OPEN ACCESS

Int. Res. J. of Science & Engineering, 2019; Vol. 7 (1): 8-16 http://www.irjse.in
ISSN: 2322-0015

Overview

An overview of earth and its atmospheric processes

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Manuscript Details

Received : 22.11.2018
Accepted: 08.02.2019
Published: 28.02.2019

ISSN: 2322-0015

Cite this article as:
Gupta Swaroopa Rani N. An overview of earth and its atmospheric processes. *Int. Res. Journal of Science & Engineering,* 2019, 7 (2): 8-16.

ABSTRACT

Latitude is distance north or south of the equator and longitude is distance east or west of the prime meridian of a circle. The Equator is the line of 0° latitude, the starting point for measuring latitude. A prime meridian is a meridian (a line of longitude) in a geographic coordinate system at which longitude is defined to be 0°. Tropic of Cancer, Tropic of Capricorn, Arctic and Antarctic Circles and the Equator are five major circles of latitude that mark maps of Earth. The Earth has a substantial magnetic field that is thought to be due to the movement of the charged particles in the liquid core. The Earth is surrounded by two regions of particularly high concentration of charged particles called the Van Allen radiation belts. These charged particles trapped in the Earth's magnetic field are responsible for the aurora (Northern and Southern Lights) seen in the sky around the poles. UV-c (red) is entirely screened out by ozone around 35 km altitude. On the other hand, most UV-a (blue) reaches the surface, but it is not as genetically damaging. It is the UV-b (green) radiation that can cause sunburn and that can also cause genetic damage, resulting in things like skin cancer, if exposure to it is prolonged. It is in the lower part of the magnetosphere that overlaps with the ionosphere that the spectacular displays of the aurora borealis and aurora australis take place. The magnetosphere also contains the Van Allen radiation belts, where highly energized protons and electrons travel back and forth between the poles of Earth's magnetic field. The ionosphere was thought to be composed of a number of relatively distinct layers that were identified by the letters D, E, and F. The F layer was subsequently divided into regions F_1 and F_2. Electron density increases more or less uniformly with altitude from the D region, reaching a maximum in the F_2 region. The solar wind compresses the magnetic field on Earth's dayside at a distance of about 10 Earth radii. On the nightside, the terrestrial field is stretched out in a giant tail that reaches past the orbit of the Moon, extending perhaps to distances in excess of 1,000 Earth radii. Most of the electrical activity in the ionosphere is produced by photoionization. Ionization in the F_1 region is produced mainly by ejection of electrons from molecular oxygen (O_2), atomic oxygen (O), and molecular nitrogen (N_2). The threshold for ionization of O_2, O and N_2 corresponds to a wavelength of 102.7 nm, 91.1 nm and 79.6 nm respectively. In the D region, NO^+ and water vapour (H_2O) can interact to form the hydronium ion, H_3O^+, and companion species such as $H_5O_2^+$ and $H_7O_4^+$. Production of hydrated ions is limited by the availability of H_2O. As a consequence, they are confined to altitudes below about 85 km (53 miles). The electron density in the D, E, and F_1 regions reflects for the most part a local balance between production and loss. Electrons are removed mainly by dissociative recombination, a process in which electrons attach to positively charged molecular ions and form highly energetic, unstable neutral molecules. These molecules decompose spontaneously, converting internal energy to kinetic energy possessed by the fragments. The most important processes in the ionosphere involve recombination of O_2^+ and NO^+.

Ions and electrons produced at high altitude are free to diffuse downward, guided by Earth's magnetic field. This paper deals with an overview of earth and its atmospheric processes which in turn is valuable for understanding different phenomenon of Auroras the most spectacular manifestations of the complex interaction of the solar wind with the outer atmosphere.

Keywords : Latitude, Longitude, Tropic of Cancer, Tropic of Capricorn, Earth's Magnetic Field, Electromagnetic spectrum, Ionosphere, Magnetosphere, Photoionization, Recombination, Diffusion.

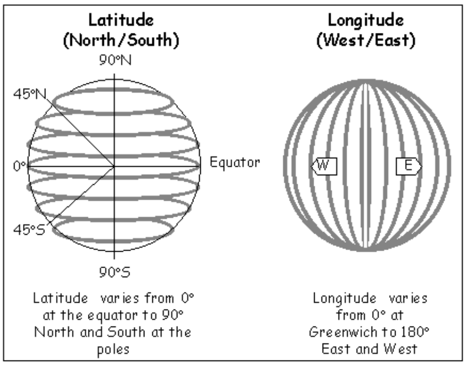
1. INTRODUCTION

Latitude and Longitude

Latitude and longitude are imaginary (unreal) lines drawn on maps to easily locate places on the Earth. Latitude is distance north or south of the equator (an imaginary circle around the Earth halfway between the North Pole and the South Pole) and longitude is distance east or west of the prime meridian (an imaginary line running from north to south through Greenwich, England). Both are measured in terms of the 360 degrees (symbolized by °) of a circle.

