# IONOSPHERE

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## The Earth's Atmosphere

Taking a look at the neutral composition of the atmosphere around our planet, we can divide it into three main regions: the homosphere to about an altitude of 90 km (55 miles), the ionosphere to an altitude of about 600 km (370 miles) and the exosphere. See **Fig 4.1**. The homosphere is subdivided in another three regions, starting with the troposphere at the lowest level, then the stratosphere, and finally the mesosphere.

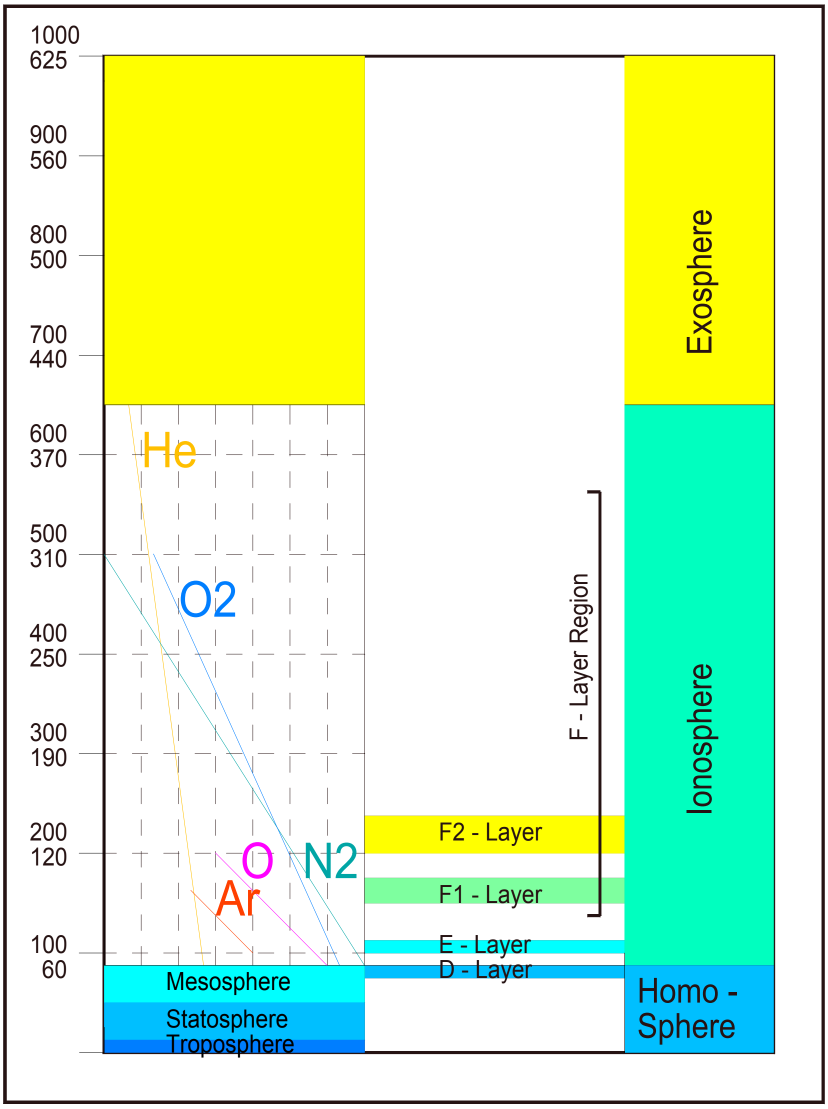

***Fig 4.1.*** *This chart gives an idea of the heights and the approximate positions of the atmospheric layers: homosphere, ionosphere, exosphere, troposphere, stratosphere, mesosphere. The chart lists the different ionized layers and the occurrence of rarefied diffused atomic and molecular gasses. Note the possible height-region for the F-Layers. The height scale is in km (top figure) and miles (bottom figure).*

The troposphere extends from the earth's surface to a height of about 10 km (6 miles). Its composition is a uniform mixture of different sorts of gases, predominantly molecular nitrogen ($N_2$) (78%), molecular oxygen ($O_2$) (21%), and minor gasses (a mixture of argon (Ar), hydrogen (H) and several other gases (1%)). All weather is confined to this lowest region; it contains 90% of the Earth’s atmosphere and 99% of the water vapor.

