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A BEGINNER'S GUIDE TO THE IONOSPHERE

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The propagation of radio waves depends on many things. One of the most important factors controlling the way they travel outward from a transmitter is the presence of layers of electrically charged particles in the atmosphere. Without these layers, radio signals would not travel more than about a hundred miles from the transmitter. In this article I intend to show these layers, collectively called the ionosphere, are produced and how they differ. In Part II I will show how radio waves are affected by the ionosphere, permitting long distance reception. Since I am not by profession a radio engineer, I do not claim to be an expert on the ionosphere, and consequently have drawn on the knowledge of others. A bibliography of works consulted is appended to this article.

Composition of the Atmosphere

The atmosphere of the earth is a mixture of gases held to the earth by gravitational attraction. It is densest at sea level and thins out rapidly as one goes upward. Almost all (97%) of the air lies within 25 kilometers (18 miles) of the surface of the earth; 50% is within 5 km (3 miles). The lowest region, within 15 km (10 miles) of the surface, called the troposphere, is of little direct interest to the DXer, since it has little effect on MW radio waves. It is of interest to the weatherman, since almost all of the water vapor responsible for weather is here. Weather seems to affect radio waves mostly in the static produced by thunderstorms, but some scientists feel that temperature changes about 30 km up produce the "midwinter anomaly".

Ordinary pure air is colorless and odorless. It consists mostly of nitrogen (78%) and oxygen (21%) molecules. Small amounts of other gases make up the other one-percent. Although the gas molecules are attracted to the earth by gravity, the fact that they are warm keeps them moving above the surface. (According to the kinetic theory of gases, the kinetic energy or energy of motion they possess is directly related to their temperatures; they move faster when they are hot.) Because of their motion, they spread outward and upward from the surface. The atmosphere never really ends; it just gets thinner and thinner until its density matches that of interplanetary space, about 10,000 km (6000 miles) above the surface. At a height of 100 km (60 miles), it is only one-millionth as dense as it is at sea level; at 300 km (the height of the F region), it is only one-billionth as dense.

At lower levels the different gases remain fairly well mixed, but at greater heights they start to separate. The light molecules rise higher than the heavier ones because gravity exerts less force on them; also at any temperature they have greater average speed. Starting about 90 km up, four distinct layers of gas are encountered: molecular nitrogen (N_2) from 90 to 200 km; atomic oxygen (O) from 200 to 1000 km; helium (He) from 1000 to 3500 km; and atomic hydrogen (H) above 3500 km. These layers do not have sharp boundaries on top and bottom, but gradually blend into one another. The division into layers is caused by their differences in weight. Molecular nitrogen, the heaviest, is closest to earth. The portion of the atmosphere we are interested in occurs between 60 and 400 km, in the molecular nitrogen and atomic oxygen layers.

Solar Radiation

The ionosphere would not be present in the earth's atmosphere if it were not for the action of the sun's radiation. Solar radiation causes molecules of oxygen and nitrogen, consisting of two atoms bound together, to separate into single atoms, or atomic oxygen and nitrogen. These, as well as some of the molecules of nitrogen and oxygen, are then ionized, i.e., one or more of the electrons of the atom gain sufficient energy to escape from the atom or molecule. Since the electron is electrically negative, the remaining atom or molecule then has a positive charge, and is known as an ion. The ionized particles in the ionosphere are ordinarily produced from atomic oxygen (O^+), molecular oxygen (O_2^+), and molecular nitrogen (N_2^+).

Solar radiation reaching the outer edges of the earth's atmosphere consists of a wide range of electromagnetic radiation. Infrared rays (heat) and visible light make up 90% of the radiation. It is the other 9%, consisting of X-rays, gamma rays and ultraviolet light, which is responsible for the ionization of the atmosphere. These rays possess much more energy than visible light or infrared rays, and thus are able to give electrons sufficient energy to escape. The energy of any type of radiation is related inversely to its wavelength. X-rays which have short wavelengths are more energetic than the longer ultraviolet rays which in turn are more energetic than visible light or infrared radiation. Wavelengths of all types of radiation up through visible light is usually expressed in units called Angstroms (one Angstrom = 10^{-10} meters). X-rays have wavelengths less than 1000 Angstroms; ultraviolet light waves are between 1000 and 4500 Angstroms.

