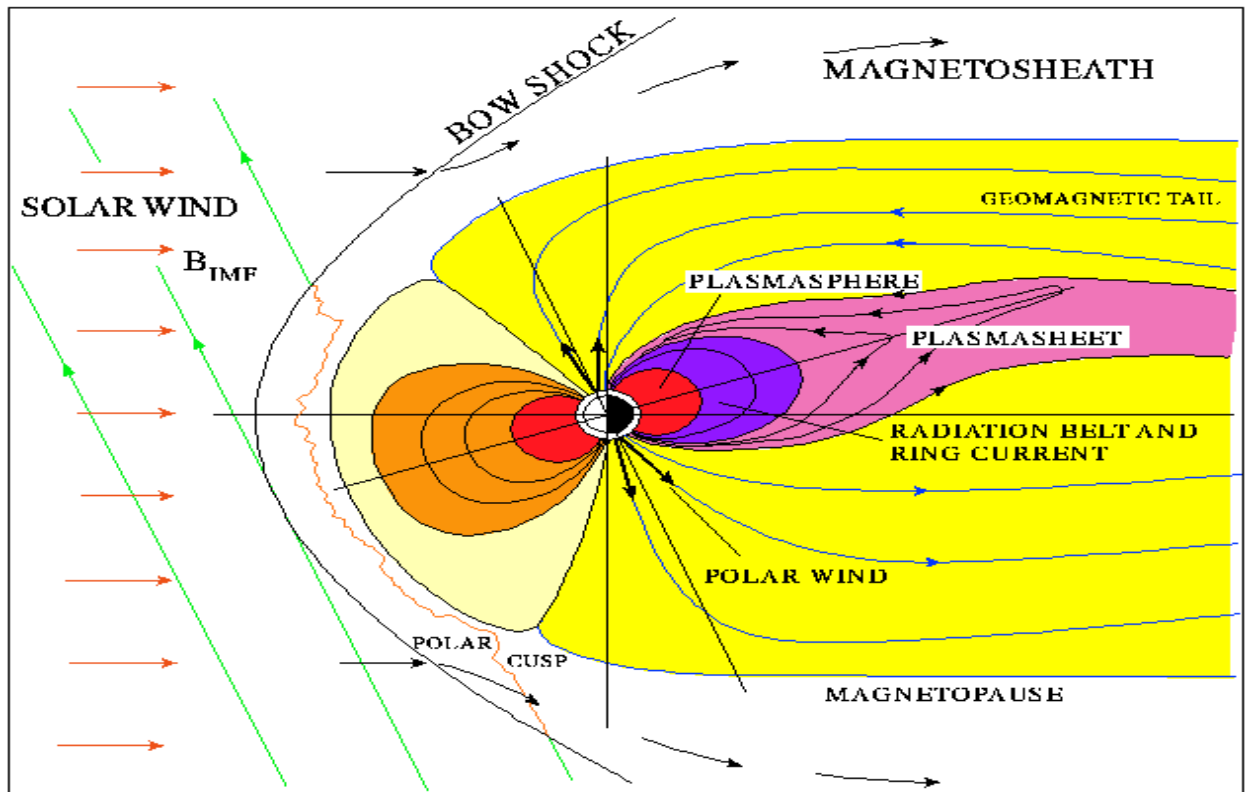


# Plasma in the ionosphere

## Ionization and Recombination



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# 1. Introduction

## 1.1 History

In 1883 Stewart suggested that there should be an electrically conducting layer in the upper atmosphere, to explain the daily variations in the Earth's magnetic field. In 1902 Kennelly and Heaviside proposed a same hypothesis to explain Marconi's successful transatlantic radio communication. For a long time ago, this conducting layer was called Kennelly-Heaviside layer. This hypothesis was experimentally proved by Edward V. Appleton in 1924 by means of reflection of radio waves and he was awarded Noble Prize in 1947 for the confirmation of the existence of ionosphere. In 1926, Scottish physicist Robert Watson-Watt introduced the term *ionosphere*.

The ionosphere is the ionized component of the Earth's upper atmosphere. The ionizing action of the sun's radiation on the earth's upper atmosphere produces free electrons. Above about 60km the number of these free electrons is sufficient to affect the propagation of electromagnetic waves. This "ionized" region of the atmosphere is plasma containing the charged particles and is referred as ionosphere.