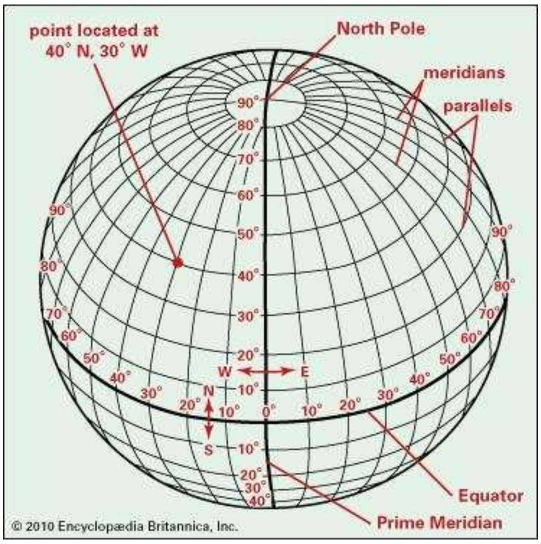
The Equator is the line of 0° latitude, the starting point for measuring latitude. The latitude of the North Pole is 90° N, and that of the South Pole is 90° S. The latitude of every point in between must be some degree north or south, from 0° to 90°. One degree of latitude covers about 69 miles (111 kilometers).

Longitude is measured in degrees east or west of the prime meridian. This means one half of the world is measured in degrees of east longitude up to 180°, and the other half in degrees of west longitude up to 180°.



Latitude and Longitude [1]

A prime meridian is a meridian (a line of longitude) in a geographic coordinate system at which longitude is defined to be 0°. Together, a prime meridian and its antimeridian (the 180th meridian in a 360°-system) form a great circle. This great circle divides the sphere, e.g., Earth, into two hemispheres. If one uses directions of East and West from a defined prime meridian, then they can be called the Eastern Hemisphere and the Western Hemisphere.

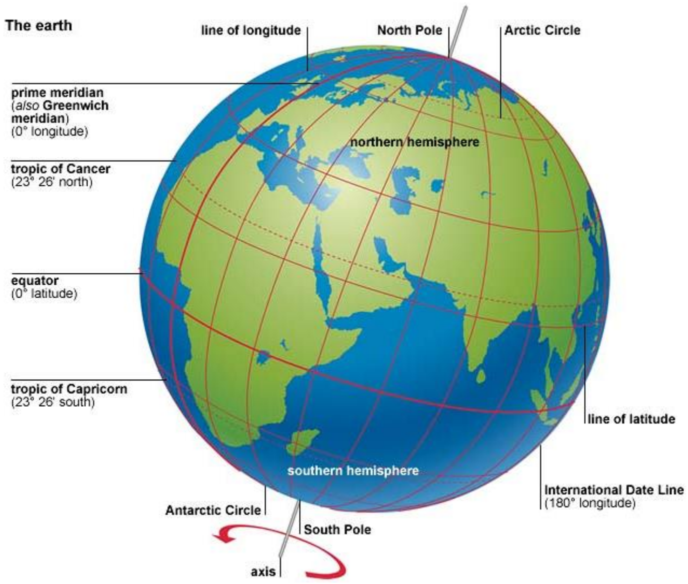


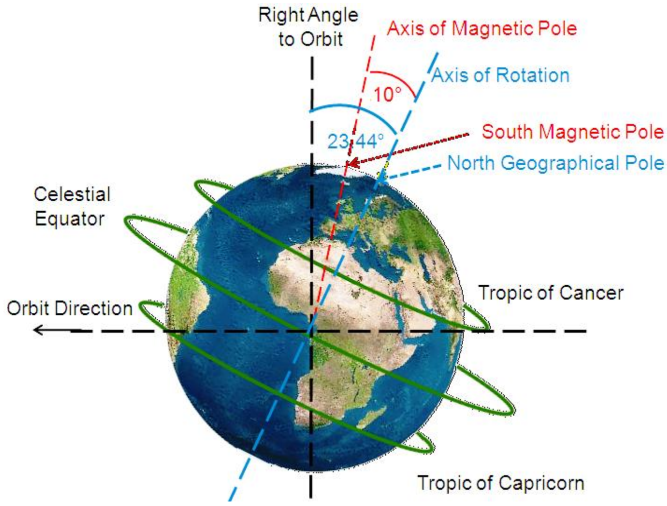
Perspective of the globe with grid formed by parallels of latitude and meridians of longitude [2]

Tropic of Cancer (Northern Tropic) and Tropic of Capricorn (Southern Tropic)

