Introduction to Atmospheric and Space Sciences
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Lecture - 42
Ionization Processes in Ionosphere

Hello, students. So, in today's class, we will continue our discussion about the Ionospheric physics, basic aspects of ionosphere how the charge transfer or charged electrons and ions are created . So, in the last class, we have seen that the ionospheric electron densities vary with respect to day of the day with respect to time on with respect to the solar cycle.

So, generally, so, its during the solar maximum the electron densities or the ion densities are the maximum and during the day time they are maximum right.

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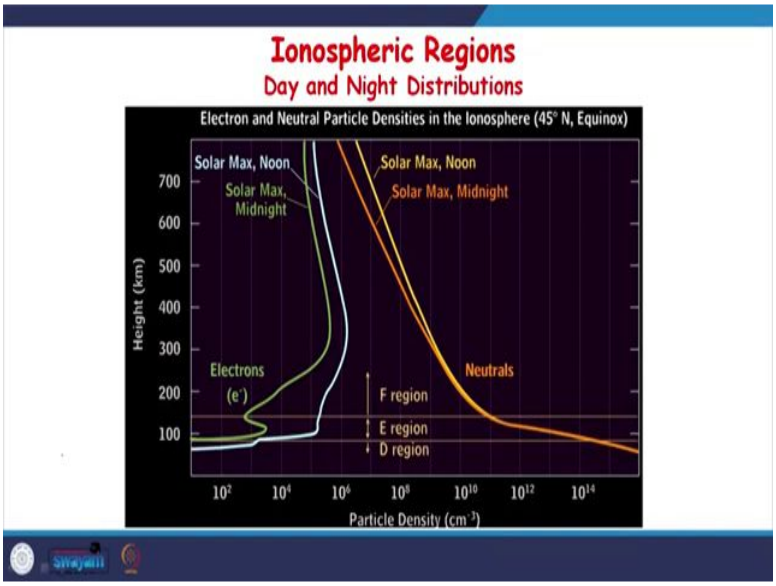

But interestingly from the ionosphere is a region which is at the 50 to 600 kilometers of the atmosphere of the earth.

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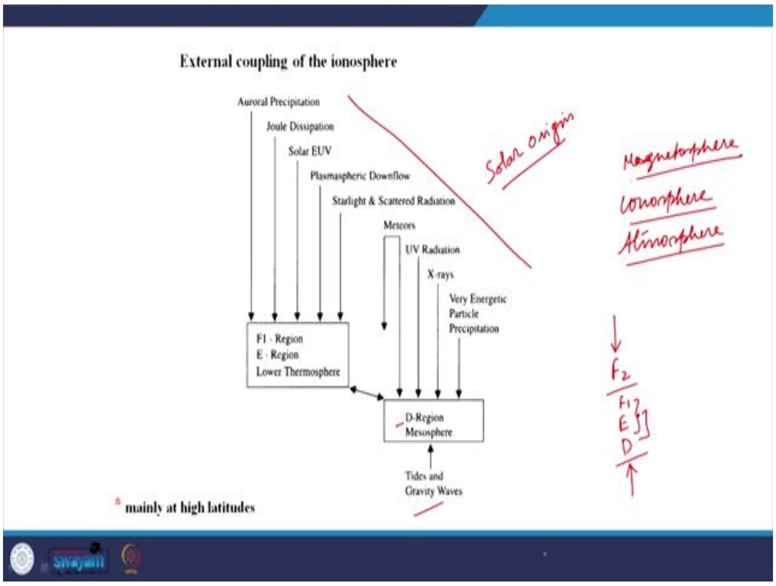

So, ionosphere is a region which comes or which couples really very well with the atmosphere there is neutral atmosphere below and the magnetosphere above. So, the ionosphere is right in between, neutral atmosphere and the top side ionosphere extends into the magnetosphere.