This plasma is not stationary, but it is constantly circulating around. Flow patterns develop which can carry plasma from day side to a night side and vice versa. [1]

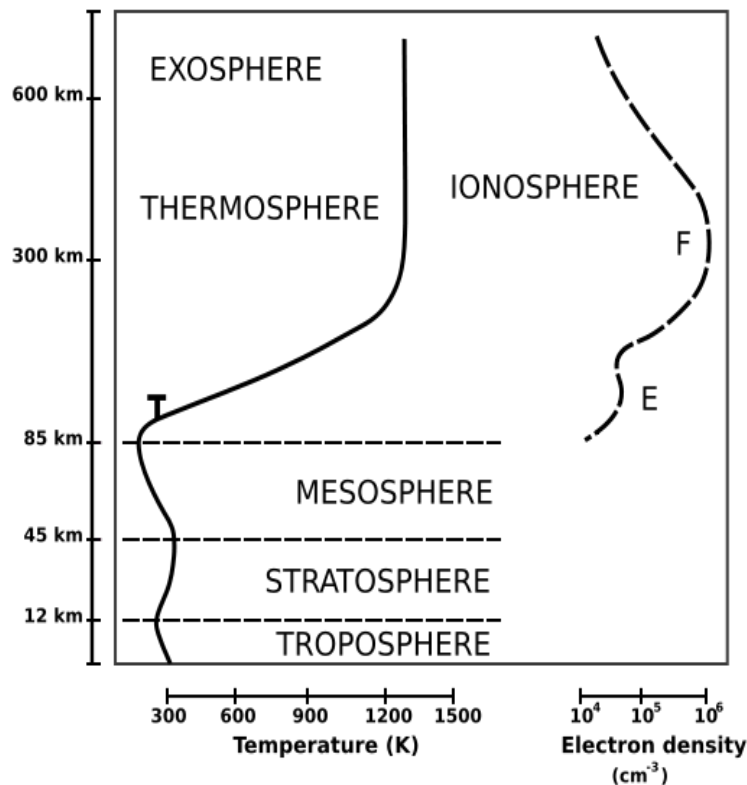


Fig.1. Relationship between the atmosphere and ionosphere. [2]

## 1.2 What is the ionosphere?

The atmosphere varies in density and composition as the altitude increases above the surface of earth. The lower part of the atmosphere is called troposphere; it extends up to about 10 km. The gases in this region are molecular oxygen  $O_2$  and molecular nitrogen  $N_2$ . All weather is confined in this region and it contains 90 % of earth's atmosphere and 99 % of water vapors. The highest mountains are still within the troposphere and all of our normal day-to-day activities occur here. The high altitude jet stream is found near the tropopause at the upper end of this region.

The atmosphere above 10 km is called the stratosphere. In this region the gas is still dense so that we can ascend hot air balloons to altitudes of 15-20 km and Helium balloons to nearly 35 km. But the air thins rapidly and gas composition alters as the altitude increases. Within the stratosphere, the incoming solar radiation at wavelengths below 240 nm is able to dissociate molecular Oxygen  $O_2$  into individual Oxygen atoms, each of which, in turn, may combine with an Oxygen molecule  $O_2$ , to form ozone  $O_3$ . The ozone layer is found up to about 25 km altitude. The gas becomes rarefied at higher altitudes, at heights of 80 km the gas is so thin that the free electrons can exist only for short time before they are captured by positive ion. The existence of charged particles at high altitudes signals the beginning of ionosphere, which is a region having properties of gas and plasma. The figure below shows the density of molecules, atoms, ions and charged particles in the ionosphere. [3]

