Introduction to Atmospheric and Space Sciences

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Lecture - 43
Ionospheric Chemical Reactions and Layers

Hello dear students. So, in today's class we will try to understand the aspects of ionosphere. So, last time we have seen what are the different layers of ionosphere, what is the chemical processes in which ionospheric electron densities are maintained. We also seen that few of the ionospheric layers will disappear during the night time. So, while discussing the various chemical reactions; we have seen that these four reactions are the main processes by which electron densities are created. And they are also lost during the absence of the sun.

So, the processes are ready to recombination in which simply and a positive ion and electron recombine to give a neutral species and some amount of energy. So, the main important aspect about this particular reaction is that it is a very slow reaction which proceeds at the reaction rate coefficient of 10 to the power of minus 12 centimetre cube per second.

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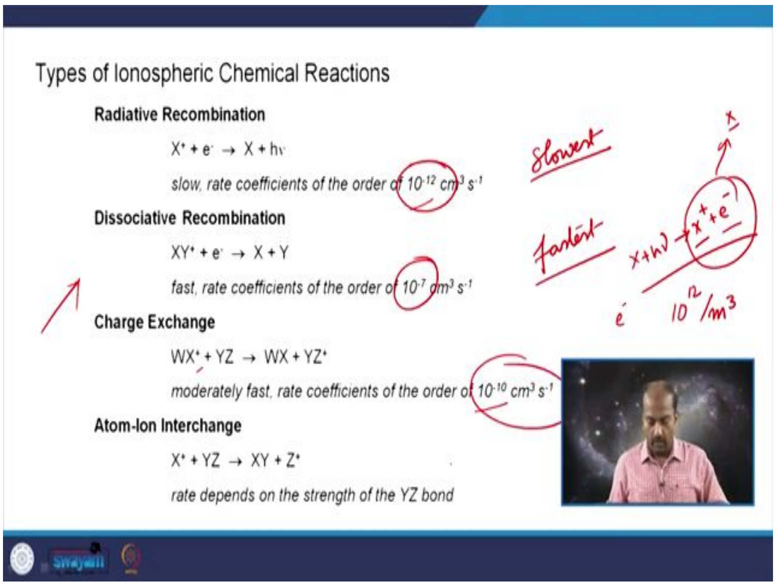

Dissociative recombination on the other side is a very fast reaction. So, it can take care of the electron densities in a very small amount of time. So, in which a molecular ion combines with an electron to dissociate into individual atoms of which have constituted that particular molecule. Charge exchange is reaction in which a charge the positive charge is transferred from one molecule to other molecule.

This reaction is also kind of very fast with the typical reaction rate coefficient of 10 to the power of minus 10. And atom ion interchange, ion atom exchange is reaction in which a positive ion comes in contact with a molecule and this charge is transferred at the same time if the molecule becomes rearranged. So, out of these four processes this is the slowest process, the radiative recombination and dissociative recombination is the fastest process.

Now why are we discussing these two processes in terms of their speed in which they can take care of the electron densities. So, ideally, when an electron is formed by photo ionization, let us say any neutral atom if it gets sufficient amount of energy it will be ionized giving you back a positive ion an electron. This should populate the ionosphere and give it the densities of 10 to the power of 12 electrons or ions per meter cube; that means, the available electron density in the ionosphere, the peak electron density in the ionosphere is of the order of 10 to the power of 12 per meter cube.

Now when you remove the source of energy which is causing this ionization to happen. Ideally, all the electrons and ions should recombine and give you back the neutral species.

Now, what happens is? It does not happen like that. I mean; the electron density is still persistently available during the night time as well. So, to explain the night time availability of electrons or ions; we need to consider the rates at which the recombination happen. So recombination is simply the reaction which will make sure the electrons and ions come together and net charge is lost. So, dissociative recombination is the fastest process.