Now, so, in each of these layers in each of these places various different physical processes are occurring and these processes are specific to the kind of pressure the kind of temperature this is available at these heights. So, what you see is that the ionosphere is coupled with various other physical aspects of this particular layers. Let us say a auroral precipitation, joule heating or joule dissipation solar extreme ultraviolet radiation, plasmaspheric down flow, star light scattered radiation, meteors UV radiation, X radiation, very energetic particle precipitation. So, most of I mean like 90 percent of these effects are of the solar origin.

So, the ionosphere is very well coupled with the processes or the effects that sun can throw. At the same time, the ionosphere, the bottom side of ionosphere which is also called as the D layer is very well coupled with the tides and gravity waves which originate in the lower atmosphere.

.So, so the top side atmosphere the tops side ionosphere is the F 2 region is very well coupled with these 4 things that are coming from the sun and the bottom side ionosphere is very well coupled or its , it has a strong bearing on the tidal and wave activities gravity wave activities that happen from the lower atmosphere.

So, in addition there is also coupling between the D layer and let us say the immediate layers above. So, there is a coupling between these two layers as well. So, that is what you see here. The E layer F1 layer the lower thermosphere layer couples very well with the D region of the ionosphere right. So, the point is the atmosphere is a couple system that we know already, the ionosphere and the neutral atmosphere are very well coupled. And ionosphere is also the region which very well couples with the solar forcing .

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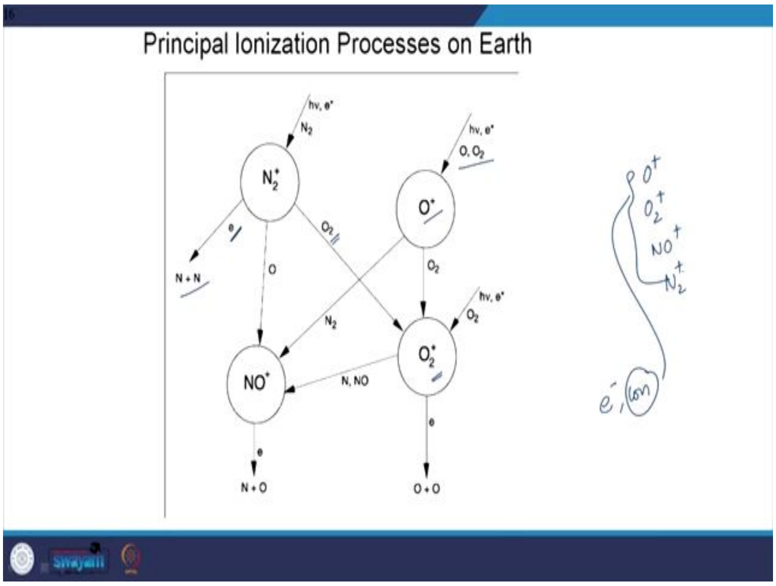

Now, if you look at the principle ionization processes, we have already seen that in the ionosphere the major chemical ion species are O plus O 2 plus N O plus. This is the major chemical species which are to be found in the ionosphere.

So, if you see the principal ionization processes, how does the ionization happen? Let us say if you start from the top. The electromagnetic radiation indicated with the h nu will interact with N 2 releasing an electron and N 2 plus and this N 2 plus may again dissociate to N plus N and may also combine with a O 2 giving you O 2 plus charge exchange reaction. And similarly, the electromagnetic radiation may ionize a neutral atomic oxygen or neutral molecular oxygen leaving behind ions of let us say O 2 plus or O plus.

So, these are the major chemical photo ionization processes which happen in the ionosphere. And because of which there is sufficient amount of electron and ion density. Now these ions can be any of this.

So, and depending on the height you will find any of these at different heights. Now so, for example, so, if you want to understand what are the major ionization processes? These are the ones which can form a cycle right.