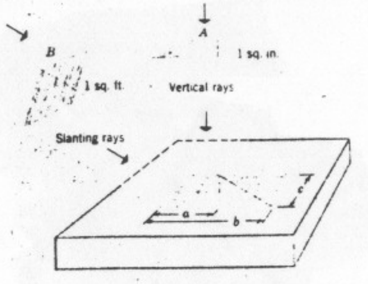


Figure 1. The angle of the sun's rays determines the intensity of energy received.

At any point on earth or in the atmosphere, the amount of solar radiation received in one day depends on the angle at which the sun's rays hit (the highest angle is called the solar zenith angle) as well as the length of time that spot is exposed to the sun.(See Figure 1). These factors are determined by the latitude of the place and the path of the sun at different seasons. The rays are most intense where the rays hit vertically as they do in the tropics. Where the rays arrive at some other angle, the same amount of radiation must spread out over a larger area, thus decreasing its intensity. Thus one square mile in the polar regions will receive less energy than one square mile in the tropics. Since the axis of the earth is tilted 23½° from the plane of its rotation around the sun, the amount of energy received at any spot changes with the seasons. A spot in the northern hemisphere will receive more intense radiation in the summer than in the winter.

Effect on the Atmosphere

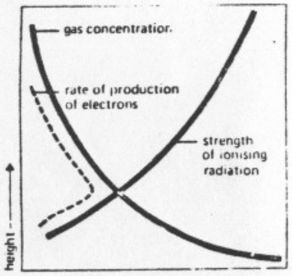
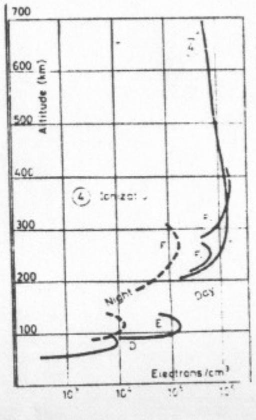


Figure 2.

The production of a layer of electrons when ionising radiation falls from above on a gas with an exponential height distribution. Electrons are produced most rapidly at a level where the downward increase of gas concentration is matched by the downward decrease in the strength of the radiation

Let us see in a general way what happens when radiation from the sun passes through the upper atmosphere. At the top of the atmosphere, since there are so few gas molecules or atoms, the number of electrons produced by ionization is extremely small. Closer to the ground, the sun's rays encounter more molecules with a subsequent increase in the number of electrons produced. Since each collision of a photon of energy with a gas molecule removes that photon from the beam of radiation, the beam gets weaker as it progresses downward. (Figure 2). At certain heights, the rate at which the number of gas particles is increasing downward is matched by the weakening of the radiation downward. At these points the rate of production is greater than at places higher or lower. These areas of greatest production are called electron peaks. Above a peak, the radiation is stronger, but there aren't enough gas molecules to produce a high concentration of electrons by ionization. Below the peak, there are more gas molecules, but the radiation has weakened to the point that fewer electrons are released than at the peak.



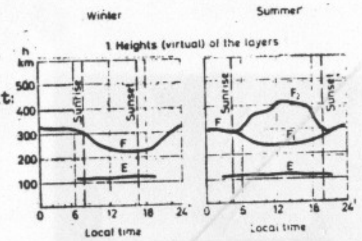
The graph in Figure 3 shows the concentrations of electrons at various heights. The peaks marked D, E, and F1 are called Chapman layers, after Sydney Chapman who studied them in detail in the 1920's. From his studies, he concluded that the height of these layers depended on the concentration and types of gases present and on the type of radiation affecting each gas. The D and E layers are produced by radiation which is not absorbed higher in the atmosphere. The rate at which electrons are produced at the peaks also depends on the strength of the radiation. Since the radiation reaching the D and E layers is not as intense as that reaching the F1 layer, the concentrations of electrons in these two layers are lower. The rate of production also depends on the angle at which the radiation arrives. Electrons will be produced in greatest quantities each day at noon when the sun's rays arrive closest to the vertical. In the yearly cycle they will be produced in greatest number in summer when the sun is highest in the sky.

