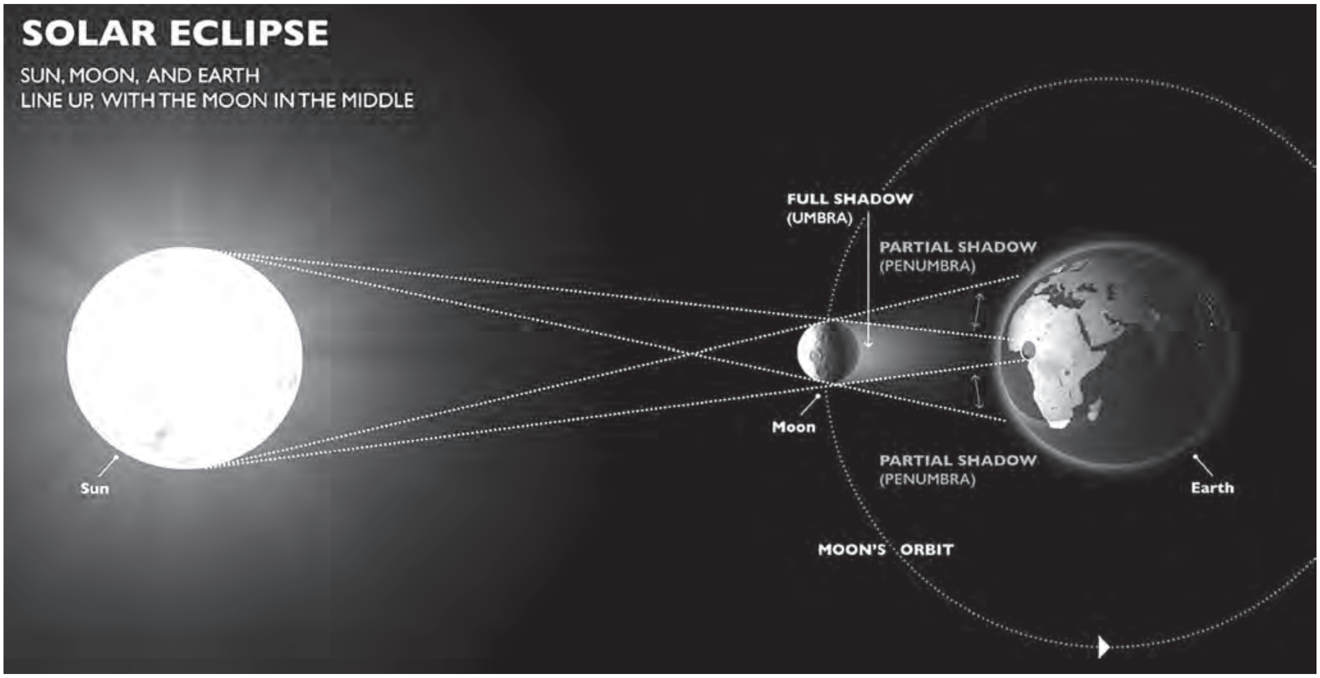
## MOON'S ORBITAL PLANE, EARTH'S ORBITAL PLANE AND ECLIPSES

The Moon's orbital plane is tilted by about **5 degrees** relative to Earth's orbital plane (the **ecliptic**). This tilt affects the occurrence of the **new moon**, **full moon**, and eclipses.

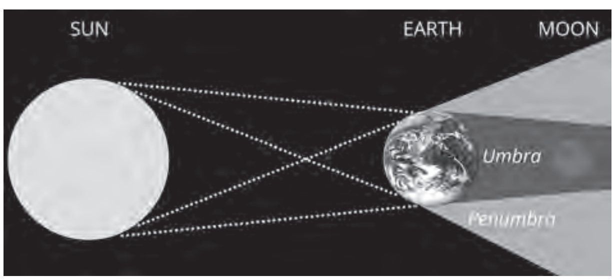
- **Phases of the Moon**
  - **New Moon:** New moon occurs when the Moon is between Earth and the Sun, and thus the side of the Moon that is in shadow faces Earth.
  - **Full Moon:** The Earth is between the Sun and Moon, but the Moon usually passes above or below Earth's shadow, preventing a lunar eclipse most months.

### Solar and Lunar Eclipses

- **Solar Eclipse**
  - **Mechanism:** Occurs during a **new moon** phase when the Moon comes between the Earth and the Sun. This blocks sunlight from reaching the Earth.
  - **Conditions:** The Moon's orbit must align with the **ecliptic plane**, allowing a perfect alignment.
  - **Types**:
    - **Total Solar Eclipse:** When the Moon completely covers the Sun as observed from Earth.
    - **Partial Solar Eclipse:** When the Sun is partially obscured.
    - **Annular Eclipse:** When the Moon appears smaller and leaves a "ring of fire."




- **Lunar Eclipse**
  - **Mechanism:** Happens during a **full moon** when the Earth comes between the Sun and the Moon, casting its shadow on the Moon.