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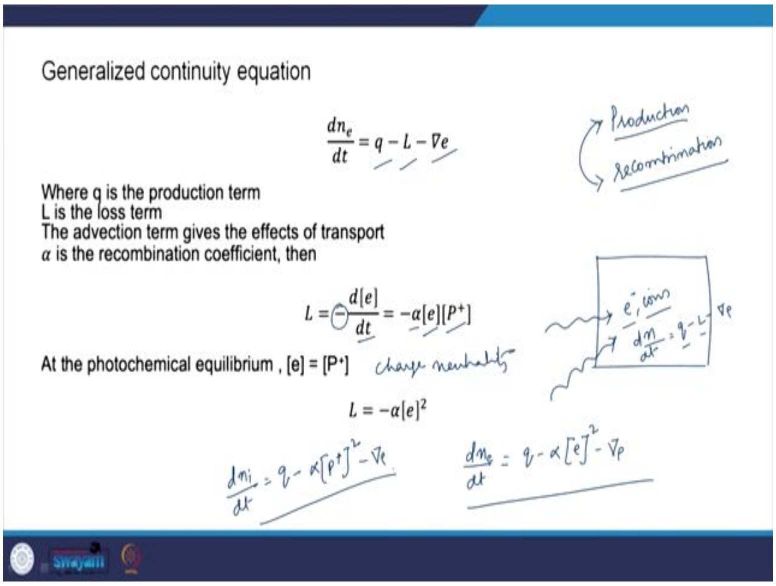

Now, so, in the ionosphere, what you see is production you see production; that means, electrons and ions are produced and the production is equally balanced to with the recombination.

So, a production is the process by which electrons and ions are released in the ionosphere and recombination because the electrons and ions will recombine giving you back the neutral species. So, these production process and the recombination process go hand in hand.

So, they will always try to minimize the effect of the other. So, if you want to write a simple continuity equation. The rate of change of electron density with respect to time, can be written as production , q is the production term L is the loss term and del e is the is the transport term.

So, at any given instant, let us say in a given space. So, if there is solar incoming radiation in this. So, there are electrons and ions produced. So, with time this electron density or ion density, let us say this is n indicated with n will change with respect to time. So, let us say for example, why does it change with respect to time. So, during the day time, let us say starting from the sunrise till the sunset. as the time changes, we will realize that more amount of solar ultraviolet radiations or x radiations is available.

So, more ionization will happen. So, the the number of electrons and ions in this volume will change with respect to time. And the total volume will change the production loss is by the recombination and there may be some transport of ion species, electron species from the outside. So, the total rate at which this charge densities change will depend on the production term, the loss term and the transport term . So, this is the basic form of the continuity equation. Now the loss , the q is the production the loss can be written as the rate at which the electron density decreases with respect to time.

So, there is a minus here. which can be written as minus times alpha is the recombination coefficient the alpha tells you how fast the electrons and ions which are created may recombine to give you back the neutral species. So, alpha will depend on the electron density and the ion density.

So, if you establish photochemical equilibrium for charge neutrality, let us say for charge neutrality, you say that the number of electrons is equal to the number of ions. So, if you substitute e for P plus or P plus for e you will realize L is equals to L minus alpha times e square. So, this is if you can substitute this into the equation.

So, the equation of continuity will look like dn by dt is equals to q minus alpha times e square minus del e. So, this is the basic form of the continuity equation. So, this is n e, you can write the similar continuity equation, you can write d ni by dt is equals to q minus alpha P plus square minus del e right. So, this is the continuity equation. What is the use of continuity equation? Continuity equation can be simply used to calculate how the electron density or how the charge density varies with respect to time.