Chapman also found that the layers of electrons have similar shapes. They differ only in their heights and rates of electron production. Strictly speaking, it is erroneous to call them "electron layers" since atoms are ionized both above and below these points. "Electron peaks" would be a more accurate way of describing the electron concentrations, but "layer" continues to be the common term used.

Layers of the Ionosphere

In 1901 Marconi succeeded in transmitting radio signals from England to America, over the bulge of the earth. Since it was known that electromagnetic waves travel in straight lines and are bent or diffracted only slightly, Heaviside and Kennelly proposed in 1902 that the radio waves had been reflected from an atmospheric layer consisting of free electric charges. Heaviside called it the "electrified layer"; others called it the Heaviside layer. Later, Appleton discovered another higher layer. To distinguish between the two layers, and to make room for other possible layers, he called the Heaviside layer the E layer and the new layer the F layer. Subsequently a lower region of ionization, the D region, was discovered. It was also found that the F layer consisted of two layers which separated during the day and merged at night, and that the concentration of electrons decreased in all layers.

Ignoring the highest layer, the F2, for the moment, we find that the next highest layer, the F1 or Appleton layer, is produced at heights of 150 to 170 km when X-rays strike molecular nitrogen and atomic oxygen. These X-rays have wavelengths between 200 and 800 Angstroms. The predominant electron producer is X-rays produced by helium in the sun, with a wavelength of 304 Angstroms.



The E layer is produced about 100-110 km up by two processes. Very energetic X-rays, with wavelengths less than 100 Angstroms, ionize oxygen and nitrogen. In addition, ultraviolet light with wavelengths near 1000 Angstroms ionize oxygen. At noon there are 10^5 electrons per cubic centimeter produced; at night the concentration drops to 10^3-10^4/cm^3.

Below 90 km, in the D region, the X-rays which have not already been absorbed are extremely energetic, with wavelengths less than 20 Angstroms. They are able to ionize any gas they encounter. They produce the little squiggle at the extreme left end of the graph in Figure 5. The amount of such X-rays is quite small and not many electrons are produced by this kind of radiation. Most of the electron in the upper part of the D region are produced in a different fashion. Between 60 and 90 km, atomic nitrogen, produced by photochemical reactions in the E region, diffuses downward and reacts with oxygen to produce nitric oxide, NO. This gas is ionized by ultraviolet light up to 1340 Angstroms. It so happens that hydrogen in the sun produces ultraviolet light in this range, 1216 Angstroms to be exact (the Lyman-alpha line). Nitric oxide is thus ionized to produce a large supply of electrons about 85 km above the surface.

In the lower part of the D region, ionization takes place because of cosmic radiation rather than solar radiation. Cosmic rays are high-energy particles produced by the stars. They hit the earth day and night from all directions. Th Their great energy allows some to penetrate even to ground level and below. Most collide with atmospheric gases about 60-70 km above the ground, producing a concentration of electrons. Because cosmic rays are deflected by the earth's magnetic field, more of them enter the atmosphere near the poles, increasing the concentration of electrons there.

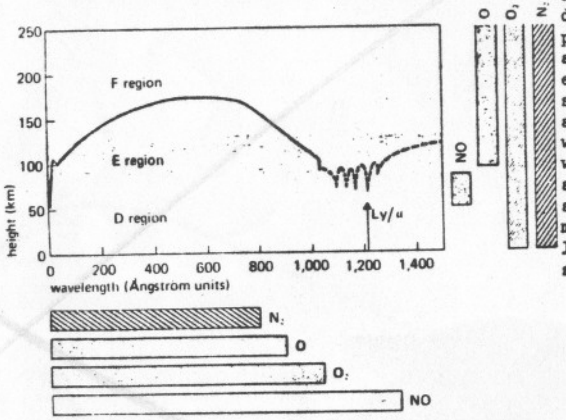
Since the electron concentration between 60 and 90 km is not as great as it in the E and F layers, and since it is more diffuse, this is called the D region, rather than the D layer.

Perhaps it might have seemed from the previous discussion that all of the gas molecules in the ionosphere have been ionized. Not so. Only a small fraction is ionized. For instance, at 100 km, in the E layer, it has been found that there are 10,000 free electrons per cubic centimeter, but that the neutral particles number 10^{12}/cm^3. In other words, one one out of every hundred million gas molecules is ionized at this level.

