**Introduction to Atmospheric and Space Sciences**
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**Lecture - 47**
**Hydrogen in Ionosphere**

Hello dear students. So, today in our continuation with the atmospheric physics ionosphere discussions. We will try to see the formation of hydrogen ions in the top ionosphere. So, we have identified various layers ionosphere, we have also seen what are the prominent types of ion species, in each different layer of ionosphere. Generally in the topmost part of the atmosphere or topmost part of the ionosphere, the most prominent ions are the hydrogen ions. So, let us see how hydrogen ion concentration will change with respect to height in the ionosphere.

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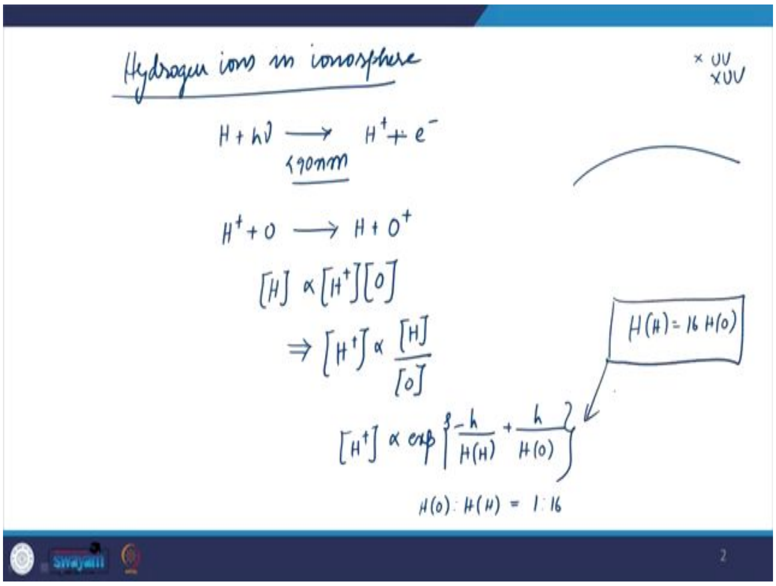


Hydrogen ions in ionosphere

$$[H^+] \propto \exp\left[\frac{15h}{16H(o)}\right]$$

So, we will try to see the height distribution of hydrogen ions in ionosphere. So, like for the rest of the ionosphere, we can say that ions are formed by the solar radiation that is incoming when it ionizes the species. So, its natural to expect that in the top part of the ionosphere the energy is the most abundant.

So; that means, all the X radiation ultraviolet XUV all the radiation is the most abundant. And at the same time one more important aspect that you should consider is that the neutral species are least abundant. And hydrogen being the lighter or the lightest you will try to occupy we will try to escape the gravitational pull. And we will try to occupy the upper altitudes of the earths atmosphere, where it gets ionized by the incoming solar radiation.

So, the primary ionization for hydrogen is let us say, when hydrogen with a photon with less than a wavelength of 90 nanometers, which is a threshold for the excitation potential or ionization potential gets ionized to H plus and electron. So, this less than 90 nanometers is most important. So, and the once the hydrogen ion thus formed can exchange its charge with an oxygen which is also present in the let us say in 150 or 200 kilometers altitude.

And can give up its charge to oxygen resulting in the formation of oxygen ions. So, if you write the production of let us say the hydrogen ion, we can write that the concentration of H will be proportional to H plus and O. Or we can write that the concentration of hydrogen ions, will be proportional to the concentration of hydrogen atoms divided by the concentration of oxygen atoms.

So, we have already seen that, in the topmost atmosphere each species will behave with its own scale height. That means, there is no scale height where you use the mean molecular weight. Rather you calculate the scale height of each particular species; because the mean free path being very very large. Each species will behave as if its it alone is occupying the entire atmosphere.

So, we can include the scale height dependences by saying the H plus is proportional to exponential minus h by scale height of hydrogen plus h by the scale height of oxygen. So, you have oxygen appearing in the denominator. So when you rise it to the numerator, it will be plus h by H naught. So, we know that the scale height of the oxygen in respect to the scale height of the hydrogen they will be in the ratio of 1 is to 16.

So, if you substitute we can say that the scale height of hydrogen is 16 times the scale height of oxygen.

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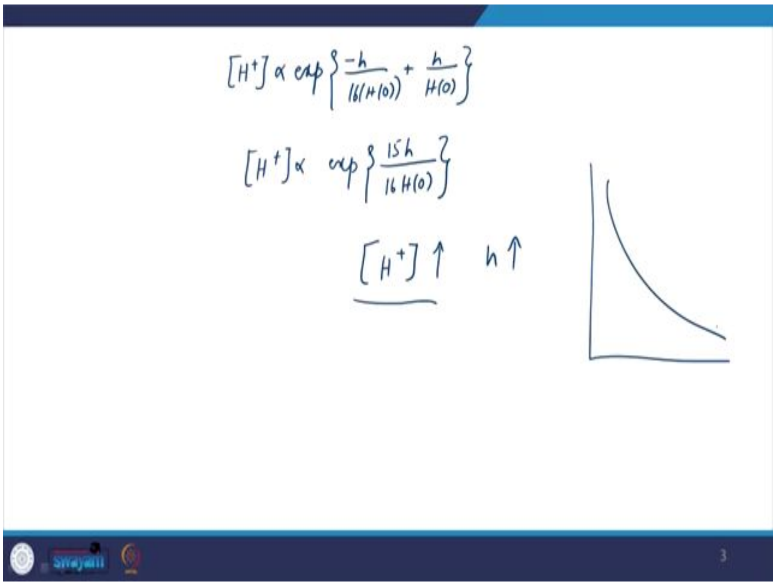


If you substitute this into this expression, what you will get is, realize that the concentration of H plus ions will be proportional to exponential minus h divided by 16 times the scale height of oxygen plus h by the scale height of oxygen.