The region above 10 km to about 50 km (6 to 30 miles) is called the stratosphere. In this region, the atmosphere is still dense enough to allow hot air balloons to ascend to altitudes of about 15 to 20 km, and Helium balloons to nearly 35 km. Incoming solar radiation at wavelengths below 240 nm is able to break up (dissociate) molecular oxygen ($O_2$) into individual oxygen atoms. Each of these atoms in turn may combine with an oxygen molecule ($O_2$) to form ozone. A molecule of ozone consists of three oxygen atoms ($O_3$). The ozone gas reaches a peak density of a few parts per million at an altitude of about 25 km (16 miles).

Above the stratosphere to about 90 km (55 miles) is the mesosphere. Here the gas becomes increasingly rarefied at higher and higher altitudes. Starting at heights of 80 km (50 miles), the gas becomes so thin that free electrons can exit for short periods of time before they are captured by a nearby positive ion. The existence of charged particles at this altitude--and higher--signals the beginning of the ionosphere, a region having the properties of both a gas and a plasma. In the ionosphere, the gases are in diffusive equilibrium and the vertical distribution of each gas is dependent on its molecular weight. The heaviest gases are situated at a lower height and the lightest ones at higher altitudes. In the lower ionosphere, molecular nitrogen and oxygen are most abundant, but above 200 km, atomic oxygen is the main component. It is mainly the ionosphere that will play a major role for our radio wave propagation behavior

At the highest atmospheric level, the exosphere, we have only a very rarefied presence of the lightest gases, hydrogen (H) and helium (He). In spite of nearly full ionization of these gasses, this area is extremely rarified and thereof not able to refract our radio waves.

In our planet's atmosphere, we also discern areas of different temperature. We distinguish, respectively, the troposphere, the stratosphere, the mesosphere and the thermosphere. The boundary lines between those temperature zones have acquired the names tropopause, stratopause, mesopause and thermopause. See **Fig 4.2**. The troposphere, the atmospheric zone of meteorological phenomena, has a decreasing temperature as we go higher. The increasing temperature in the stratosphere is mainly due to the absorption of UV-rays by the ozone layer. After a temperature decrease in the mesosphere, the temperature increases again in the thermosphere to asymptotical values of 300 to 1700 Celsius. The actual value strongly depends on whether it is day or nighttime and the level of the sun's activity. The increasing temperature in the thermosphere is due to a partial absorption of the UV-ray by the oxygen molecules ($O_2$). Diffusion and thermal properties explain the slow decrease of the density in the ionosphere. The mean density distribution is also strongly dependent on the sun's activity.

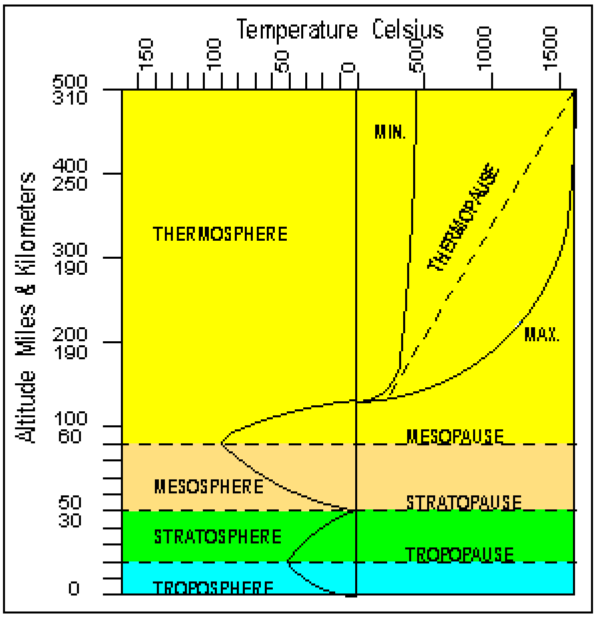

***Fig 4.2*** *A picture of the temperature changes in the earths atmosphere.*

The properties and behaviors of the ionosphere, the region that will dictate radio wave propagation, will now be handled in depth.