Below the D region the amount of high energy solar rays drops to such a low level that practically no free electrons are produced. Since it is the electron layers which are responsible for the refraction and absorption of radio waves, we will not concern ourselves with the lower atmosphere. Just as a point of interest, only about 50% of the sun's energy mostly in the form of visible light, actually reaches the surface of the earth.

Figure 5.

The formation of the ionospheric layers. The gases available to be ionised are distributed in height as shown on the right-hand side, while the wavelengths of radiations that can ionise them are marked below the horizontal scale. When radiations of different wavelengths are absorbed in the atmosphere they have their strengths reduced by a factor 1/e at the heights shown by the curve. Those that can ionise the major atmospheric gases (the continuous part of the curve) produce electrons most rapidly at these levels. Those that cannot ionise the main gases are indicated by the broken line. The strong Lyman-α radiation at 1216 Å penetrates far enough to ionise the nitric oxide (NO) in the D region.



Recombination

After electrons have been produced by the disassociation of atmospheric molecules, they remain free for some time. Since they are constantly moving about, eventually they will collide with positive ions and recombine to form neutral atoms and molecules. Some strike neutral atoms and combine to form negative ions. The rate at which electrons are lost by recombination with positive ions depends on the number of encounters and on the concentrations of electrons and ions. The more electrons there are, the greater the chance of recombination, all other factors being ignored. Remember that at the same time electrons are usually being produced by the action of sunlight on neutral molecules. The net effect is a relatively stable number of electrons in a region over a period of time.

In the D region formed by cosmic radiation, there are enough gas molecules for frequent collisions with electrons. Many electrons attach themselves to neutral atoms to produce negative ions. During the day, however, other solar radiation break these negative ions down almost immediately. Thus the free electron concentration is greater during the day than at night. This, as we shall see, is partially responsible for daytime absorption of radio skywaves. At dusk, when the radiation from the sun becomes weaker and eventually disappears, fewer negative ions are disassociated and thus the concentration of free electrons drops, almost completely disappearing at night.

At higher levels, the distance between particles is greater on the average than in the lower D region. Hence the probability of a collision between an electron and an ion or molecule becomes smaller. For instance, at 80 km in the D region, a particle travels an average of about 4 millimeters (1/5 inch) before collision. At 100 km in the E region, it must travel about 9 cm (3½ inches), while in the F region, it must travel many hundreds of meters (thousands of feet). Just for comparison, at sea level, a gas particle travels about 8.6 x 10^{-6} cm (0.000003 inches) before colliding with another gas particle. Since there are fewer collisions at the heights of the E and F1 layers than in the D region, it takes longer for the electrons to disappear by recombination. At night there is a lowering of the concentration. However, it has been noted that the E and F1 layers do not entirely disappear at night, even during the long polar night. In fact they continue to exhibit their usual daily increase and decrease even during the long absence of sunlight. The reason for this is not clear. Ionization due to meteors has been suggested. Upward movement along the geomagnetic field lines into regions where the density is too low to allow for recombination might be responsible for the durable F1 layer. Other possibilities which have been suggested include solar wind particles penetrating into the magnetospheric "tail" of the earth and then coming back upstream, as it were, into the polar regions. It is also possible that aurora-like low energy particles continuously bombard the polar caps.

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Occasionally there are "clouds" of ionization called "sporadic E" at low E layer altitudes. This may be due to heavy ions deposited at these altitudes by meteors. If the proper wind conditions exist at these altitudes, the heavy ions may form a layer that would be very highly conductive.

The F2 Layer

Above the F1 layer, starting at an altitude of about 250 km, another layer of electrons has been discovered. At one time it was thought that this was just another Chapman layer, similar to the D, E, and F1 layers. However, serious discrepancies appeared between the observed daily variations in the electron density and the theoretical values and rates of recombination. Since the theory just did not fit, the scientists went back to their drawing boards and came up with a more acceptable explanation. Now two reactions are believed to take place:

1) $O^+ + N_2 = NO^+ + e^-$

2) $e^- + NO^+ = N + O$

The first reaction is an ion-atom interchange. The atomic ion O^+ changes place with a nitrogen atom in the N_2 molecule to produce a molecular ion, NO^+. In the second reaction, an electron recombines with the molecular ion NO^+ to form atomic nitrogen and oxygen. It is believed that just above the F1 peak the concentration of molecular nitrogen (N_2) drops. This would occur above the peak of the molecular nitrogen layer mentioned earlier in this article. As the concentration of gas drops, so too does the amount of NO^+ produced by reaction 1, simply because of a lack of nitrogen. As a result, in this region, reaction 2 does not take place to any great extent, since it depends on NO^+ ions. Without reaction 2, electrons remain free and their concentration increases. Another factor governing electrons is their weight. Since they are much lighter than the molecular ions, they diffuse upward more rapidly, thus further increasing their concentration upward. At present, it is thought that at the peak of the F2 layer, the effects of diffusion and recombination are equal. Below the peak, the governing factor is the combined processes of electron production and loss, whereas above the peak, it is the diffusion of electrons and ions. The F2 layer does not disappear by recombination at night since its presence is governed more by the presence of molecular nitrogen than on solar radiation.

Changes in the Electron Layers

As mentioned above, the D, E, and F1 layers are governed by the energy that they receive from the sun. As a region of the ionosphere goes into the earth's shadow, electrons are no longer being produced, and the process of recombination proceeds unhindered. The electron density keeps on dropping until sunlight again strikes the region. During summer, when the daytime electron concentration is very high, the level to which the electron concentration drops just before sunrise is still high compared with the winter levels.

As the earth progresses around the sun in its yearly path, the angle at which the sun's rays hit any spot changes. During December, for instance, the rays come in at a much lower angle in the northern hemisphere than they do in June, and the rays spread out more. Thus it should be that the electron concentration in the various layers should be lower. There is one other factor which slightly changes this. Since the earth is actually closer to the sun in December than in June, the intensity of solar radiation is slightly stronger. This has the effect of producing a greater electron concentration in the F layer.

As most DXers know, the number of sunspots changes in an eleven year cycle. Changes in the solar activity somehow affect the number of electrons present in the ionosphere, but the exact reason is not clear. Perhaps the increased solar activity increases the geomagnetic field of the earth, thus allowing more electrons to be trapped. The absorption of radio waves does increase in years of high solar activity.

On occasion the sun sends out flares, or streams of charged particles. When they reach the earth, they cause disruptions in the Van Allen belts of charged particles high above the ionosphere. Electrons and protons fall from the Van Allen belts into the ionosphere, changing the electron concentration drastically. Gordon P. Nelson, in his lengthy article on Medium Wave Signal Paths in 1969-70 has described fully what happens on such occasions when "auroral conditions" are produced.

II. Radio Waves and the Ionosphere

So far we have seen that the atmosphere contains regions with high concentrations of electrons. We are now interested in seeing what happens to a radio wave as it enters one of these regions. To begin with, in order to simplify the explanation, let's ignore the magnetic field of the earth which, as we shall see, is influential in the way that radio waves are absorbed.

A radio wave has associated with it an electric field. This field exerts a force on charged particles in the ionosphere. Since electrons are much lighter than the positive ions in the ionosphere, they are more strongly influenced by this electric field. In fact, the effect of the electric field on the positive ions can be ignored since it is negligible in comparison with the effect on the light electrons.

The force exerted on the electrons causes them to vibrate along a path which is parallel to the flux lines of the wave, and at right angles to the direction of the wave. The lower the frequency of the wave, the greater will be the size of the vibration of the electrons and also the average velocity of the electrons. Changes in the velocity of the electrons will be 90° out of phase with the electric field of the wave since the moving electrons offer intertia reactance to the forces acting on it. Since the electron is a charge particle, its vibrations produce a charge electric current, which in turn makes the electron act like a small antenna, taking energy from the initial wave and re-radiating it in a different phase. Since there are many electrons vibrating, the wavelets produced by each will be in phase in certain directions and out of phase in others. In general, the wavelets will add up to produce a strong wave in the forward direction; in other directions, the combined waves will produce a weak wave by destructive interference.