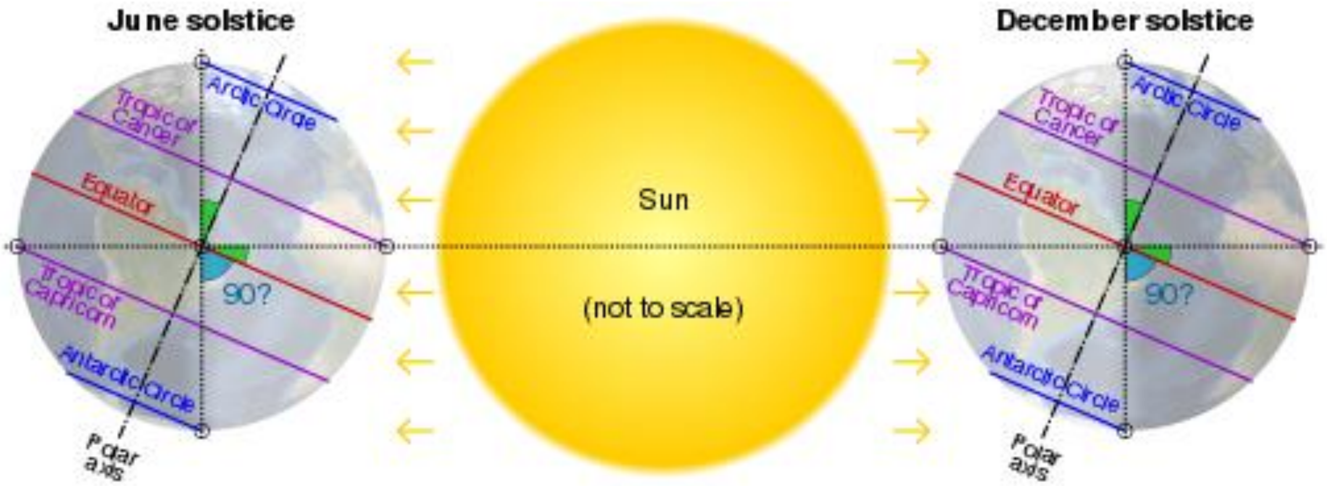
The Tropic of Cancer, also referred to as the Northern Tropic, is currently 23°26′12.9″ north of the Equator. It is the most northerly circle of latitude on Earth at which the Sun can be directly overhead. This occurs on the June solstice, when the Northern Hemisphere is tilted toward the Sun to its maximum extent.

Its Southern Hemisphere counterpart, marking the most southerly position at which the Sun can be directly overhead, is the Tropic of Capricorn, is the circle of latitude that contains the subsolar point on the December (or southern) solstice. As of 10 May 2018, its latitude is 23°26′12.9″ south of the Equator, but it is very gradually moving northward, currently at the rate of 0.47 arc seconds, or 15 metres, per year. [3]

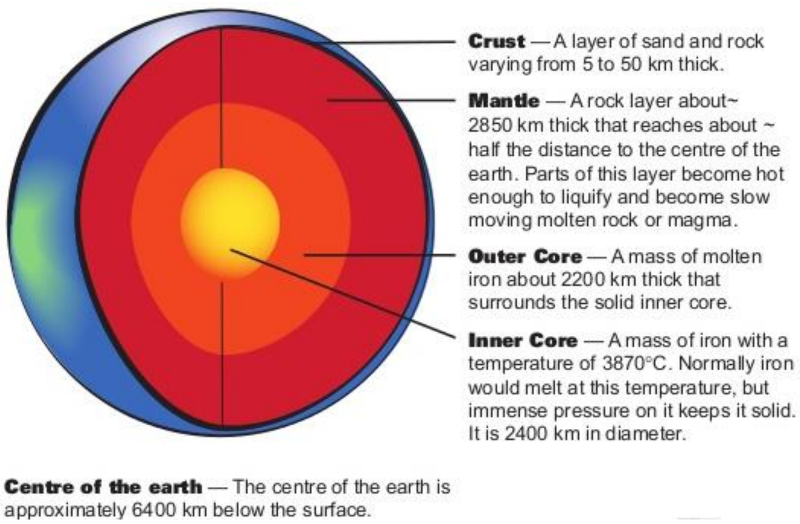




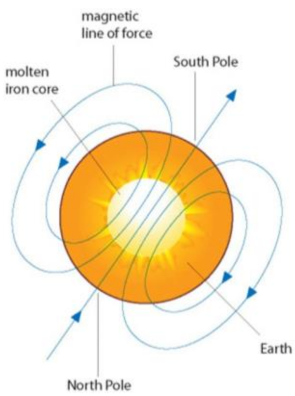
These tropics are two of the five major circles of latitude that mark maps of Earth; the others being the Arctic and Antarctic Circles and the Equator. The positions of these two circles of latitude (relative to the Equator) are dictated by the tilt of Earth's axis of rotation relative to the plane of its orbit.