## The Ionosphere

The ionosphere derives its name from the term *ION*. High up in our atmosphere, roughly between 60 km. (38 miles) and to 500 km. (310 miles) or even higher, we encounter regions of rarefied diffused gases. At these heights, the pressure is low enough that ions can be formed and travels freely for a considerable length of time without colliding and recombining into neutral atoms. What causes the formation of ions? At the outer reaches of the earth's environment, solar radiation strikes the atmosphere with a power density of 1370 Watts per square meter, a value known as the *Solar Constant*. This intense level of radiation is spread over a broad spectrum, ranging from radio frequencies through infrared, visible light, ultra violet, to X-rays. Cosmic rays and solar wind particles also play a role, but their effect is minor compared with the sun's electromagnetic radiation. Only at nighttime can the influence of them sometimes be noticed.

When a photon--radiated from the sun in the form of UV (Ultra Violet light), EUV (Extreme Ultra Violet light) or X-rays (soft or hard ones)--collides with an electron gyrating around an atom of the rarefied gas, there is a great possibility that the electron will change its course and come loose from the atom. See **Fig 4.3**. The free negatively charged electron exists on its own for some time and leaves behind a positively charged atomic part, called an ***Ion***. After some time the free electron can recombine with an ion and form again a neutral atom (or even a negative charged ion). This process is called recombination. The recombination rate depends on the density grade of the ionized gas. See **Fig 4.4**.

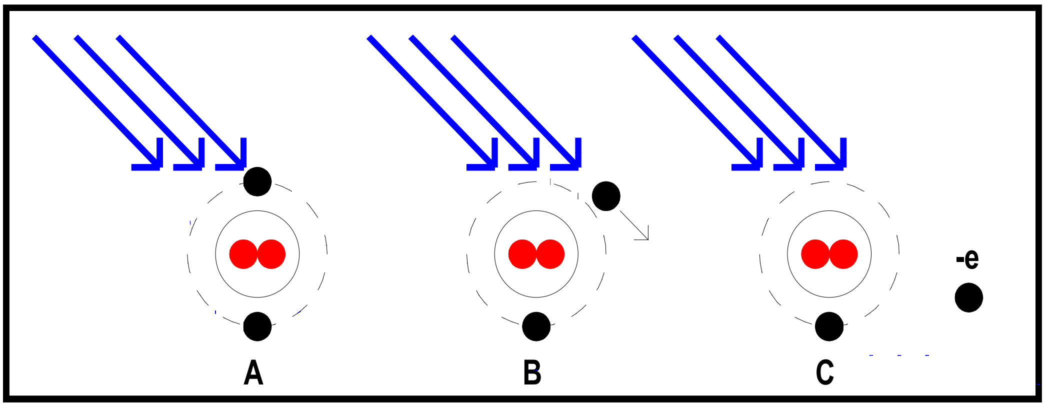

***Fig 4.3****. Ionization process. When as electron is catapulted free, a positive ion and a free electron result.*

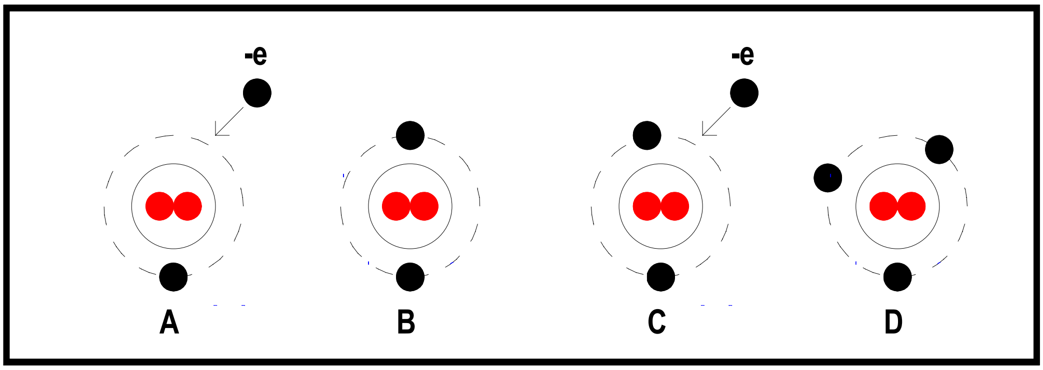

***Fig 4.4*** *Recombination process: both neutral atoms and negative ions can be formed.*

We find different layers of rarefied gases at different heights and with different ionization densities. Why does the ionization density differ among layers? As we noted earlier, it is the radiation of the sun that causes the ionization. So the sun is the prime motor that drives the whole process. Therefore, solar conditions will be of great importance to the propagation factors. Derived from the sun's leading role and influenced by the ionization capabilities of the rarified gasses, ionization density is strongly dependent on whether it is day and night, what time of the day or night it is, whether it is winter and summer (season of the year), and the specific location, (longitude and latitude). Location means how close to or far away from one is from the equator. In turn, location also determines if we have longer or shorter daytime and nighttime, in contrast to more or less equal daytime and nighttime near the equator. In other words, we can divide the main phenomena into the following categories: **Diurnal, Seasonal, Geographical and Cyclical**. In later issues, we shall explore each of these categories in depth. Each will have its own subdivisions.