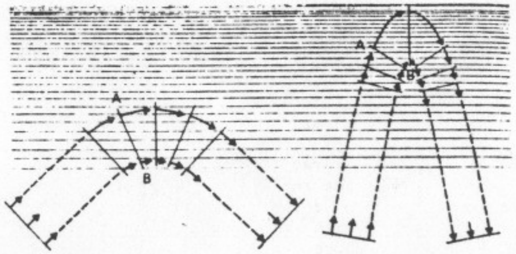
Since the phase is advanced by 90° in each of the wavelets produced by an electron, the combined wave from all the electrons occurs a little earlier than the original wave travelling through free space. To put it in another way, the phase velocity of the wave is greater than the group velocity. The result is that the wave appears to have travelled a little faster than the original wave, and will arrive earlier. As the wave travels into a region in which the electron concentration is greater, the re-radiated wave is greater so that in the combined wave the oscillation occurs even earlier than before. (The phase velocity increases.) The phase velocity of the wave depends on the frequency and on the concentration of electrons. The change in velocity is greatest for low frequencies and for high concentrations of electrons.

Refraction

Let us see what happens to a wave which hits the electron layer at an angle. Suppose that the concentration of electrons increases upward. The top of the wave enters this denser region first, and after being re-radiated, travels more rapidly than the bottom of the wave. As the wave continues to advance, the top of the wave continues to get further ahead of the bottom. The effect is that the direction in which the wave is travelling gradually changes: the wave gradually swings around until it is reflected back to earth. (See Figure 6.) Waves that hit the layer at a small angle need only be bent a small amount before returning to earth. For larger angles of incidence, the wave must penetrate further into the layer. In doing so, the number of the vibrating electrons which collide with other gas particles increases, and hence the amount of absorption increases. The electric field of the wave increases in strength when the wave speeds up. The electrons are thus thrown into greater oscillation, with a greater loss of energy, even though the number of collisions may not increase significantly. Since the electrons oscillate at higher speeds, this means, in terms of the kinetic theory of gases, that their temperature has increased. Experiments have been conducted, or at least planned, to send extremely high energy radio waves into the ionosphere, heating the atoms there to the point that they emit visible light.

Let us see what happens to a radio wave which travels straight up. Using the same line of reasoning as in the preceding paragraph, the wave will be reflected straight back down if its phase velocity becomes infinitely great so that it can swing over quickly enough. This

2·4 When a wave falls obliquely on an atmosphere containing charged particles whose concentration increases upwards, the top (A) of the wave front travels more rapidly than the bottom (B) so that the wave swings over and is reflected. A wave arriving more steeply must travel higher to find enough charged particles to reflect it.



will happen if the frequency of the wave is low enough or if the concentration of electrons is high enough. If the frequency of the wave is too high, or if the concentration of electrons is low, the wave will not reach an infinite phase velocity and thus will not be reflected, but will instead penetrate the electron layer, perhaps to reach another electron layer of greater density. Scientists use this phenomenon to measure the height and electron density of the different layers. Radio waves of different frequencies are sent vertically upward. By noticing which are reflected and from the time lapse, they can tell the height and electron concentration of the layers.

The highest frequency to be reflected from a layer is called the critical frequency. The critical frequencies for the various ionospheric layers are really only of theoretical interest to the medium wave DXer, since all frequencies in the broadcast band are well below the critical frequencies, and then will be reflected back to earth. The shortwave DXer or ham must pay heed to the critical frequency or a lower value known as the maximum usable frequency (MUF); otherwise, higher frequencies will simply continue through the ionosphere into space, perhaps being refracted but not enough to return to earth.

Even though all broadcast band frequencies will be refracted back to earth, this does not mean that a station will be heard via skywave only. A station closer than about 200 km (125 miles) will probably be received via groundwave, since the intensity of the groundwave is much stronger than the skywave at this distance. At about 200-250 km, the intensity of the skywave and groundwave are about equal, and consequently there is often interference between the two waves, weakening the signal. Above 250 km (160 miles) the station will be heard primarily by skywave. Since as we have seen, a wave entering the ionosphere at a small angle is not absorbed as much since it does not have to penetrate as far into the layer, waves refracted from the ionosphere have an optimum angle of refraction, of about 10°. For angles smaller than this, there is too much absorption from the lower atmosphere. Because the earth is curved, the maximum distance away from a transmitter that a signal can be received is about 1200 km from the E layer and about 3000 km from the F layer. Signals can reflect off the ground to once again hit the ionosphere. All long-range DX is of this multi-skip type.