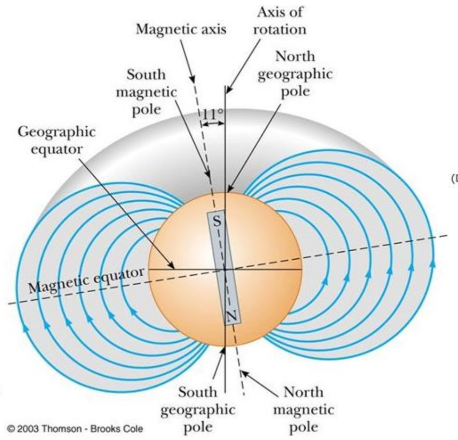


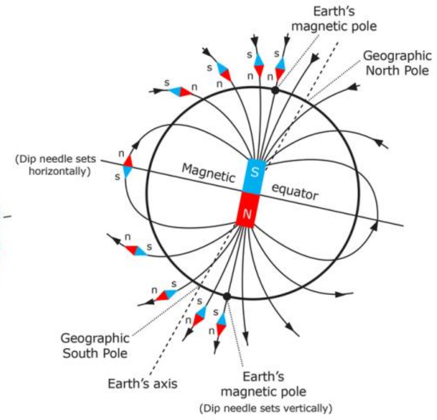
Relationship between Earth's axial tilt to the tropical and polar circles [4]



The Layers of the Earth [5]







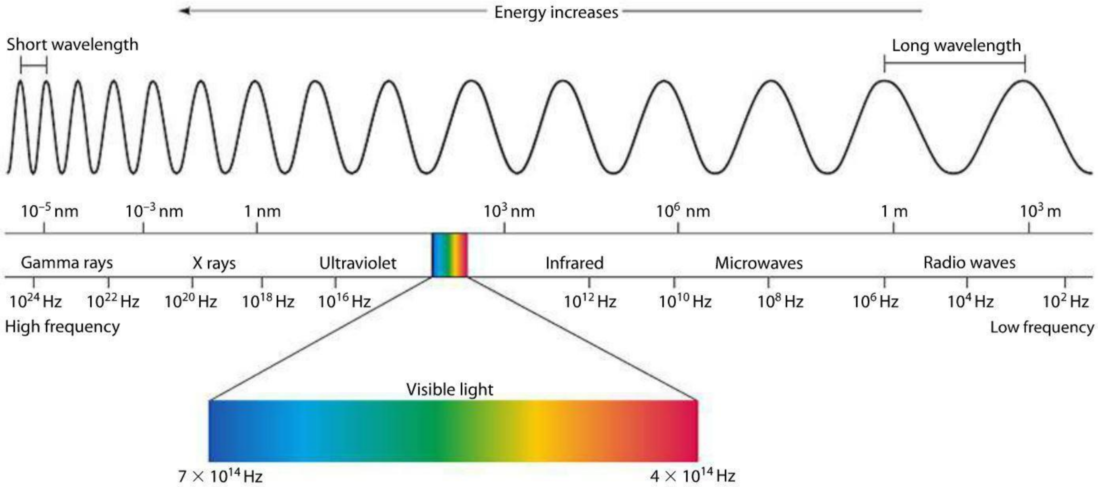
The Earth's Magnetic Field
The Earth's field lines are similar to those of a simple bar magnet. The Earth's magnetic north is not at the true north. The Earth rotates around an imaginary line that joins the true north and true south poles the Earth's Axis or the Geographical Meridian. The axis line for the geographical true north/south is called the geographical meridian and the axis line joining the magnetic north/south is called the magnetic meridian. The angle between them is called the magnetic declination.

The Earth has a substantial magnetic field that is thought to be due to the movement of the charged particles in the liquid core. Moving charges produce magnetic fields and also electric currents. The origin of the Earth's magnetic field is not completely understood by scientists, but is thought to be associated with electrical currents produced by the spinning of the liquid metallic outer core (made of iron and nickel) creating convection currents within this layer. This mechanism is called the dynamo effect.