The sun plays the leading role and has its own properties and phenomena. We shall study these phenomena in a special column: SOLAR AND EARTH PHYSICS AND PHENOMENA. The propagation results of different events, including exceptional ones, will be studied in depth and made visual with the help of graphs, charts, tables, maps, and presentation wizards.

## Formation of the Ionosphere

Solar radiation occurs over a broad range of wavelengths, UV, EUV, soft and hard X-rays, Lyman alpha. All of these rays, and even cosmic rays coming from outer space, travel earthwards into our earth-surrounding atmosphere. Some of these radiations are more dominant, brighter, or more intense than others. The varying dominance and intensity will be responsible for various peaks in ionization observed in the ionosphere at different altitudes. The density and the temperature of the rarified gases at different altitudes and diversity of radiation are the chief causes of the formation of different kinds of ionized layers at different height in the ionosphere.

As the radiations sweeps into the earth's atmosphere from above, they first encounter a sparse population of gas particles in the extreme upper part of it, beginning at height of approximately 1000 kilometers. At this height, the ionization process absorbs a very small--practically negligible--fraction of the radiation. Traveling further earthwards, the rays encounter increasing populations of gas atoms and molecules. Ionization therefore increases, which increases the density of electrons. The UV and the EUV rays play the major role for ionization between approximately 140 and 350 kilometers height. They form a layer of high electron density known as the F-layer. During daytime the F-region is often divided into two separated layers, known as the F2 and the F1 regions. The F2 region is the most dominant and located higher, above the F1 region. Of the two F-regions the F2 is the most important one for our radio communications. As one travels earthward through the F-regions, most UV and EUV rays are consumed by the ionization of that region.

Solar soft X-rays penetrate further into the earth's atmosphere, and they do not lose much of their strength traveling through the most upper altitudes. At a height between 90 and 140 kilometers, they ionize a region and deposit most of their energy. This region is known as the E-layer. It is here that we discover a second peak of electron density at an altitude of approximately 105 kilometers. It is also in this region that we will find sporadic additional ionization, in the form of drifting clouds with high electron densities, known as sporadic E or Es.

Solar radiations with higher frequencies and with greater energy are capable of penetrating further into the earth atmosphere before being extinguished. That is the reason why hard X-rays and Lyman-alpha are able to penetrate to altitudes between 50 to 90 kilometers to ionize the lowest region of interest for radio communications. The region is known as the D-layer region, and its role is very much a negative one relative to our radio signals.

As you will understand, there is no absolute frontier between the different layers. The gaps between identified layers are regions with lesser ionization, either because the gas density is lower or because the gasses lack the specific rays to ionize them. The earlier passing-through and ionization process decreases the intensity of specific rays, with most of their energy being consumed and absorbed.

We explained which rays were responsible for ionizing particular regions in our earth's atmosphere. Other rays will also ionize the regions, but to a minor degree. It is known that during nighttime, when there are no direct solar rays and the F2-layer is less ionized due to recombination, the ionization of the F2-layer is sometimes increased to a higher ionization level by cosmic rays.