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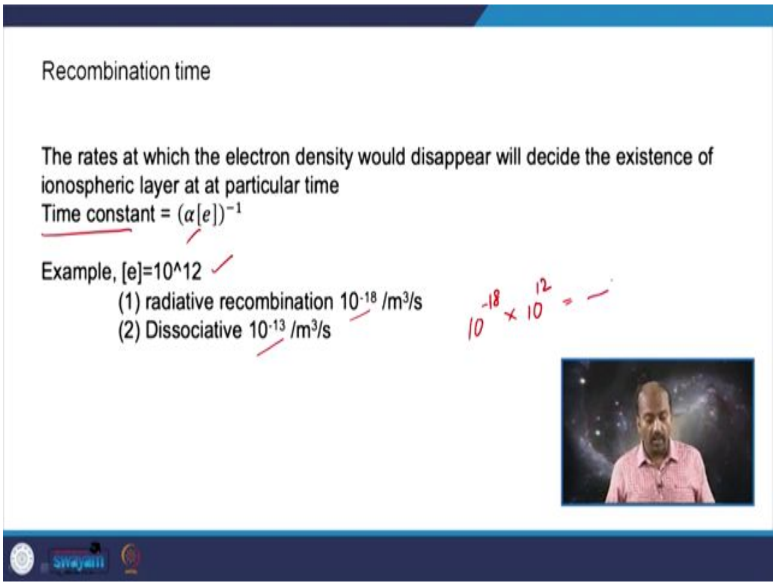

Let us see if it is the case so, simply speaking. So, the rates at which electron densities would disappear will decide the existence of ionospheric layer at a given time. So, time constant is that , how do you define time constant? Time constant is the duration of time by over which electron density will successfully recombine with the ion density to give you neutral species.

So, alpha is a recombination coefficient , the recombination coefficient has already been seen in these four different reactions. So, these are the recombination coefficients . And e is the electron density at particular time. So, typically for a peak electron density of 10 to the power of 12, radiative recombination with a recombination coefficient of this and dissociative recombination this. We already seen we all calculated. So, Let us say 10 to the power of minus 18 put against 10 to the power of 12.

So, we will give you duration of time which is very very large in. So, 10 to the power 12 is that peak electron density, if you take the radiative recombination process to be alone responsible for the loss of electron density in the ionosphere. The approximate of approximate amount of time that it will take has also been calculated. So, this is of the order of several hours and this is of the order of few seconds.

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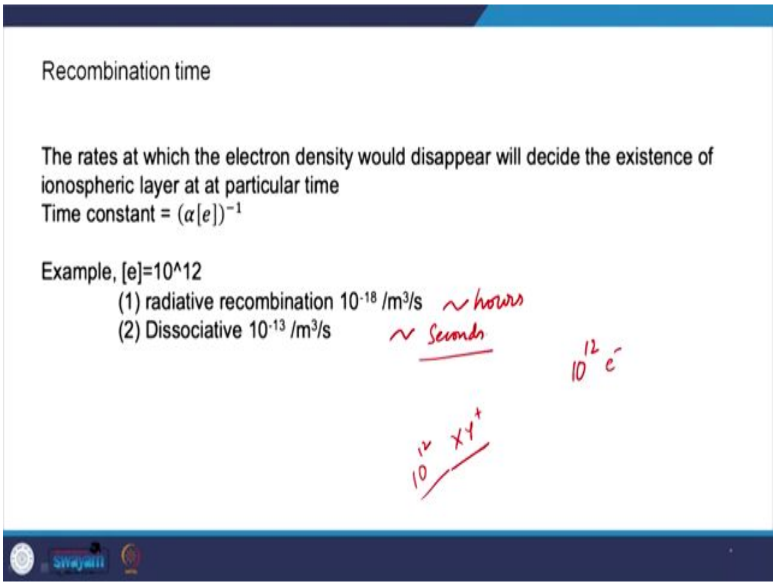

So, if dissociative recombination is the only process available or only process which is working in the ionosphere to take care of the electron density. It will only take few seconds or few minutes to the maximum for the entire ion density to say disappear or for entire electron density to disappear. But if radiative recombination is the only process by which electrons and electrons and ions recombining it will take several hours.

Let us say which will stretch beyond the duration of the night what it means is that; dissociative recombination is more effective in taking electrons and recombining with ions to get the neutral species. But more importantly, what is limiting dissociative recombination to take care of the entire electron density is that. It is limited by the availability of molecular ions.

So, it is not required that if 10 to the power of 12 electrons are available, it is not mandatory that 10 to the power of 12 ions in terms of molecular Let us say XY plus configuration are also available. So, depending on the number of available molecular ions and the number of available atomic ions suitably some process will take place which is not so effective for the complete disappearance of the electron density in the ionosphere during the night time.