So, if you look at the principle chemical processes in detail in the thermospheric and ionospheric system. So, basic processes are photo ionization; that means, incoming photon ionizes an atom or molecule or dissociate a molecule. The incoming photon,

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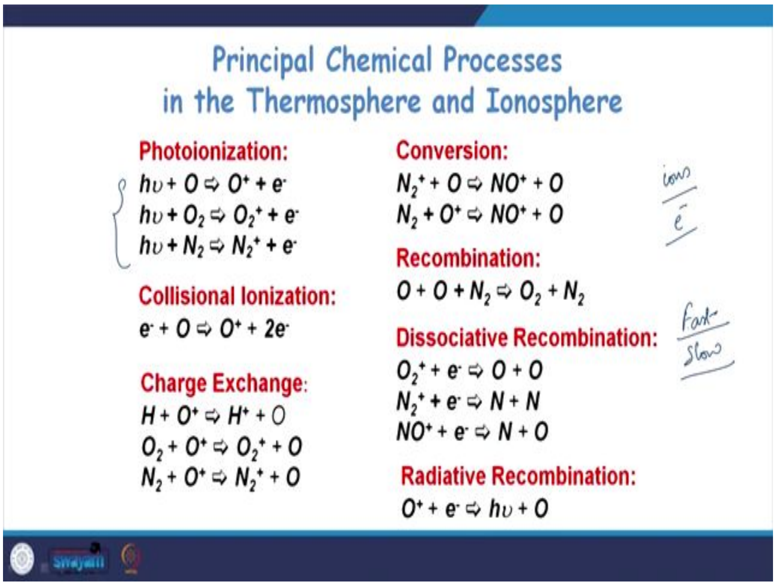

if it has sufficient amount of energy it may ionize an atom or molecule this process is called as photo ionization. Collisional ionization is the one in which an ion species collides with the neutral species and transfers the charge onto the neutral species .

So, collisional ionization is the process in which an electron; can come in contact with a neutral species and ionize because of the excess amount of energy that the electron has. Charge exchange is the process in which, when a neutral species and an ion species come together and the charge, because of the interaction between them its only the charge which will get exchanged from one constituent or one species to another species.

Conversion is the process in which an ion species may come in contact with the neutral species and as a result some dissociation may happen and overall there is equal availability of ions. And recombination is the process in which species will recombine and giving you back the neutral species. And dissociative recombination is the one in which, if a molecular ion, let us say it comes in contact with an electron. This molecule which has an ion will be dissociated because of the excess amount of energy that electron has. And radiative recombination is the one in which electron will simply recombine with an ion giving you the neutral species plus some amount of energy.

So, this is the basic names of the processes are: photo ionization, collisional ionization charge exchange conversion, recombination, dissociative recombination and radiative recombination. So, for example, here what do you so, we have already seen these are the major chemical ion species that you see in the ionosphere O plus O 2 plus and N 2 plus. How do they form? Here one very important thing is that the energy of these photons is not same. So, the energy that is required to ionize molecular oxygen and nitrogen will be different.

So, it may happen in the topmost part of the ionosphere are 250 kilo meters or 200 kilo meters, it may happen if the particles has enough amount of energy, they simply ionize giving you ions .

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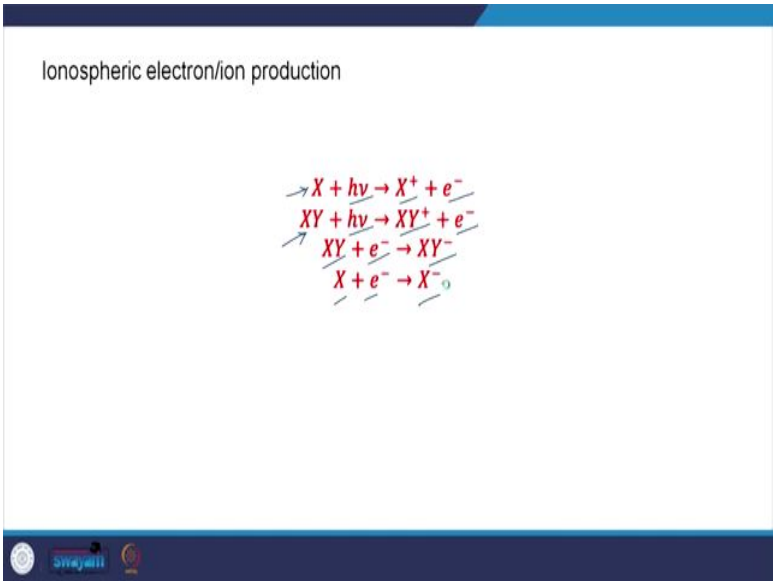