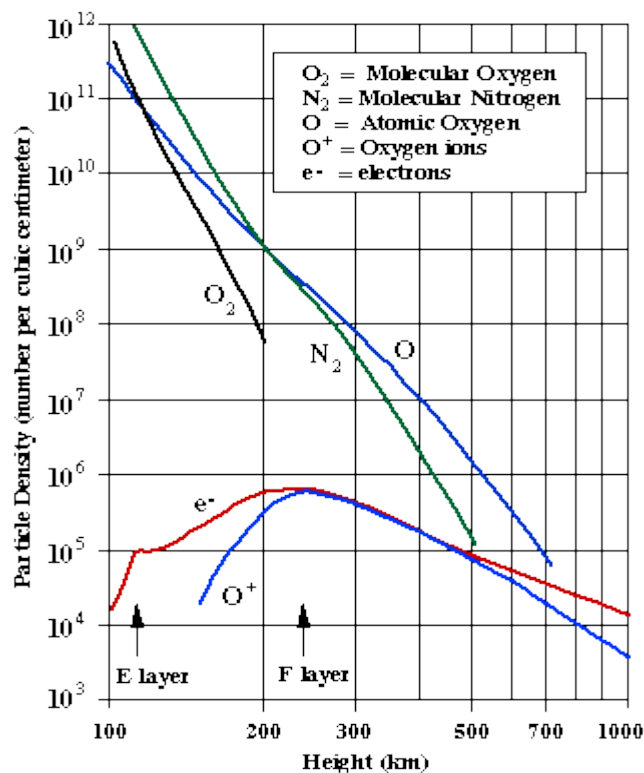


Fig.2. Particles density variation in the ionosphere. [3]

## 2. Ionization and recombination

In the outer earth's environment, solar radiation strikes the atmosphere with a power density of  $1370 \text{ watt/m}^2$ . This intense level of radiation is spread over a spectrum ranging from radio frequency through IR and X-ray. The intense X-ray and UV radiations from the sun ionize the atoms or molecules. The photons of energy at these frequencies are capable of dislodging an electron from the gas atom or molecule. The mechanism is simplified below in the figure.

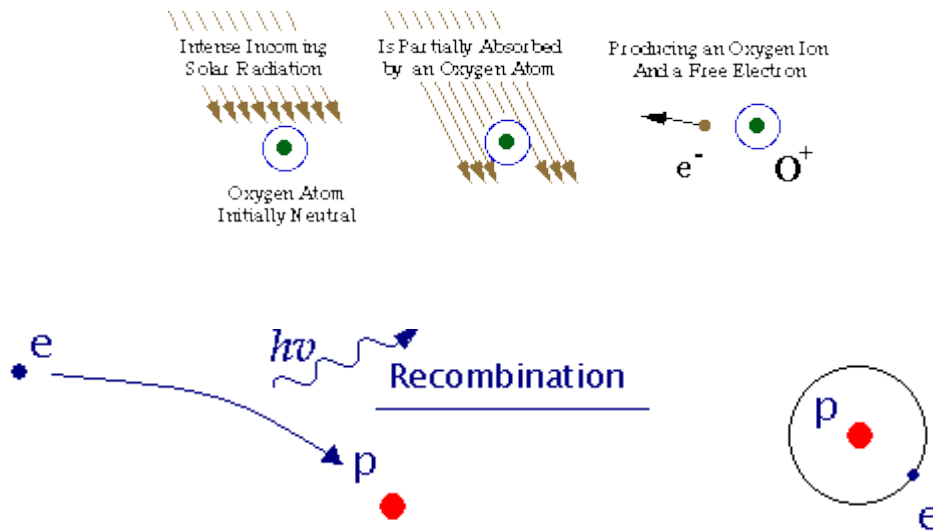


Fig.3. Ionization and recombination.

When the solar radiation is incident on a gas atom or molecule, the part of this radiation is absorbed by the atom, a free electron and a positively charged ion are produced. At the highest altitude the solar radiation is very strong but there are only few atoms available to interact, so the ionization is small. As the altitude decreases, the more gas atoms or molecules are present to interact so the ionization is greater. At the same time an opposite process called recombination starts to happen in which a free electron is captured by a nearby positive ion. As the gas density is high at lower altitudes, so the recombination increases at lower altitudes.

As we are coming down, the density of gas atoms or molecules increases further and there is more absorption of energy from photons of UV radiation. However the intensity of this radiation is smaller at lower altitudes because some of it was absorbed at high altitudes. A point is reached where lower radiation, greater gas density, greater recombination rates, balance out and ionization starts to decrease at lower altitudes. This leads to the formation of ionization peaks or layers which are called D, E, F<sub>1</sub> and F<sub>2</sub> layers. [3]