Let's note a common misconception about densities in particular. The existence of free electrons plays the main role that facilitates the propagation of radio signals, but this fact does not mean that we should assume that electrons dominate the ionosphere. Compared to other constituents in the ionosphere, free electrons are quite diminutive in density. In the F-region where the electron density reaches a maximum level, the density of ions and neutral particles is about 100,000 times greater than the density of free electrons. In the E-region, where we encounter a secondary peak of electron density, the existence of neutral particles outnumbers the free electrons by a factor of about one hundred billion. See **Fig 4.6.**

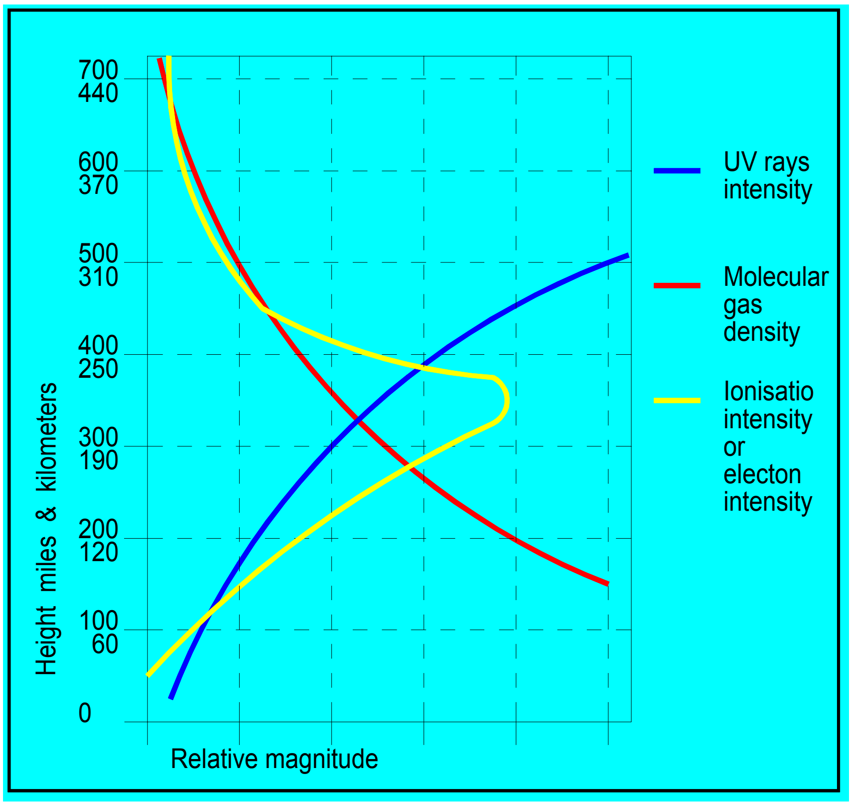

***Fig 4.6.*** *The region with a rather high molecular gas density and a rather high UV rays intensity gives the highest ionization peak.*

In the ionosphere, the propagation of radio waves requires interaction with charged particles. Ions are also charged positive or negative, but they are much more massive than an electron. For this reason, the range of motion of an ion produced by the electric field of a radio wave is much smaller than that of an electron and can be disregarded in most radio wave propagation discussions.

The electron density is expressed in Ne/cubic meter. Ne = the number of electrons.

## LAYERS IN THE IONOSPHERE

Starting approximately 60 km (38 miles) above the earth's surface and extending to about 500 km (310 miles), we shall encounter three layers of importance for our radio HF waves. The lowest known region is called the D-Layer. Next we meet the E-Layer. Finally, we encounter the F-Layer, which may split up into two distinguishable layers, F1 and F2. The degree of ionization is strongly controlled by the radiation from the sun. The ionization of the various layers goes through pronounced changes from daylight through darkness, from differences in latitude, and from changes in the season. The height of the F-layer can vary the most and depends most on these factors. The height of the D-layer and the E-layer are mostly very constant. We shall next look at the different properties of the layers and the reasons for the differences in those properties.

## D - LAYER

The D-layer is the lowest and closest to the earth. This region is situated about 60 km to 100 km (38 to 65 miles) altitude. Between 90 and 100 km (55 and 60 miles), the D-layer is ionized with the hard X-rays as the primary source. From 80 to 90 km (50 to 55 miles), Lyman Alpha line radiation is the controlling source. From 65 to 80 km (40 to 50 miles), galactic cosmic rays have been shown to be the primary ionizing source. Enhancement of any of the sources causes an immediate increase in ionization of the D-layer. It builds up at sunrise, disappears at sundown, and reaches the highest ionization density at midday. The D-layer exits only during daytime. It needs constant radiation to supply continuously the ions that otherwise recombine very quickly to neutral atoms. Remember that the gases are less rarified here and, therefore, the free electrons form much more easily and are sooner captured by an ion. These are consequences of the much smaller distances between. The D-layer is lesser ionized compared with the F-layer, but the denser concentration of more massive ions causes radio wave energy to be easily absorbed.