Now, generally combining all this processes the basic way in which ions can be produced or electrons can be produced is a neutral species and energetic photon giving you a positive ion and an electron. This is the most common process , a neutral molecule and a high energetic photon giving you a positive ion, the molecular ion and an electron.

At sometimes it may happen that you have a neutral species and an electron can get attached to this neutral molecule and giving you a negative molecular ion. This may happen with an atom as well giving you a negative ion.

So, here at this point before it is always the positive ion. So, the positive polarity is held only with the ions and the negative polarity is held with only with the electrons. Now in addition to these set of reactions, it may also happen that electrons can exist in the plasma or in the ionosphere.

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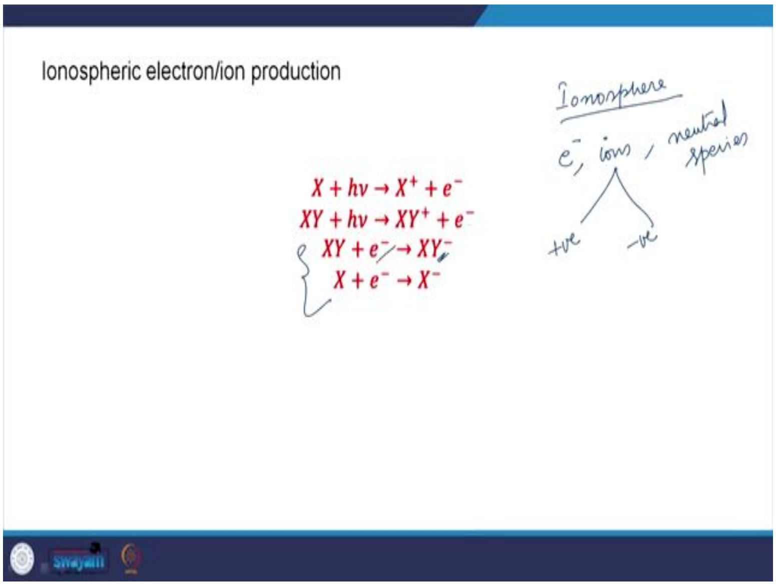

So, the major chemical species of ionosphere could be electrons ions. So, in these ions you can have positive ions you can also have negative ions and you have neutral species. Neutral species as in O, O 2, N 2 things like that. So, the point is in the ionosphere, there will be positive ions as well as negative ions.

So, this will talk in detail about this type of reactions which are called as the attachment reactions, where the electrons simply gets attached to a neutral species and forms an ion because of the ion is now a negative ion.

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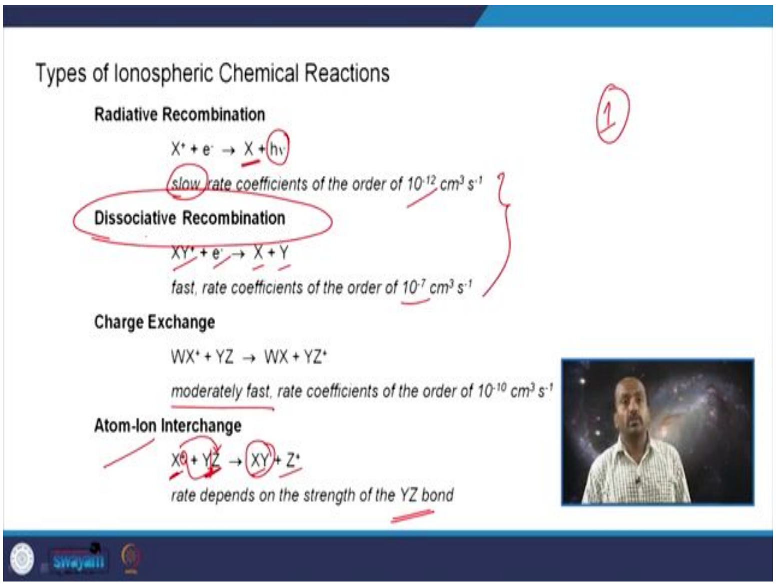

Now, the various different types of chemical reactions.