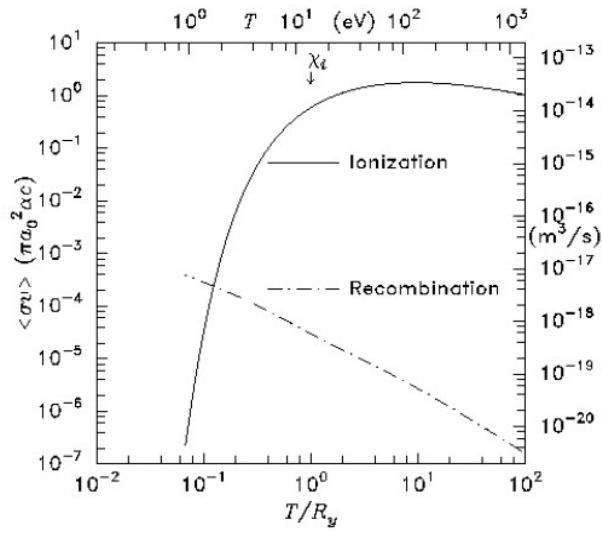


Fig.4. ionization and recombination rates.

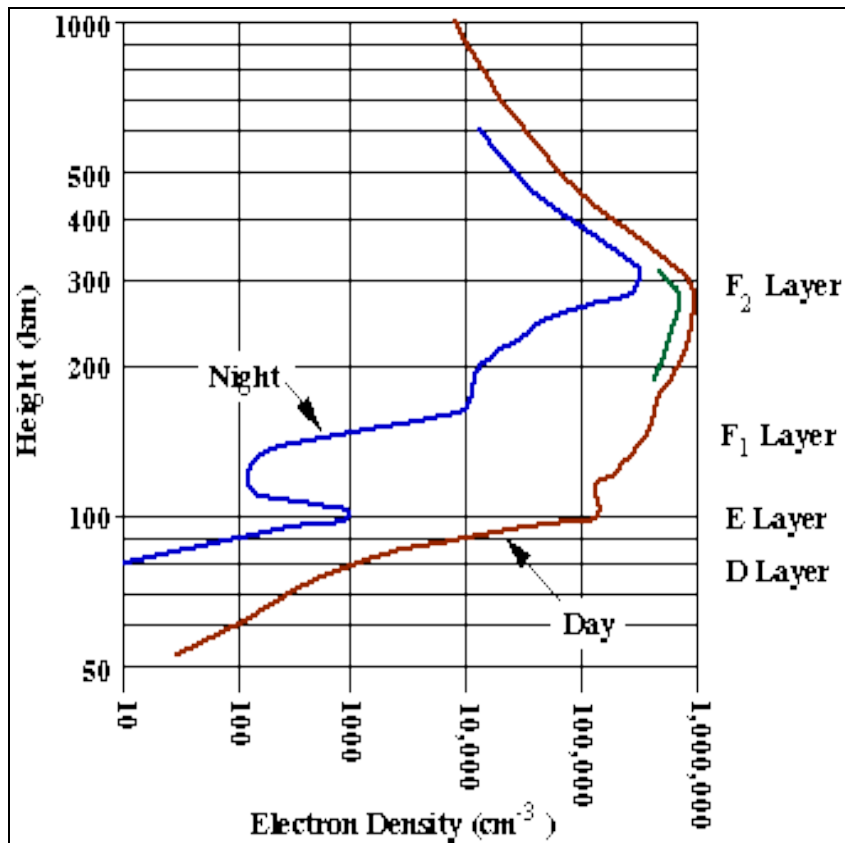
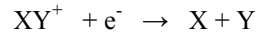
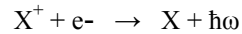


Fig.5. Variations of reactions in day and night. [3]

After sunset the molecular ions e.g. H<sub>2</sub> and He in the D, E and F<sub>1</sub> layer vanish quickly through dissociative recombination of the form



The F<sub>2</sub> layer consists of atomic ions and dissociative recombination.



And



Where M is third particle, and process is much slower, Hence F<sub>2</sub> decays much less during night time.

Normally the ionization and recombination play an important role in the conductivity of the ionosphere. Usually it depends upon the collision frequencies of atoms or molecules, if the collision frequencies are lower, then the conductivities also lower, but it also depends upon the proportion of neutral molecules.

So three kinds of conductivities are distinguishable

**Parallel conductivity,  $\sigma_{\parallel}$** , is the conductivity parallel to the magnetic field.

**Pedersen conductivity,  $\sigma_p$** , is the conductivity which is parallel to the component of electric field that is perpendicular to magnetic field.