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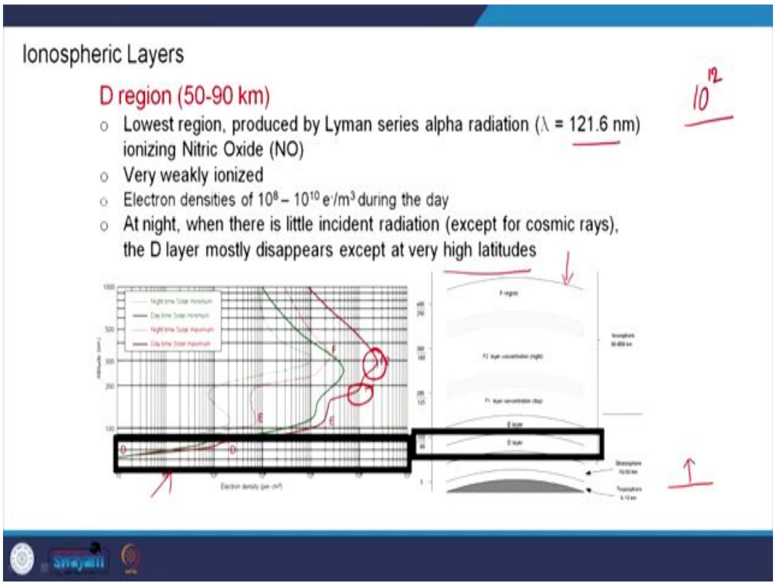

So, now what we will do, we will try to look at the various ionospheric layers in its full detail . So, we have seen that ionospheric layers are 4. Mainly D, E, F 1 and F 2. And these ionospheric layers, the structure of this ionospheric layers has also been discussed already. So, the bottom most layer is called as the D layer or D region, which extends from 50 to 90 kilometres in the atmosphere.

So, this is the bottom most layer, this is the lowest region. This is fundamentally produced by Lyman alpha radiation at a wavelength of 121.6 nanometres by ionizing nitric oxide. So, this layer is not very intensely ionized, it is very weakly ionized. So that means, the electron densities are considerably small in comparison to the peak electron densities that you can find in the ionosphere.

So, electron densities are typically of the order of 10 to the power of 8 to 10 to the power of 10 electrons per meter cube during the day time . So, that you always remember this 10 to the power of 12 number, I mean; 10 to the power of 12 is the peak electron density that you can find in the ionosphere in the F region in the day time . So, you see here the bottommost layer is highlighted with this box you see this as the D layer or D region.

And during the night time when there is little incident radiation except for the cosmic rays when there is no sunlight direct sunlight available, the D layer mostly disappears except for very high latitudes. At very high latitudes, the source of energy is something else. in terms of energy particles and something like that. But other than that in the low latitudes or in the mid latitudes, the D layer will completely disappear. One very important aspect about the D layer is that the incident radiation is coming from the top electron from the bottom, the neutral densities are decreasing exponentially.

So, incident radiation encounters a lot of gases in the atmosphere as it travels towards the ground. But , its energy, the amount of energy carried by the incident solar radiation also decreases as it encounters more and more neutral atmosphere as it travels towards the ground. So, at this time when it reaches the bottom most, let us say 50 to 90 kilometres altitude not much of the energy is left, I mean; all the energy is already spent in the upper atmosphere or in the upper ionosphere.

So, as a result because of the low energy that is available; the electron density that can be seen in D layer is considerably low which is the lowest of the four different layers in the ionosphere. And most importantly because of the lack of direct solar radiation or because of the non availability of direct solar radiation during the night time the D layer disappears. So, and a few more important characteristics of this D layer. The electron density in the D layer; normally, it does not have a distinct peak.

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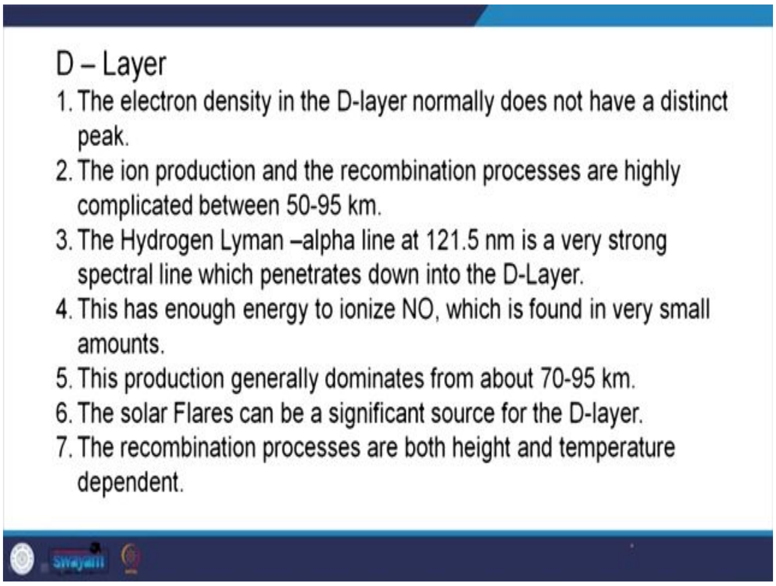

So, if you see the F layer, You have a distinct peak as in where the electron density goes increases to a particular point and then it decreases. You do not see something like that. So, D layer; the electron density in the D layer normally does not have a distinct peak. The ion production and the recombination processes are highly complicated between 50 to 95 kilometres.