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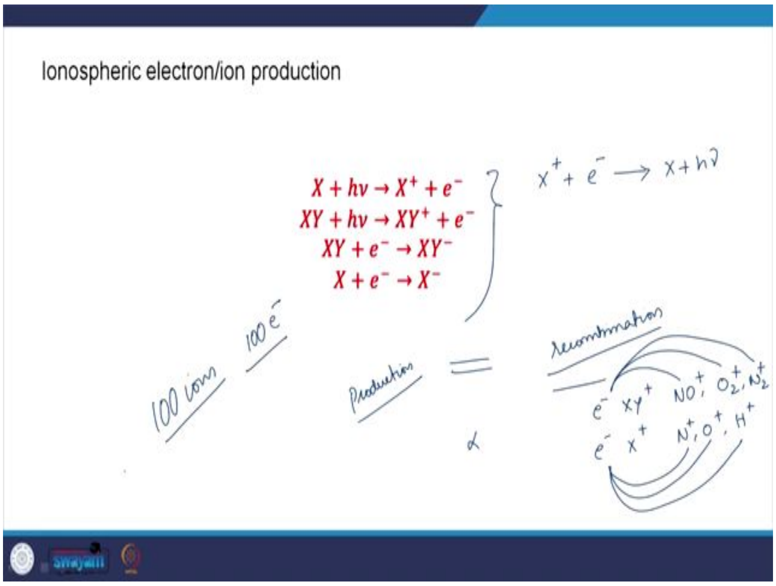

So, here one very specific thing we have to understand is that let us say. Now these are the processes in which electrons are released; that means, these are the processes which will form the ionosphere. Now generally what happens you have a reverse process like this?

So, you have X plus, plus electron giving you X plus h nu; that means, a radiative recombination right. So, you can also have all these processes in the reverse direction; that means, this is production and recombination like I say production creates the ionosphere recombination will lose the electron density that is available in the ionosphere.

So, ideally the production should be equal in number with the recombination; that means, all the electrons or ions that are produced should be lost, when you remove the source of light or source of energy for the ionization, but it does not happen like that. Why does it happen? I mean why does not happen is that.

So, different recombination reactions with different species; let us say if you have a recombination with electron and a molecular positive ion. If you have a recombination with electron and an ion, the rates and now this XY plus could be anything this XY plus could be NO plus this XY plus could be O 2 plus , this and this X plus could be n plus this XY plus could be could as will be N 2 plus this X plus could be N plus O plus H plus.

So, that means, that what I am trying to say is, the way in which electron can recombine with N O plus or O 2 plus or N 2 plus will be different. How will be different? I mean in which parameter is it going to be different? This parameter is generally called as the recombination coefficient. Recombination coefficient will tell you how fast electron can recombine within NO plus how fast electron can recombine with the O 2 plus.

So, similarly electron can also recombine. So, the point is it may depend on the way in which recombination may happen between selected species. So, let us say if you have 100 ions ,100 ions can be can be a combination of this different types of ions and on the other side you have 100 electrons. These 100 electrons are subjected to recombined with various species.

So, what may so, happen that some processes could be very fast and some processes may not be so fast. So, the processes which are not very fast will make sure the availability of electron and ion density during the night time. This is the main reason, why electron density does not cease to exist when you remove the source of energy the sun.