  - **Types**:
    - **Total Lunar Eclipse:** The Moon is fully covered by Earth's umbra (darkest shadow). Appears red due to **Rayleigh scattering** (same phenomenon that causes sunsets to appear red) and atmospheric refraction.
    - **Partial Lunar Eclipse:** Only a part of the Moon enters the Earth's umbra.
    - **Penumbral Eclipse:** The Moon passes through the Earth's penumbra, causing a subtle dimming.

### Key Notes

- **Ecliptic Plane:** The imaginary plane containing Earth's orbit around the Sun, essential for the alignment needed for eclipses.
- **Red Moon During Lunar Eclipse:** The Earth's atmosphere bends sunlight, filtering out blue light and illuminating the Moon with red hues.
- **Rarity:** Eclipses do not occur every month because the Moon's orbit is tilted (~5°) relative to Earth's orbit, so perfect alignment is infrequent.Because of the Moon's tilt, eclipses don't occur every new or full moon. Eclipses happen during **eclipse seasons** when the Moon's orbit crosses the ecliptic plane during these phases.

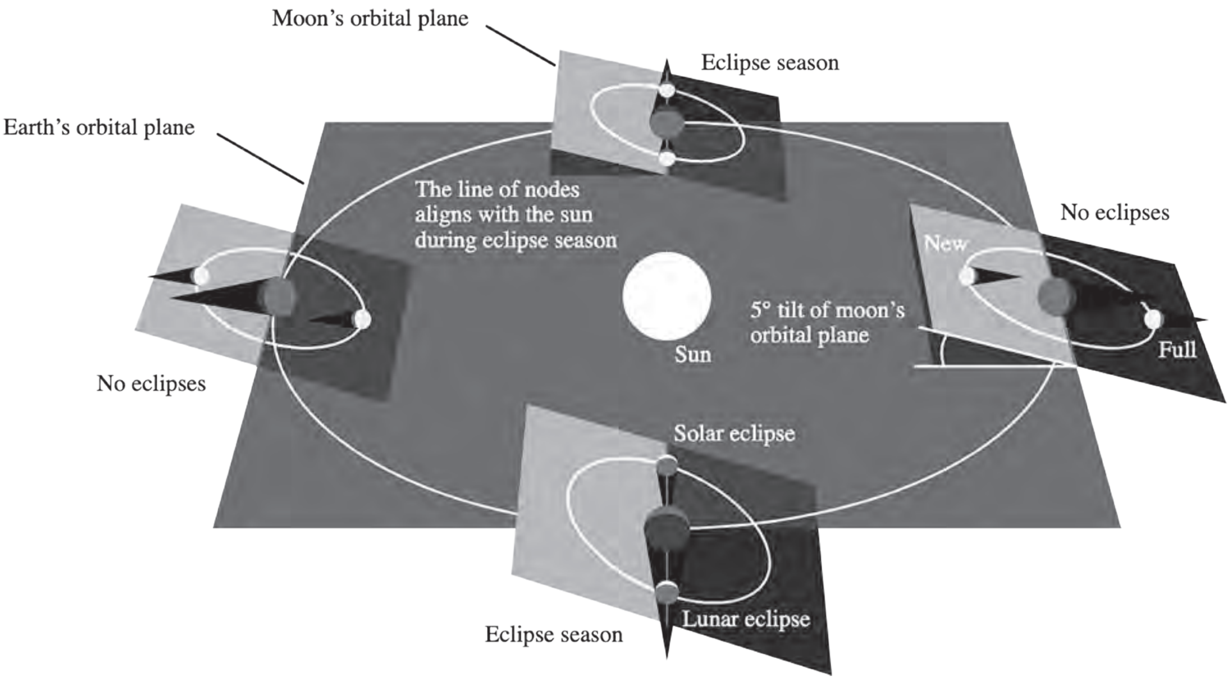



**Fig.** Eclipse Formation

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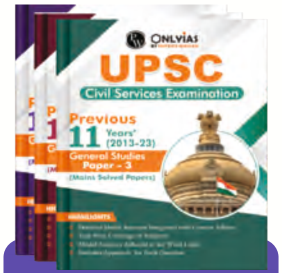


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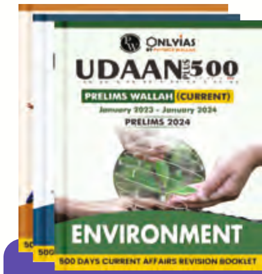


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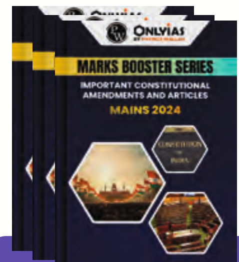


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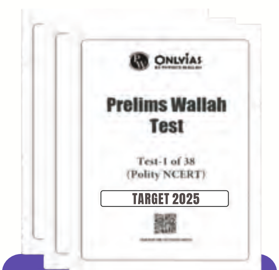


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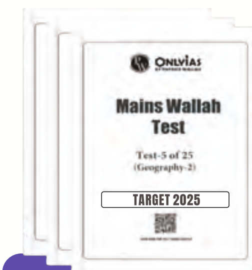


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