The ion density of the D-layer at its maximum is Ne = $10^{10}$ / cubic meter.

The D-layer layer is not an aid to our communications; in fact, it is a gigantic attenuator, an absorber of our HF waves, especially for the lower frequencies. We find D-layer absorption to be strong on the 160- and 80-meter bands and to a slightly lesser degree on the 40-meter band. Attenuation varies as the inverse square of frequency: the higher the HF frequency in use, the less the D-layer absorbs the radio signal. The higher the ionization level, the greater the attenuation of those low band waves. The D-layer ionization grade also changes with the sunspot cycle. Absorption and attenuation increases during sunspot maximums. During daytime, radio waves up to 5 MHz are mostly totally absorbed. From 5 MHz to 10 MHz, the waves still undergo an absorption grade that we should not underestimate. From 10 MHz upward, the waves penetrate the D-layer with much less attenuation to continue their travel to meet the next layer. During the dark hours and nighttime the D-layer ionization completely disappears, and therefore, there is no attenuation at all. Occasional sun flare eruptions and other solar events can ionize the D-layer dramatically and cause a temporary radio communication blackout to some extent.

## E - LAYER

About 100 to 125 km (60 to 75 miles) up, we encounter the next region of interest in the ionosphere. The E-layer is mainly ionized by the soft X-rays and also by EUV (Extreme Ultra Violet). It is a thin layer, roughly from 5 to 10 km (3 to 6 miles) thick. During daytime hours, the ionization characteristics are practically similar to those of the D region: the greatest ionization takes place near local noontime and mostly disappears at night. Depending on your latitude (nearer to or more distant from the equator), summer or wintertime (more or less daylight hours), the E-layer will nearly completely disappear during the night or still exit with a very weak ionization grade. Experiments in the early 1980's, during the peak of solar cycle 21, revealed that the E-layer did not go totally away at night, but in fact sometimes was an exceptional or efficient source of nighttime propagation. Ionization increases rapidly after sunrise, drops off quickly after sundown, with the maximum around noontime and the minimum after midnight, all in local time.

The ion density of the E-layer at its maximum is Ne = $10^{11}$ / cubic meter

This layer is the first portion of the ionosphere that is more or less useful for long distance communication. The propagation possibilities with the E-layer--alone or in combinations--will be studied and evaluated in detail later, some very interesting propagation modes or combinations becoming possible for short time periods. Partial E-layer refraction and E-layer screening are some of the possibilities. The E-layer also displays another amazing phenomenon named sporadic E (Es). In this layer, we can have areas of localized and sporadically intense ionization, occurring between about 100 and 115 km with a peak near 105 km. (We shall discuss more about Es later.) The critical frequency of the E-layer is mostly between 1.5 and 4 MHz: higher during a sunspot maximum than during a sunspot minimum. The critical frequency of sporadic E can exceptionally reach to about 30 MHz. (We shall learn more about the critical frequency later.) Because this region is more rarified than the D-layer, the recombination factor is also a bit lower. Therefore, the electron density is higher, and the decrease after sunset is not so sudden.

## F - LAYER

From approximately 150 km (94 miles) height, we encounter the third region. This layer is the most interesting one for our long distance communications. The F-layer is ionized by Extreme ultraviolet light (EUV) and high ultra violet. During daylight, it splits the layer into two parts. The lower part starts at about 150 km (94 miles) altitude and becomes the "F1-LAYER." The higher portion starts at about 200 km (125 miles) altitude and becomes the "F2-LAYER." The given heights are not to be taken as absolute; they vary continuously. The F1-layer is much weaker and plays only a minor role in propagation. It acts more like the E-layer than the F2-region. The maximum ionization of the F1-layer occurs near noon local time. The F1 ionization degree varies in much the same manner, as does the E-layer, being dependent on the sun’s elevation. During the winter, however, the F1-layer usually merges with the F2-layer and cannot be separately identified, except in the equatorial regions. The height of the F-layers varies the most, from 160 km (100 miles) to more than 500 km (310 miles), depending on the season of the year, the latitudes, the time of the day, and most of all the sun's activities. Sun eruptions, sun storms, and sunspots play a dominant role in the ionization density. That density degree predicts the lower and upper frequencies this region will refract. In contrast with all the other layers, the F2-layer exits throughout the day and night and will almost be capable of continuously sustaining skywave propagation at some of the HF frequencies. This is the most durable and completely ionized layer of all and therefore also the most important aid to short-wave signal propagation. The recombining of the electrons occurs more slowly than within the D- and E-layers, since it is the most rarefied layer of the three. This fact means that the free electrons have to travel a greater distance before they are attracted by an ion. A little before sunrise we have the lowest electron density. After sunrise the ionization increases to reach (after 1 to 2 hours) the mean ionization level. During the night, even with a lower ionization level, the F-layer is still good for our lower frequency bands. During daytime, the F-layer is very useful for the higher frequency bands.