Absorption

Electrons which are vibrating will occasionally collide with gas molecules. As they do, kinetic energy acquired from the radio wave is partially transferred to the gas molecules and partially radiated in the form of a disordered radio wave. This disordered wave adds nothing to the transmission of the original wave. The net result is that the passing radio wave becomes weaker because of the loss of energy by absorption. The amount of energy absorbed depends on the number of collisions and on the velocity of the electrons. Most of the absorption of waves takes place at the lower edges of the ionized regions because the atmospheric pressure is greatest there. The possibility of collisions is greatest there because of the larger number of gas molecules. Since low frequency waves cause the electrons to vibrate more than high frequency waves, low frequency waves are absorbed more. That is why medium wave frequencies do not penetrate the D region in daytime. A relatively high gas pressure exists in this region. The large oscillations of the electrons increases the possibility of collision.

Sky waves of considerable intensity are returned from the E layer. Nighttime sky waves frequently penetrate the E layer and are reflected from the F layer, particularly at the high frequency end of the MW band, and at nearly vertical angles of incidence.

Sunrise Absorption

Under ordinary circumstances, a distant station east of a receiver will be received until absorbing layers of electrons build up to block the path of the waves. (See Figure 7.) Point A in the diagram is the control point. The amount of absorption at this point determines whether the signal will reach the receiver or not. The main factor governing absorption here is sunlight. When sunrise occurs at this point in the ionosphere, the concentration of electrons builds up very rapidly, thus decreasing signal strength very quickly. Gordon Nelson has computed for particular paths the time at which such absorption will occur. He calls these times "E20" times since they indicate the time when a drop of 20 db in signal strength occurs because of the absorption of the E layer. The E20 times change from month to month because of the changing angle of the sun. E20 times are not identical with the time of sunrise at either the transmitter or at point B, directly below the control point. However, for most cases, the E20 times fall within a few minutes of sunrise at the transmitter site. This allows us to use the time of sunrise at the transmitter as a good indicator of the latest time that good reception can be expected. It is extremely rare that there is reception via skywaves for more than ninety minutes after transmitter sunrise. Sunrise at the control point usually causes the electron concentration to build to such a point that only a small portion of the strongest skywaves can penetrate.

There should be an analogous E20 time for stations to the west of a receiver, that is, there should be a predictable time at which a western station will fade in. This is less predictable, however, since it takes some time for the already existing electrons to recombine, reducing the amount of absorption to the point where the signal can penetrate. Since the transmitter is still in daylight in such cases, noise levels also will be generally higher. Thus signals travelling eastward should be expected to fade in later than their westward counterparts fade out. More work needs to be done in this particular area.

The Earth's Magnetic Field

The magnetic field of the earth also influences the moving electrons of the ionosphere. Any charged particle in motion, such as an electron, produces a magnetic field around it. The interaction between the magnetic component of the radio wave and the magnetic field of the electron causes it to vibrate back and forth on a line at right angles to the direction of the wave. Now if a third magnetic field, that of the earth, is added, the electron will then move in an elliptical path. The exact shape of the ellipse depends on the frequency of the wave and the strength of the earth's field. At high frequencies the ellipse will be long and narrow, but as the frequency is lowered, the ellipse becomes closer to a circle. At certain broadcast band frequencies, the path of the electron becomes a spiral. The exact frequency at which this occurs depends on the strength of the earth's magnetic field at that point. The direction in which the electron is travelling is reversed at the same instant that the electrostatic flux of the wave changes polarity. At these frequencies the electron velocity can increase without limit. The electron takes out more energy than it is re-radiated. At these frequencies, called thegyro-frequencies, the wave is thus weakened. The smallest gyro-frequencies occur near the equator, about 680 kHz over Brazil; the largest near the poles, about 1700 kHz near New Zealand. Thus reception from certain directions on certain frequencies becomes almost impossible.

Conclusion

In this brief article I have attempted to present as clearly as possible without a great deal of mathematics a description of the ionosphere and the ways that radio waves are affected by it. By no means has this been a complete or detailed analysis. However, I hope that some understanding of the ways in which radio waves are affected by the ionosphere will help the DXer to avoid wasting time and energy in looking for stations which simply could not be heard because of conditions in the ionosphere preventing such reception.

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