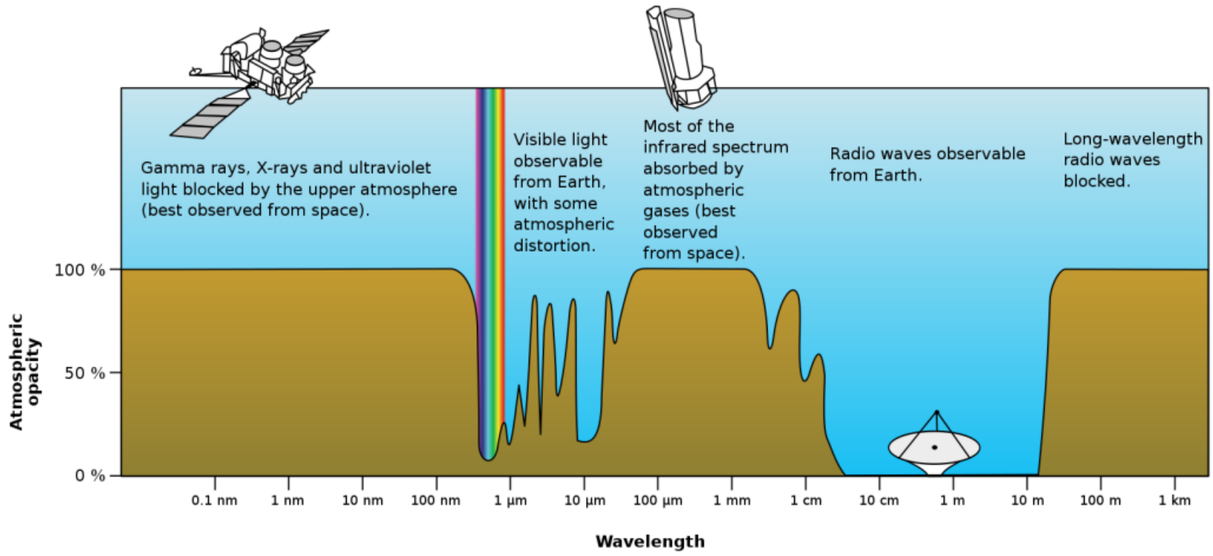
The magnetic field of the Earth is not fixed. Rocks formed from the molten state contain indicators of the magnetic field at the time of their solidification. The study of such magnetic fossils indicates that the Earth's magnetic field reverses itself every million years or so (the north and south magnetic poles switch).

Magnetic fields exert forces on moving electrical charges. So, the Earth's magnetic field can trap charged particles moving in the atmosphere, making them spiral back and forth along the field lines. The solar wind is a stream charged particles that are emitted from our Sun. The Earth's magnetic field shields us from much of the solar wind as it deflects many of the particles out into space and traps some of them in the upper atmosphere. It was discovered in the late 1950s that the Earth is surrounded by two regions of particularly high concentration of charged particles called the Van Allen radiation belts. It is believed that most of these particles come from our Sun. These charged particles trapped in the Earth's magnetic field are responsible for the aurora (Northern and Southern Lights) seen in the sky around the poles.

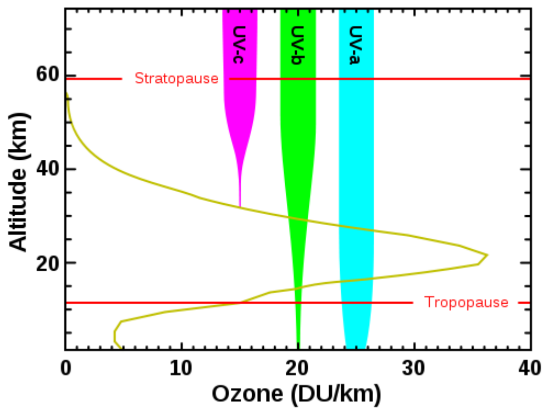
Electromagnetic spectrum



Electromagnetic spectrum



Plot of Earth's atmospheric transmittance to various wavelengths of electromagnetic radiation [6]