The ion density of the F-layer at its maximum is $Ne = 10^{12}$ / cubic meter.

## F-layer anomalies

There are a number of F-layer phenomena that deviate from the above-mentioned general rules and behaviors. At certain times and places, some strange anomalies occur. We list them below and will discuss and illustrate them in later columns.

### ***Daytime anomaly***

The highest solar zenith angle (noontime) does not always coincide with the highest electron density. In most cases, we have two maximum density times. One occurs before noontime; the other occurs in the early afternoon. This phenomenon will become visual in forthcoming Maximum Usable Frequency (MUF) graphs and in electron density profile graphs. The cause of this phenomenon is not yet completely clear and understood by the scientists, but they think it has something to do with the ratio of oxygen and ozone $O_2$ / $O_3$

### ***Nighttime anomaly***

Normally during nighttime, the ionization of the F2-layer decreases, but ionization increase can also take place during the dark hours when there is no direct sun radiation. Sometimes cosmic ray radiation can increase the formation of free electrons or maintain the density degree.

### ***Polar anomaly***

During polar (north or south) wintertime, an F2 layer still exits, even when there is no direct solar radiation in those areas during the wintertime period.

### ***Seasonal anomaly***

Because the position of any point on the earth, relative to the sun, is constantly changing as the earth moves in its yearlong orbit around the sun, the ionospheric properties are also constantly changing. The seasonal behavior of the F2-layer is rather complicated.

During the northern hemisphere winter months, higher but shorter during ionization is noticed. The earth revolves around the sun in a rather elliptical orbit. The fact that the sun is not in the exact midpoint of that ellipse results in the earth being closest to the sun at the 21 December solstice period and furthest from the sun at the 21 June solstice period. Being closer to the sun means that we receive higher levels of UV and other radiation: this results in heavier ionization of the F-layer. The wintertime period means colder temperatures, even at the layer heights. Colder temperatures mean denser and lower in height-situated layers. Denser highly ionized layers give a better refraction and a higher critical frequency. Lower height means a shorter one hop covering range. During the long hours of winter darkness--longer nights--the ionosphere has more time to recombine, therefore yielding weaker and longer periods of low-level electron densities.

In the summer, a heating process takes place in the F2-layer, causing it to expand during the longer daytime hours. This results in a lower ionization density than observed during winter. Due to the layer expansion due to more heating, the layer is more rarified and broader. On the other hand, because of the longer daylight hours during the summer, recombination does not occur to the extent that it occurs during the winter. The variation or differences between day and night electron density levels in summer is much smaller and not so extreme compared to wintertime.

During the equinox periods (Spring and Autumn), and also during summer, the maximum electron density does not occur at the highest solar zenith angle, but some time before and after. The highest electron density occurs some short time after the highest solar zenith in the early afternoon. Another high level is noticed in the late morning before noon. In between those two high level peaks, around local noontime, a good visual dip is noticeable. The summer midday dip is much longer than the equinox time dip, and the time of the afternoon high peak during summer happens much later, often in the very late afternoon.

### ***Earth magnetic anomaly***

At the time of the equinox, when the sun is in zenith above the equator, the ionization grade is the highest at more northerly and more southerly regions than at the equator region itself. A lower ionized layer, a belt that stretches along the magnetic equator, separates both high-ionized regions. The geographic position of the two high and one lower ionized equator belts, moves northward as we approach and depart from the June 21 solstice, and the position moves northward as we approach and depart from the December 21 solstice.

### ***South Atlantic and Southeast Asiatic anomaly***

The south Atlantic and the southeast Asiatic zones are areas where we find a very irregular F2-layer, caused by high earth magnetic field densities in those regions. **–30-**

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