Because of the large availability of neutral species, then production process as well as the recombination process becomes very complicated to understand. And the hydrogen Lyman alpha line at 121.6 nanometres is the very strongest spectral line which penetrates up to D layer. So, if energy is traveling from the top to bottom. So, the energy has to be very intense and strong to be able to penetrate all the way to the bottom most D layer. So, Lyman alpha does that.

So, there is this particular Lyman alpha has enough energy to ionize the nitric oxide molecule which is generally found in very small amounts in the D layer or in the 50 to 95 kilometres altitude. So, the production is generally dominant not in the 50 to 95, as such it is very much strong in 70 to 95 kilometres. And also the solar flares could be a significant source of the D layer, I mean; during the solar flares or .

Solar active periods; the D layer strength could be proportionate to the amount of solar flare activity. The recombination processes are both height and temperature dependent. So, the recombination process are like we have seen these processes could be dependent on the height naturally the height along with the availability of neutral species at that particular height and the temperature at that particular height.

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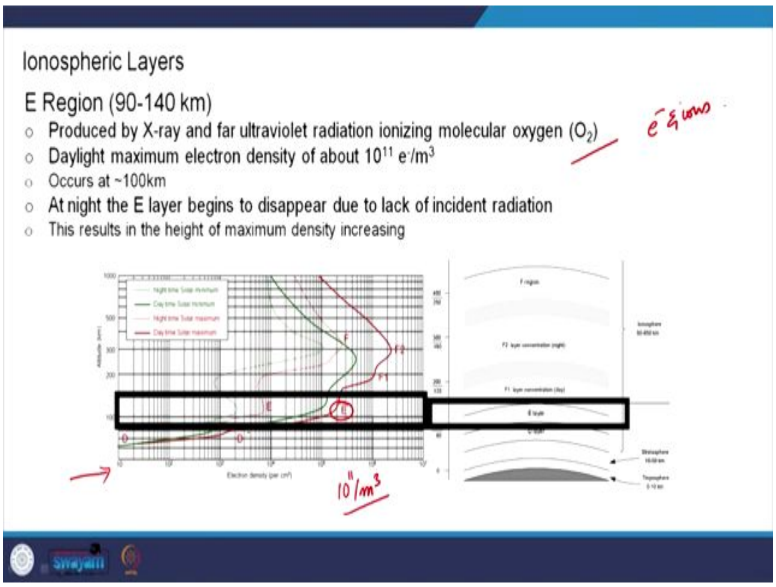

Then the E layer. So, E layer is the region of the ionosphere that is above the D layer and below the F1 layer. So, this layer is mainly produced by X rays and far ultraviolet radiation by ionizing the molecular oxygen.

So, in the D layer; it was the hydrogen Lyman alpha which ionizes the nitric oxide and produces electron density to the order of magnitude of, let us say 10 to the power of 8 to 10 to the power of 9 or 10 to the power of 10 per meter cube. In the E layer; some X rays which are X rays are considered very very energetic, some X rays will travel all the way from the top of the ionosphere to these particular heights 90 to 140 kilometres by ionizing and they ionize the oxygen molecule to release electrons and ions .

So, daylight maximum electron density is of the order of nearly 10 to the power of 11 electrons per meter cube. Typically, the electron density, the maximum electron density that you can find in E layer between 90 to 135 or 140 kilometres is roughly of the order of 10 to the power of 11 per meter cube. And this peak electron density occurs at 100 kilometres approximately. So, this is 100 to 110 or 120 kilometres. This is the peak of E layer which appears at; which appears at 10 to the power of 11 per meter cube. So, the axis that is given here is in centimetre cube.