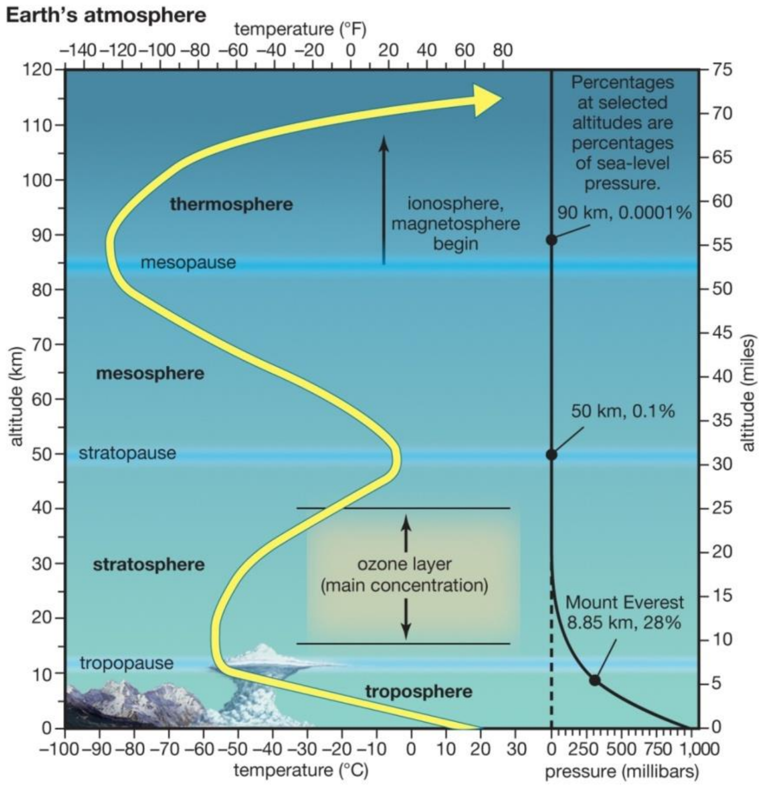


The amount of penetration of UV relative to altitude in Earth's ozone

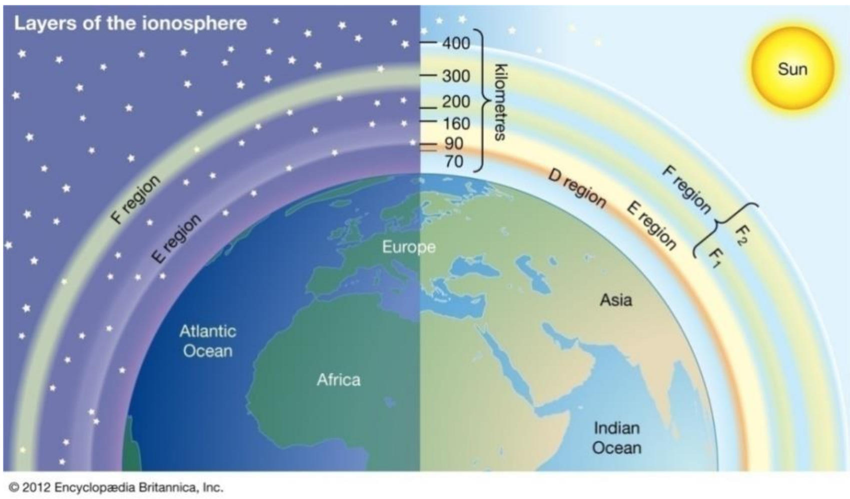
Levels of ozone at various altitudes, and related blocking of several types of ultraviolet radiation. The ozone concentrations shown are very small, typically only a few molecules wide O_3 per million molecules of air. But these ozone molecules are vitally important to life because they absorb the biologically harmful ultraviolet radiation from the Sun. There are three different types of ultraviolet (UV) radiation, based on the wavelength of the radiation. These are referred to as UV-a, UV-b, and UV-c. The figure also shows how far into the atmosphere each of these three types of UV radiation penetrates. UV-c (red) is entirely screened out by ozone around 35 km altitude. On the other hand, most UV-a (blue) reaches the surface, but it is not as genetically damaging. It is the UV-b (green) radiation that can cause sunburn and that can also cause genetic damage, resulting in things like skin cancer, if exposure to it is prolonged. Ozone screens out most UV-b, but some reaches the surface. Were the ozone layer to decrease, more UV-b radiation would reach the surface, causing increased genetic damage to living things. [7]

Ionosphere and magnetosphere

Ionosphere and magnetosphere, regions of Earth's atmosphere in which the number of electrically charged particles—ions and electrons—are large enough to affect the propagation of radio waves. The charged particles are created by the action of extraterrestrial radiation (mainly from the Sun) on neutral atoms and molecules of air. The ionosphere begins at a height of about 50 km (30 miles) above the surface, but it is most distinct and important above 80 km (50 miles). In the upper regions of the ionosphere, beginning several hundred kilometres above Earth's surface and extending tens of thousands of kilometres into space, is the magnetosphere, a region where the behaviour of charged particles is strongly affected by the magnetic fields of Earth and the Sun. It is in the lower part of the magnetosphere that overlaps with the ionosphere that the spectacular displays of the aurora borealis and aurora australis take place. The magnetosphere also contains the Van Allen radiation belts, where highly energized protons and electrons travel back and forth between the poles of Earth's magnetic field. [8]



The layers of Earth's atmosphere. The yellow line shows the response of air temperature to increasing height. [9]



The day-and-night differences in the layers of Earth's ionosphere [10]

Layers of the ionosphere

Historically, the ionosphere was thought to be composed of a number of relatively distinct layers that were identified by the letters D, E, and F. The F layer was subsequently divided into regions F_1 and F_2. Electron density increases more or less uniformly with altitude from the D region, reaching a maximum in the F_2 region.

D region

The D region is the lowest ionospheric region, at altitudes of about 70 to 90 km (40 to 55 miles). The D region differs from the E and F regions in that its free electrons almost totally disappear during the night, because they recombine with oxygen ions to form electrically neutral oxygen molecules. At this time, radio waves pass through to the strongly reflecting E and F layers above. During the day some reflection can be obtained from the D region, but the strength of radio waves is reduced; this is the cause of the marked reduction in the range of radio transmissions in daytime. At its upper boundary the D region merges with the E region.