So, this is the main reason; that means, that out of the various physical the various chemical processes that we have seen, every chemical process has a rate I mean has a speed with which it will proceed. So, few processes of these are very fast and few processes are kind of slow.

So, it matters I mean which process is taking place at which particular altitude and how long is this process going to take and as a result if this is taking beyond the scope of the night, it will make sure that throughout the night there are enough number of electrons present in the ionosphere right. So, types of ionosphere chemical reactions.

So, the most important process is the radiative recombination process. Radiative recombination is a very simple process, where the ion will recombine with electron just the exact opposite of the production process. So, it will result in the ion getting neutralized with an electron as to form X and h nu.

So, this reaction is very slow, I mean this has resulted into the neutral species plus some amount of energy right. This reaction is very slow, I mean this reaction rate coefficient is of the order of 10 to the power of minus 12 centimeter cube per second . The next process is the dissociative recombination reaction. So, this is a very important process, when you have a molecular positive ion if it combines; if it recombines with an electron this will break this will neutralize this molecule and this will also break to conserve momentum and energy this will break the molecule into 2 atoms.

So, this could be anything, this could be any molecular ion could be an example for this. But this dissociative recombination is a very fast process. It happens very fast, but; that means, at this process not only recombines or not only makes the charge density disappear, but it will also make sure that there are neutral atoms available in the ionosphere. So, this is a very fast process the reaction rate coefficient is 10 to the power of minus 7 centimeter cube per second.

So, this is like very fast in comparison to this . If you compare these two the radiative recombination reaction will take a lot of time for removing certain amount of electron density from the ionosphere, but the dissociative recombination is the very fast process in comparison to the radiative process right.

Charge exchange is simply transfer of charge from one molecule to other molecule. So, this process is again I mean this process is moderately fast, but the most important thing is charge exchange will not be able to remove electron density. So, our first objective is to understand, why does ionosphere exist in the night time?.

So, because when we say that solar energy is the one which creates the ionosphere, its natural to ask a question if you go to the night side where there is no sun why should the ionosphere exist? So, now, the answer for that, there are several processes which happen kind of slow and fast. As a result of all these processes there will be ion density and electron density.

So, charge exchange is a process in which does not actually gets rid of the electron density is just a transfer charge from one ion to another ion. And atom ion interchanged, what happens if an ion comes in contact with a neutral molecule what happens is? So, the atom is also getting exchanged this is taking the place of let us say, this is this X plus is taking the place of Z and Z also at the same time transferring the positive charge to Z .

So, this results I mean charge is exchanged and atom has switched places into the molecule. So, the rate mainly depends on the strength of YZ bond. So, how close are they bond are so, that. So, this the energy that is carried by X plus should be able to break this molecule and then attach this neutral X with the Y so, as to form this molecule .

So, in a sense what you see here is that one very good message is that, it is the dissociative recombination reaction which is the fastest chemical process that happens in the ionosphere. So, dissociative recombination takes care of many things, I mean we will see how they will differ , but let us see how exactly do they matter.

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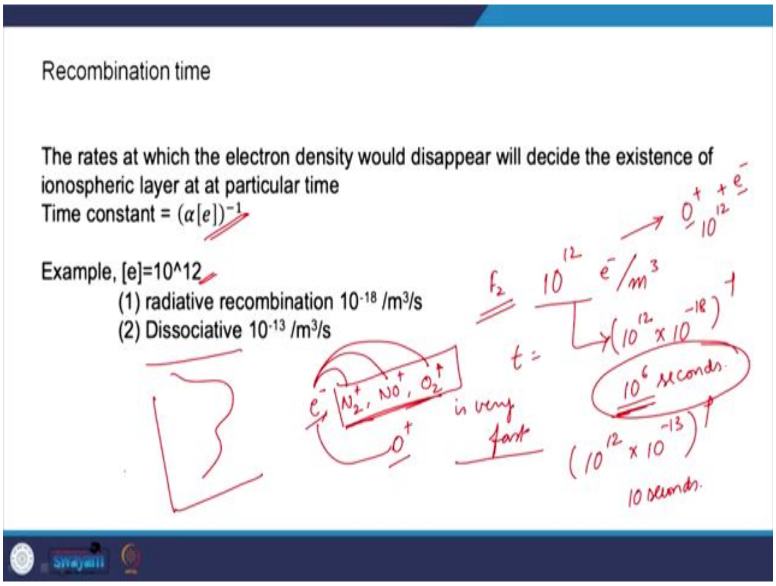