So, what I am writing here is in per meter cube. So, during the night, at night the E layer begins to disappear because of the lack of incident radiation. So, E layer so, if you see night time densities are indicated with the dotted curve. So, as you see the solid line that you see, solid red line that you see is during the solar maximum; E layer electron density, the ionospheric electron density during the solar maximum is given by the solid red line. Let us say and as you see the dotted red line is remarkably weak in density and it starts to disappear due to the lack of incident radiation.

So, it is mainly the incident radiation which is due to the non availability of which you do not see E layer during the night time. So, this results in height of maximum density increasing. So, this is a different thing. So, at the night time you do not find much of the E layer. So, D layer is 50 to 90 kilometres E layer is 90 to 140 kilometres.

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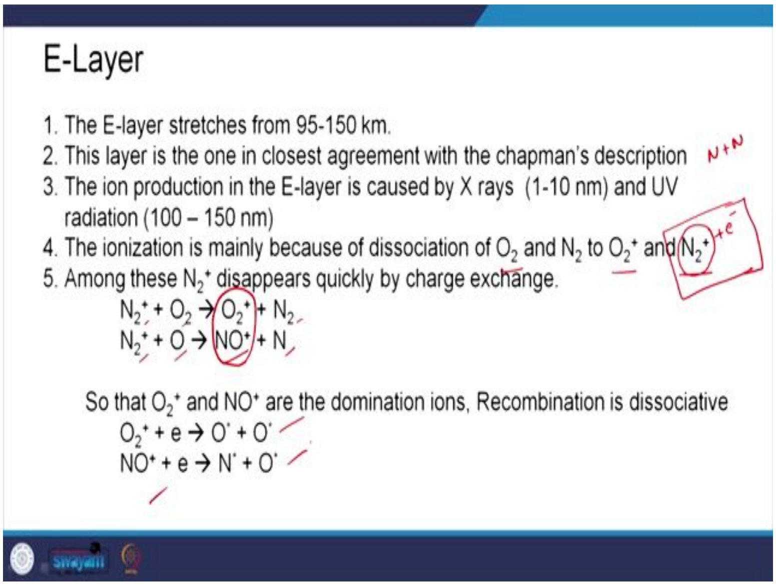

And few more important characteristics about the E layer is E layer stretches from 95 to 150 or 140. Many books say it is 135 kilometres something like that. So, this layer is one of the closest in agreement with a chapman description of the ionospheric layers, ionospheric layer production. The ion production in the E layer is caused by X rays, 1 to 10 nanometres and ultraviolet radiation from 100 to 150 nanometres.

So, this is like the far ultra violet radiation. The ionization is mainly because of the dissociation of molecular species such as O 2, N 2, O 2 giving you leading to the formation of O 2 plus and N 2 plus. Now you see if these ions which are molecular in nature are available for the electron to recombine this reaction will be very fast; that means, this will immediately give you N plus N and the electron will be lost as a result.

And this process will be fast. Among these N 2 plus being a molecular ion quickly disappears by charge exchange. So, N 2 plus will not be available as it is. So, N 2 plus will quickly disappear by charge exchange with the neutral species such as O 2 and O. So, in this reaction what you see is charge is getting exchanged from nitrogen to oxygen. So, this O 2, now becomes O 2 plus and N 2 will be neutral molecule.

So, N 2 plus may also combine or interact with neutral oxygen atom giving you N O plus and nitrogen . So, charge is getting exchanged and ion atom rearrangement is also happening here. So, that now this gives you the availability of these two molecular species; O 2 plus and

N O plus. O 2 plus and N O plus are the dominant ions. So, which can recombine very fast with the electron giving you neutron excited atoms .

So, now we have seen about D layer and E layer. So, D layer is the bottom most layer, E layer is the layer above the D layer. The electron density is available in the E layer are more in comparison to electron densities that are available in the D layer .

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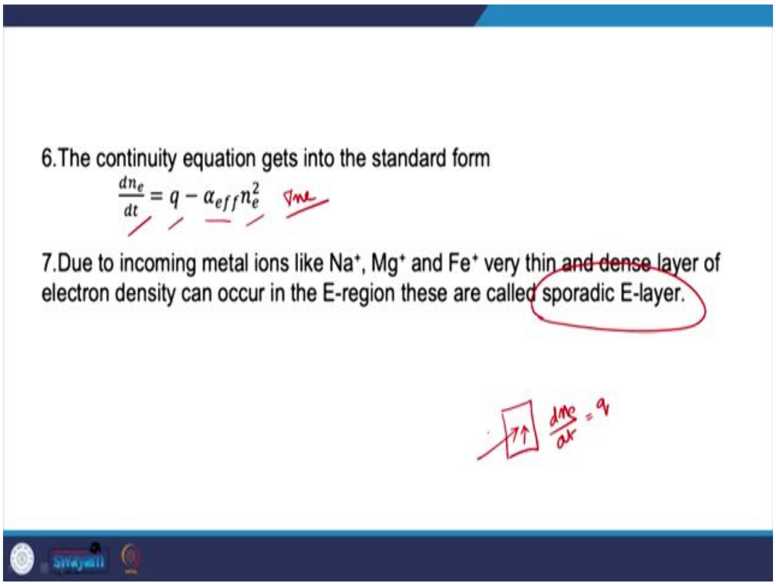