$O_2^+ + e \rightarrow O_2$ (During Night)

E region

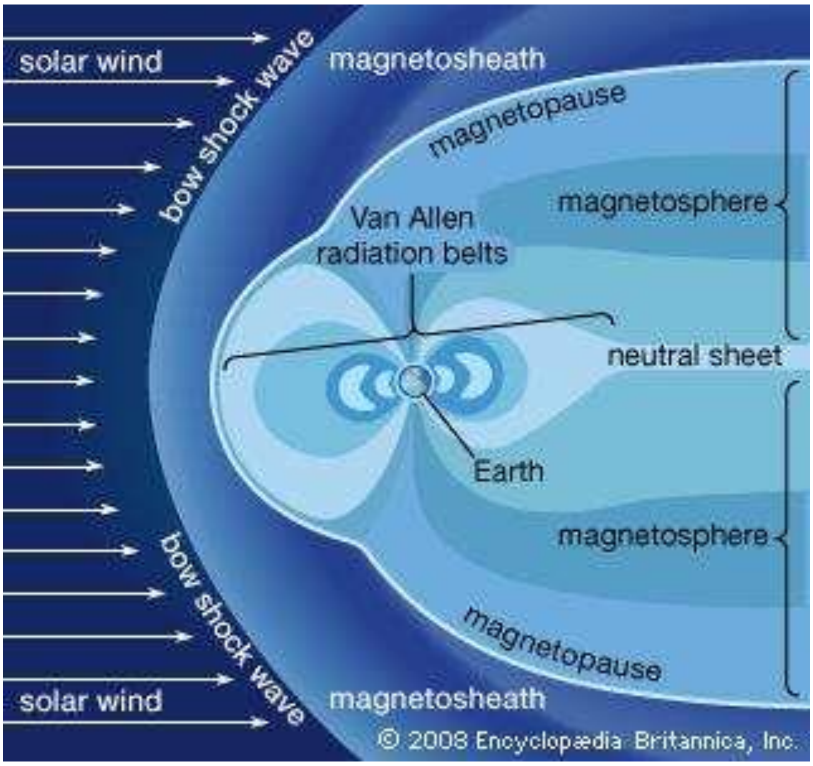
The E region is also called Kennelly-Heaviside layer, named for American electrical engineer Arthur E. Kennelly and English physicist Oliver Heaviside in 1902. It extends from an altitude of 90 km (60 miles) to about 160 km (100 miles). Unlike that of the D region, the ionization of the E region remains at night, though it is considerably diminished.

F region

The F region extends upward from an altitude of about 160 km (100 miles). This region has the greatest concentration of free electrons. Although its degree of ionization persists with little change through the night, there is a change in the ion distribution. During the day, two layers can be distinguished: a small layer known as F_1 and above it a more highly ionized dominant layer called F_2. At night they merge at about the level of the F_2 layer, which is also called the Appleton layer. This region reflects radio waves with frequencies up to about 35 megahertz.

Magnetosphere

The overall structure of the outer ionosphere the magnetosphere is strongly influenced by the configuration of Earth's magnetic field. Close to the planet's surface, the magnetic field has a structure similar to that of an ideal dipole. Field lines are oriented more or less vertically at high latitudes, sweep back over the Equator, where they are essentially horizontal, and connect to Earth in a symmetrical pattern at high latitudes. The field departs from this ideal dipolar configuration, however, at high altitudes. There the terrestrial field (Earth's magnetic field) is distorted to a significant extent by the solar wind, with its embedded solar magnetic field. Ultimately the terrestrial field is dominated by the interplanetary field, which is generated by the Sun.



The Van Allen radiation belts contained within Earth's magnetosphere. Pressure from the solar wind is responsible for the asymmetrical shape of the magnetosphere and the belts. [11]

The solar wind compresses the magnetic field on Earth's dayside at a distance of about 10 Earth radii, or almost 65,000 km (40,000 miles) from the planet. At this distance the magnetic field is so weak that the pressure associated with particles escaping from Earth's gravity is comparable to the opposing pressure associated with the solar wind. This equilibrium region, with a characteristic thickness of 100 km (60 miles), is called the magnetopause and marks the outer boundary of the magnetosphere.

On the nightside, the terrestrial field is stretched out in a giant tail that reaches past the orbit of the Moon, extending perhaps to distances in excess of 1,000 Earth radii. The magnetotail can extend to such great distances because on the nightside the forces associated with the magnetic field and the solar wind are parallel. [12]

Photoionization

Most of the electrical activity in the ionosphere is produced by photoionization (ionization caused by light energy). Photons of short wavelength (that is, of high frequency) are absorbed by atmospheric gases. A portion of the energy is used to eject an electron, converting a neutral atom or molecule to a pair of charged species an electron, which is negatively charged, and a companion positive ion. Ionization in the F_1 region is produced mainly by ejection of electrons from molecular oxygen (O_2), atomic oxygen (O), and molecular nitrogen (N_2). The threshold for ionization of O_2, O and N_2 corresponds to a wavelength of 102.7 nm, 91.1 nm and 79.6 nm respectively.