**Hall conductivity,  $\sigma_H$** , perpendicular to both electric and magnetic field.

In the E and F layers,  $\sigma_{\parallel}$  is several orders of magnitude greater than the others. [1]

### 3. Ionospheric layers

As we have discussed before that the solar radiation, acting on the different compositions of the atmosphere with height, generates layers of ionization. We will elaborate now layer by layer these ionizations. The typical altitudes, electron densities, ion concentrations and the causes of ionization are summarized in the table below. [1]

Layer	D	E	F1	F2
Altitude (km)	60-85	85-140	140-200	200-ca1500
Night time electron density (cm-3)	$<10^2$	$2 \times 10^3$	–	$2-5 \times 10^5$
Daytime electron density (cm-3)	$10^3$	$1-2 \times 10^5$	$2-5 \times 10^5$	$0.5-2 \times 10^6$
Ion species	$\text{NO}^+ \text{O}_2^+$	$\text{NO}^+ \text{O}_2^+$	$\text{NO}^+ \text{O}_2^+ \text{O}^+$	$\text{O}^+ \text{He}^+ \text{H}^+$
Cause of ionization	Lyman $\alpha$ (121.5nm)	Lyman $\beta$ (102.5 nm) X-rays	UV	V U

#### D-Layer

The D layer is the innermost layer of the ionosphere which goes from 50 km to 90 km above the surface of the Earth. Ionization here is due to Lyman series-alpha hydrogen radiation at a wavelength of 121.5 nanometer (nm) ionizing nitric oxide (NO). In addition, when the sun is active with 50 or more sunspots, hard X-rays ( $\lambda < 1 \text{ nm}$ ) ionize the air ( $\text{N}_2$ ,  $\text{O}_2$ ). During the night time, cosmic rays produce a residual amount of ionization. Recombination is high in the D layer, thus the net ionization effect is very low and as a result high-frequency (HF) radio waves are not reflected by the D layer. The frequency of collision between electrons and other particles in this region during the day is about 10 million collisions per second. The D layer is mainly responsible for absorption of HF radio waves, particularly at 10 MHz and below, with progressively smaller absorption as the frequency gets higher. The absorption is small at night and greatest about midday. The layer reduces greatly after sunset, but remains due to galactic cosmic rays. A common example of the D layer in action is the disappearance of distant AM broadcast band stations in the daytime.

#### E-Layer

The E layer is the middle layer of ionosphere which goes from altitude 90 km to 120 km above the surface of the Earth. Ionization in this layer is due to soft X-ray (1-10 nm) and far ultraviolet (UV) solar radiation ionization of molecular oxygen ( $\text{O}_2$ ). This layer can only reflect radio waves having frequencies less than about 10 MHz. It has a negative effect on frequencies above 10 MHz due to its partial absorption of these waves. The vertical structure of the E layer is primarily determined by the competing effects of ionization and recombination. At night the E layer begins to disappear because the primary source of ionization is no longer present. This results in an increase in the height where the layer maximizes because recombination is faster in the lower



layers. The increase in the height of the E layer maximum increases the range to which radio waves can travel by reflection from the layer.

### E<sub>s</sub>-Layer

The E<sub>s</sub> layer or sporadic E-layer, Sporadic E propagation is characterized by small clouds of intense ionization, which can support radio wave reflections from 25 – 225 MHz. Sporadic-E events may last for just a few minutes to several hours and make radio waves very excited, as propagation paths which are generally unreachable, can open up. There are multiple causes of sporadic-E that are still being pursued by researchers. This propagation occurs most frequently during the summer months with major occurrences during the summer, and minor occurrences during the winter.

### F-Layer

The F layer or region, also known as the Appleton layer, is 120 km to 400 km above the surface of the Earth. It is the top most layer of the ionosphere. Here extreme ultraviolet (UV, 10–100 nm) solar radiation ionizes atomic oxygen. The F layer consists of one layer at night, but in the presence of sunlight (during the day), it divides into two layers, labeled F<sub>1</sub> and F<sub>2</sub>. These F layers are responsible for most sky wave propagation of radio waves, facilitating high frequency (HF, or shortwave) radio communications over long distances. They are thickest and most effective in refracting radio signals on the side of the earth facing the sun. [2]

## 4. References:

1. Lectures: Professor Kjell Rönmark
2. <http://en.wikipedia.org/wiki/Ionosphere>
3. <http://www.harp.alaska.edu/harp/ion1.html>