And the heights and the during the night time due to the lack of energy it also affects the strength of the both these layers. The continuity equation gets into its standard form where d ne by d t is the rate at which electron densities will change with respect to time.

Q is the rate of production alpha is the recombination coefficient and n e is an electron density . So, due to the incoming metal ions such as Na plus, Mg plus, Fe plus very thin and dense layer of electron density can occur in the E region called as sporadically layer. So, this is a very important concept in the ionospheric studies. The point is if you have we already know due to the meteor copulation lot of metallic species are available in the mesosphere.

And these metallic species available in the ion densities if they are available as ion densities. You also find these ion densities will get added to the densities of E layer. So, this particular E region is called as a sporadic E layer . Now, this continuity equation may also have an additional transport term let us say, del n e; this is the transport term. So, at any given instant of time the rate at which electron density changes with respect to time, you consider a small volume.

The electron density that changes in this volume is the rate at which electron density is produced into this volume and electron density that is lost by the means of recombination from this volume and then you have the transport term which takes care of the additional electron density which may get transported into this volume or out of this volume right.

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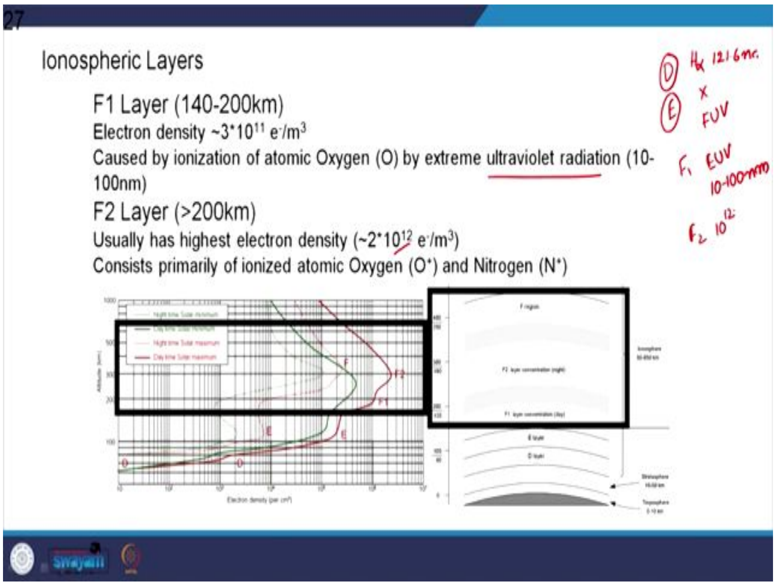

Then, the above the E layer you have this composite F layer which is a combination of F1 and F2 layers. So, F1 layer is something that stretches between 142 to 200 kilometres.

So, F1 layer is very dense in nature in comparison to D and E layers. Electron density is typically of the order of 10 to the power of 11. Several 10 to the 11 electrons per unit volume, let us say in per meter cube. So, this is mainly caused by the ionization of atomic oxygen by extreme ultraviolet radiation. So, now, if you consider the solar spectrum we are able to get different parts of solar spectrum ionizing the atmosphere at different altitude.

So, just to remember it was the hydrogen Lyman alpha at 121.6 nanometres which causes ionization in the D layer. And in the E layer, it was the X rays and far ultraviolet. And now in the F1 layer; the most important ionizing radiation is ultraviolet radiation, 10 to 100 nanometres which is extreme ultraviolet radiation EUV which is from 10 to 100 nanometres. And the typical densities are of the order of 10 to the power of 11 per meter cube.

F2 layer is consider the most strongest electron density that is to be found in F2 layer the highest electron density. F2 layer occurs above 200 kilometres usually has the highest electron density which is of the order of 10 to the power of 12 per meter cube. And this consists mainly of the atomic oxygen ions and nitrogen ions. So, F2 is 10 to the power of 12 electrons per unit volume.

