

PHYSICS OF IONOSPHERE

History

In 1901, Marconi, who is often called the "Father of Wireless," proved transatlantic communication by receiving a signal in Newfoundland that had been sent from Cornwall, England. Because of his pioneering work in the use of electromagnetic radiation for radio communications, Marconi was awarded the Nobel Prize in physics in 1909.

Marconi's famous experiment showed the way toward universal communication, but it also raised a serious scientific problem. Up to this point, it had been assumed that electromagnetic radiation traveled in straight lines like light waves. If this were true, the maximum possible communication distance would be determined by the geometry of the path as shown in Fig.1 to the left.

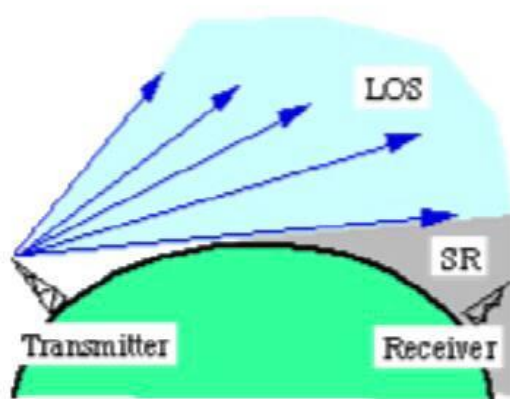


Figure 1: Areas in the light blue region are within the radio "Line of Sight" (LOS). The receiving antenna is in the shadow region (SR) and cannot receive a signal directly from the transmitter.

The radio signal would be heard up to the point where some intervening object blocked it. If there were no objects in the path, the maximum distance would be determined by the transmitter and receiver antenna heights and by the curvature of the earth. Drawing this distance is often called the "Line-of-Sight" (LOS) distance. In Marconi's transatlantic demonstration, something different was happening to cause the radio waves to bend around the Earth's curvature so that the communication signals from England could be heard over such an unprecedented distance.

In 1902, Oliver Heaviside and Arthur Kennelly each independently proposed that a conducting layer existed in the upper atmosphere that would allow a transmitted EM signal to be reflected toward the Earth. Up to this time, there was no direct evidence of such a region and little was known about the physical or electrical properties of the Earth's upper atmosphere. If such a conductive layer existed, it would permit a dramatic extension of the "line-of-sight" limitation to radio communication as shown in Fig. 2 to the left.

During the mid-1920s, the invention of the Ionosonde allowed direct observation of the ionosphere and permitted the first scientific study of its characteristics and variability and its effect on radio waves.

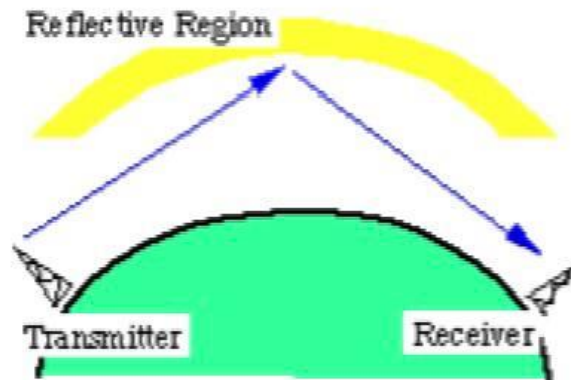


Figure 2: A conductive region at high altitude would "reflect" radio signals that reached it and returned them to Earth.

Requirements for an Ionosphere

The only requirements are a neutral atmosphere and a source of ionization for the gases in that atmosphere. Sources of ionization include photons and energetic particle "precipitation" The process involving the previous is referred to as photoionization, and the later is often labeled impact ionization.

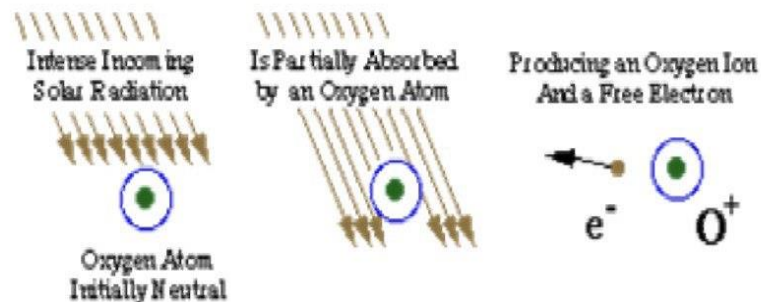


Figure 3: The conceptual drawing is a simplified explanation of ionization process. Solar photons in the extreme ultraviolet (EUV) and ultraviolet (UV) wavelength range of approximately 10nm to 100 nm typically produce at least the dayside ionosphere of the planets.

The photons come primarily from the Sun. Ionizing particles can come from the galaxy (cosmic rays), the Sun, the magnetosphere, and the ionosphere itself if a process for local ion or electron acceleration is operative. Precipitating energetic electrons produce additional ionizing photons within the atmosphere by a process known as bremsstrahlung or breaking radiation.

The only requirement on the ionizing photons and particles is that their energies, i.e., $h\nu$ in the case of photons, and kinetic energy in the case of particles exceed the ionization potential or binding of a neutral atmosphere atomic or molecular electron.

The Neutral Atmosphere

The density n_i of a constituent of the upper neutral atmosphere obeys a hydrostatic equation:

$$n_i m_i g = -\frac{dP}{dh} = -\frac{d}{dh}(n_i k T_i)$$

which expresses as a balance between the vertical gravitational force and the thermal-pressure-gradient force on the atmospheric gas.

Here,

m_i : molecular or atomic mass,

g : the acceleration due to gravity,

h : altitude variable,

and

P : the thermal pressure, $n_i k T_i$

k : Boltzmann's constant,

T_i : temperature of the neutral gas under consideration

If T_i is assumed independent of h , this equation has the exponential solution

$$n_i = n_0 \exp\left(-\frac{(h-h_0)}{H_i}\right) \quad (2)$$

Where

$$H_i = k T_i / m_i g \quad (3)$$

This equation defines the scale height of the gas, and n_0 is the density at the reference altitude h_0 .

Note that the scale-height dependence on particle mass is such that the lightest molecules and atoms have the largest scale-height.

Most planetary atmospheres are dominated at high altitudes by hydrogen and helium. Of course, T_i may depend on h , so this simple exponential distribution will not always provide an accurate description.