So, if you want to calculate the recombination time. Let us say you have electron density certain amount of electron density. If you want to calculate the recombination time, let us say for example, if you have certain amount of electron density available in the ionosphere and if you remove the sun I mean if you remove the source of ionization from the picture. The recombination time is the duration of time over which all the ions and electrons will recombine and result in the net neutral condition . So, the rate at which the electron density will disappear would decide the existence of fine ionospheric layer at the particular time. So, time constant is defined as a time constant. So this is in the dimensions of time.

So,alpha is a recombination rate of a particular reaction of a particular chemical reaction. Alpha and e is the electron density which is participating in that particular chemical reaction. So, take an inverse, you will get the value of time constant. So, for example, if you have electron density, let us say if all the F2 layer peak electron density which is 10 to the power of 12 electrons slash ions per unit volume.

So, this is the peak F2 layer density, if all this peak F 2 layer density is handed over to radiative recombination process which is 10 to the power of 12 into 10 to the power of minus

18 taken an inverse. So, this is the amount of time 10 to the power of 6. What is it; 10 to power 6 seconds. So, which is several hours nearly like hundreds of hours right.

So; that means, that if all the electron density that is existing at the F2 peak which is 10 to power of 12 electrons per unit volume are handed over to one single process, let us say you get hold of O plus which are again 10 to the power of 12 in number and then you allow this electrons and ions to recombine.

So, it is going to take 10 to the power of 6 seconds for all the electron density to vanish or recombine with the positive ion, but generally what happens? If at any given height you have electrons I mean you cannot choose this. So, you have ions and you have various different types of ions right.

So, some electrons may try to recombine with this, some electrons may try to recombine with this, some electrons may try to recombine with this, some electrons may try to recombine with this. What you will realize is that, all the recombination that happens with the molecular ions is very fast is that means, it will be able to take care of the electron density in a very brief time. So, let us say dissociative recombination is the reaction that I am talking about

So, if you put 10 to the power of 12 against 10 to the power of minus 13. So, this is 10 to the power of minus 13 raised minus 1. So, this is just simply like what 10 seconds. So, this is very fast.

So, if you hand over all the electrons to the molecules the entire electron density will vanish within a matter of few seconds, but if you do not have the availability of molecular ions, if you have only a single atomic ion then it is going to take forever.

That means, so, this time frame is beyond the scope of the night; that means, it will make sure enough amount of electron density is available at any point in the night time. But, so, at the point, at different altitudes in the ionosphere different type of chemical species.

For example, different type of chemical positive ions will exist and depending on the number in which electrons will interact with each of these ions due to the reaction rate coefficients being different few reactions will be done in a very short period of time and few reactions will not be done over a very long period of time eventually leaving behind the scope that electron density or the ionosphere to exist beyond the night. Now so, this is the discussion pertaining to various layers of the ionosphere and various chemical processes which will occur in the ionosphere.

So, for example, we have seen that let us say if you go back simply. every reaction has a characteristic lifetime and this characteristic lifetime is what decides, how far or how long are they going to be available in the ionosphere.

So, now, in the next class we will try to discuss the various layers of ionosphere in detail. What are the chemical processes that will be existing or there will be dominant in each of the layer by layer we will try to understand. And layer by layer we will try to write the equation of continuity in the suitable form . So, that is about the ionospheric introduction we will continue with this discussion tomorrow.