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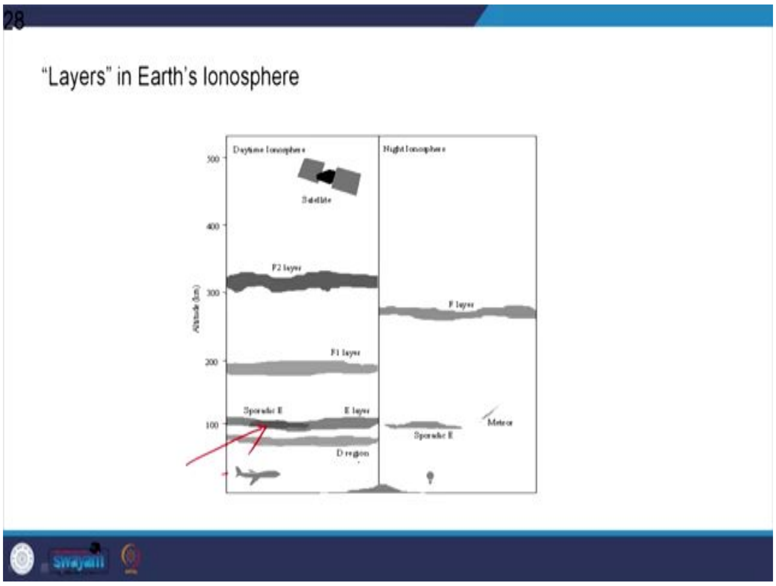

So, if you just put them for reference. So, this is during the day time ionosphere. So, for reference this is like what 10 kilometres or 9.5 kilometres. So, D layer, the bottom most D layer appears at 50 kilometres 50 to 95 kilometres, then the E layer. Then the sporadic E layer is due to the occurrence of metallic ions in this E layer, then you have the F1 layer, this is the peak F1 layer that is being shared and the peak F2 layer occurs at nearly 10 to the power of 12 per meter cube and during the night time much of the D layer and E layer disappear and only the F layer will remain during the night time.

Now, during this the discussions about ionosphere; we will try to understand, if the recombination processes are effective in nature? There should not be a provision for having electron densities in the night time. So, we should look at the processes which will help to maintain the electron density even during the night time. That is going to be a topic of discussion for let us say after a couple of lectures .

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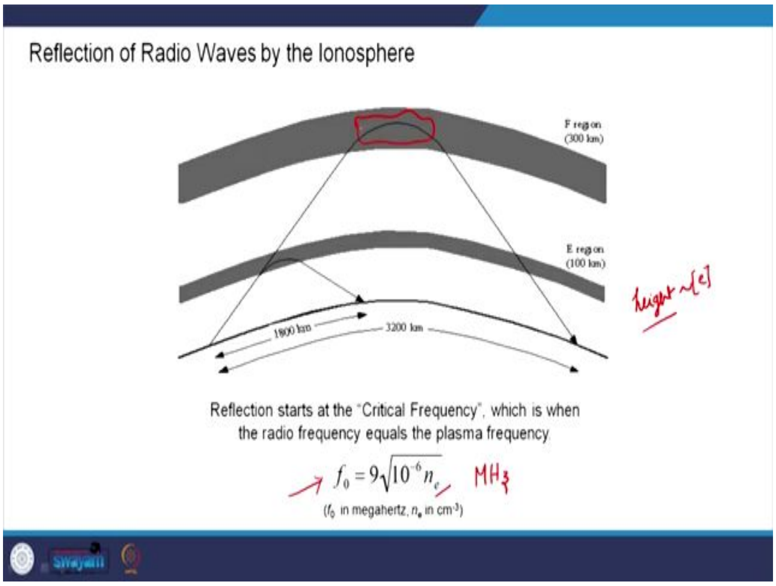

Now, so, like we began the discussion of ionosphere by saying that ionosphere is the region of power atmosphere where electrons and ions are present sufficiently large in number. So, that they can influence the radiowave communication. So, ionosphere is working as a reflecting mirror in the sky which reflects the incoming electromagnetic radiation or a radio wave communication from the earth. So, that means that ionosphere gives you a provision to carry out communication beyond the limit of a line of sight communication .

So, what happens is, how does the ionosphere reflect the incoming radio wave radio wave signals. So, if you have ionosphere; so, this ionospheric layers are defined in height and also height interrelated with the electron density. Electron density e within square bracket means electron density . So, the height there are the ionospheric layers are defined in height and they are interrelated with the electron density.