Positive ions in turn can react with neutral gases. There is a tendency for these reactions to favour production of more-stable ions. Thus, ionized atomic oxygen, O^+, can react with $O_2$and N_2, resulting in ionized molecular oxygen (O_2^+) and ionized nitric oxide (NO^+), as shown by:

$O^+ + O_2 \rightarrow O + O_2^+$ (1)

$O^+ + N_2 \rightarrow NO^+ + N$ (2)

Similarly, ionized molecular nitrogen (N_2^+) can react with O and O_2 to form NO^+ and O_2^+ as follows:

$N_2^+ + O \rightarrow NO^+ + N$ (3)

$N_2^+ + O_2 \rightarrow N_2 + O_2^+$ (4)

The most stable, and consequently most abundant, ions in the E and F_1 regions are O_2^+ and NO^+. At lower altitudes, O_2^+ can react with the minor species of atomic nitrogen (N) and nitric oxide (NO) to form NO^+, as indicated by:

$O_2^+ + N \rightarrow O + NO^+$ (5)

$O_2^+ + NO \rightarrow O_2 + NO^+$ (6)

In the D region, NO^+ and water vapour (H_2O) can interact to form the hydronium ion, H_3O^+, and companion species such as $H_5O_2^+$ and $H_7O_4^+$. Production of hydrated ions is limited by the availability of H_2O. As a consequence, they are confined to altitudes below about 85 km (53 miles). [13]

$NO^+ + H_2O \rightarrow H_3O^+ + H_5O_2^+ + H_7O_4^+$

Recombination

The electron density in the D, E, and F_1 regions reflects for the most part a local balance between production and loss. Electrons are removed mainly by dissociative recombination, a process in which electrons attach to positively charged molecular ions and form highly energetic, unstable neutral molecules. These molecules decompose spontaneously, converting internal energy to kinetic energy possessed by the fragments. The most important processes in the ionosphere involve recombination of O_2^+ and NO^+. These reactions may be summarized by:

$O_2^+ + e \rightarrow O + O$ (7)

$NO^+ + e \rightarrow N + O$ (8)

A portion of the energy released in reactions (7) and (8) may appear as internal excitation of either nitrogen, oxygen, or both. The excited atoms can radiate, emitting faint visible light in the green and red regions of the spectrum, contributing to the phenomenon of airglow. Airglow originates mainly from altitudes above 80 km (50 miles) and is responsible for the diffuse background light that makes it possible to distinguish objects at Earth's surface on dark, moonless nights. Airglow is produced for the most part by reactions involved in the recombination of molecular oxygen. The contribution from reactions (7) and (8) is readily detectable, however, and provides a useful technique with which to observe changes in the ionosphere from the ground. Over the years, studies of airglow have contributed significantly to scientific understanding of processes in the upper atmosphere.

As indicated above, dissociative recombination provides an effective path for removal of molecular ions. There is no comparable means for removal of atomic ions. Direct recombination of ionized atomic oxygen (O^+) with an electron requires that the excess energy be radiated as light. Radiative recombination is inefficient, however, compared with dissociative recombination and plays only a small role in the removal of ionospheric electrons. The situation becomes more complicated at high altitudes where atomic oxygen (O) is the major constituent of the neutral atmosphere and where electrons are produced primarily by its photoionization. The atomic oxygen ion, O^+, may react with N_2 and O_2 to form $NO^+$and O_2^+, but the abundances of N_2 and O_2 decline relative to O as a function of increasing altitude. In the absence of competing reactions, the concentration of O^+ and the density of electrons would increase steadily with altitude, paralleling the rise in the relative abundance of O. This occurs to some extent but is limited eventually by vertical transport.

$O^+ + O_2 \rightarrow O + O_2^+$

$O^+ + N_2 \rightarrow NO^+ + N$

Diffusion

Ions and electrons produced at high altitude are free to diffuse downward, guided by Earth's magnetic field. The lifetime of $O^+$is long at high altitudes, where the densities of O_2 and N_2 are very small. As ions move downward, the densities of O_2 and N_2 increase. Eventually the time constant for reaction of O^+ with O_2 and N_2 becomes comparable to the time for diffusion, and O^+ reacts to produce either O_2^+ or NO^+ before it can move much farther. The O^+ density exhibits a maximum in this region. Competition between chemistry and transport is responsible for the formation of an electron-density maximum in the F_2 layer. The dominant positive ion is O^+.

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