So, each layer is distinct in its height as well as in its electron density. So, generally reflection of the incoming radio wave signal starts at the critical frequency which is when, the radio frequency that is you are trying to send that you are using to communicate becomes equal to the plasma frequency. Now in our discussions of plasma physics we already derived a relation for plasma frequency which is as this.

So, here n e is the electron density. So, n e defines the plasma. The plasma strength is defined by n e number of electrons or ions that are present per unit volume will decide what will be the frequency of that particular plasma. Now if this frequency becomes equal to the incoming radio wave frequency, then the reflection will happen. Now this reflection can happen at the bottom of a particular layer or in the peak density region of a particular layer it can happen anywhere.

So, generally the criteria is whenever this condition is met just like resonance whenever this condition of the radio wave frequency being equal to the frequency of the plasma ionosphere is plasma, then the reflection will happen. So, you always remember this particular formula the plasma frequency is given up by given by 9 times square root of 10 to the power of minus 6 n e and this frequency is given already in mega Hertz.

So, this is the important thing. So, some sometimes what happens depending on the type of communication that you want to achieve you will appropriately take suitable frequency and this frequency will have a characteristic height at which it will get reflected from the ionosphere. Now, more importantly, most importantly what may happen is?.

Let us say , if you have some abnormal occurrence of electron densities due to some, let us say solar flares or some solar prominences this electron densities will be hugely disrupted and it the plasma being an electro dynamical entity, plasma allows several different types of instabilities to occur or instabilities to be present in the plasma. Now if you have an instability which is called as let us say for example, a plasma bubble which may span several 100s of kilometres.

Then, if you are trying to achieve radio wave communication and by chance if this plasma bubbles falls in the line of this communication, then there may be a severe disturbance for the communication. So, the point is ionosphere is plasma. So, plasma is this plasma is interconnected with the solar activity. So, many physical processes may disturb the ionosphere and as a consequence; the communications may severely be affected because of the solar activity. So, height at which the radio waves reflect is dependent on the maximum electron density of a particular layer.

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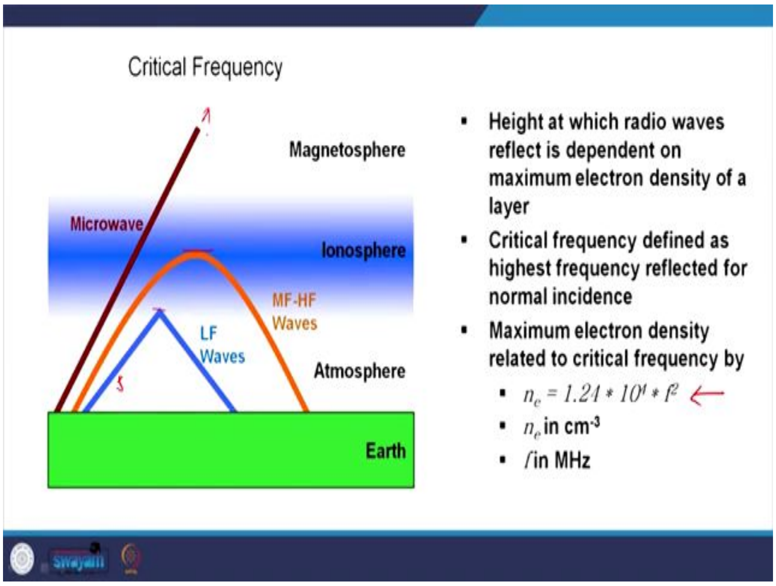

So, critical frequency is defined as the highest frequency that is reflected for normal incidence. So, critical frequency is not for oblique incidence, but for normal incidence. Maximum electron density reflected that is maximum electron density related to the critical frequency can be. So, just from the same formula can be obtained in this way. So, what you see here is depending on the frequency. So, low frequency, medium to high frequency and microwave. So, this is the based on the frequency incoming frequency; it will get reflected at a particular point.

So, you will have to choose which particular frequency you want to use for which certain type of let us say communication. Now, this is something about the layers of ionosphere how the layers are structured, what are the important chemical processes which are active in these layers and how the some layers of the ionosphere will only be visible during the day time and how some layers sustain to be visible in the during the night time as well.

So, this is a brief discussion about or kind of an introduction to ionosphere. So, in subsequent classes we will try to understand, what are the physical processes by which the ionospheric layers are maintained and several other things.