So, simplifying this expression. We will get the concentration of hydrogen ions in the atmosphere will be exponentially let us say 15 h by which implies that the hydrogen ion concentration will increase with respect to the height. So, this is the most important thing about the hydrogen ion. Generally, in our atmospheric physics discussions so, far we have never seen a species which is increasing with respect to the height.

We always seen every species density will decrease exponentially with the height, but we have never seen a exponentially increasing function so far. So, because of its charge exchange or because of its low mass, hydrogen being available in the higher atmosphere on the upper atmosphere has a natural tendency to increase with respect to the height.

So, this is something very important about the hydrogen ions. Now, in continuation to this, we have several times made a remark saying that, although the atmosphere is made up of the ionosphere is made up of three layers D, E and F.

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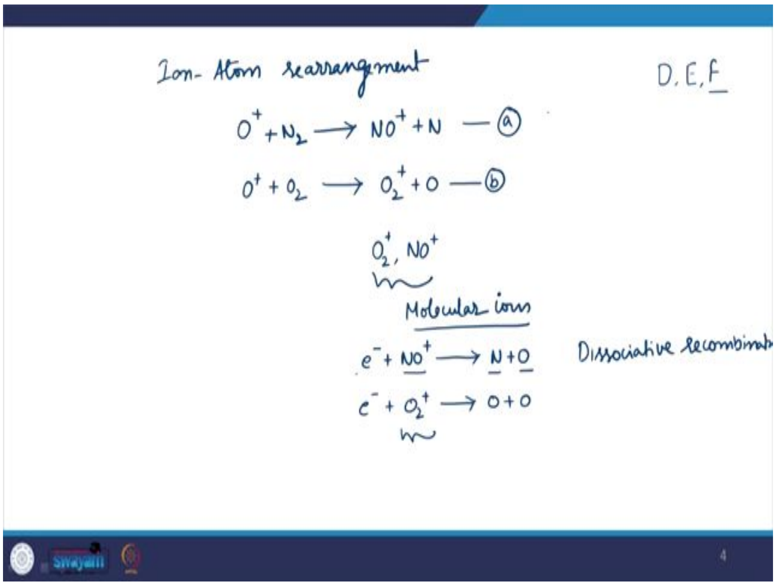


There are few layers which will disappear during the night time, due to the least amount of ionization that is available. And at the same time due to the fact that the direct sunlight is not available during the night time. So, in today's class we will try to see what are the factors, which will influence the formation of the F layer. And what are the factors which will influence which will decide whether the night time the F layer should be existing or not.

So, generally we have seen that, when a positive ion collides with the neutral molecule of nitrogen, the ion can exchange places with one of the atoms. And this kind of a process is called as the ion atom rearrangement. So, while we will discussing the availability of the electron density or ion densities during the night time. And we have also calculated the time scales over which the ion density will recombine with the electron density.

And we have seen some processes will be able to take care of the entire electron density within a few minutes. While some other processes will take several days for the electron density to be removed from the ionosphere. So, if you have both these processes working together at the same time, let us say in the ionosphere at a particular altitude it may so, happen that one process can , get rid of all the available electrons.

But the occurrence of this process is also decided by the availability of other species let us say oxygen ion. And some other processes which are very slow will eventually decide whether the ion density will remain in the throughout the night or will be removed by sometime after the sunset right. So, when a positive ion oxygen ion collides with a neutral molecular nitrogen, the ion can exchange places with one of the atoms in the molecule and this is called as the ion atom rearrangement reactiont.

So, let us say what happens in this process is that, an oxygen ion which is most likely to be found in the 150 or 180 kilometers altitude. When it comes together with a molecular nitrogen, you will get to see the formation of nitric oxide ion plus nitrogen. So, here the molecule is rearranged to take care of the additional positive charge that is available, let us call this reaction as a.

Similarly, when it collides with a neutral molecular oxygen. So, when the oxygen ion collides with a neutral molecular oxygen, let us say O plus plus O 2 just like that there will be again charge exchange plus O; let us say we call this process as b. So, once either of these reactions has taken place, there is a positive neutral molecular ion available in the ionosphere.

So, once any of these two reactions. Let us say whether depending on the availability of O 2 or N 2. The most important thing that happens in terms of recombination is that, atmosphere has now the available molecular ions. These two are let us say these two are the molecular ions. What is the advantage of having molecular ions? Is that, they participate in the dissociative recombination reactions; that means, let us say dissociative recombination reactions when they participate.

Let us say electron plus NO plus will now give you N plus O. So, now, the molecule is dissociated NO plus molecule is dissociated into N plus O. So, this process is called as the dissociative recombination. What is the importance of this process? Now electron if it gets in contact with O 2 plus it will give O plus O.

So, the most important aspect about the dissociative recombination is that the dissociative recombination is very fast. The dissociative recombination can take care of the electrons in a higher speed in comparison to any other process. That means, if there are more molecular ions available in the ionosphere, the electron density will be taken care or electron density will be removed from the ionosphere much quickly.

But if it is not the case if you run out of all the molecular ions ultimately the electrons have only the other type of atomic ions, which will take a lot of time for the recombination to continue. So that means that, it only depends on the extent to which molecular ions concentration is available in the ionosphere. That will decide the availability or the existence of a particular layer of ionosphere during the night time or not. If you see more further into these details.

So, let us try to graphically understand this particular problem. Let us suppose we call this process as a and b. So, keep a note of these two processes we will use these processes with their equation numbers. Let us suppose the equation a is the appropriate process by which electrons are removed.

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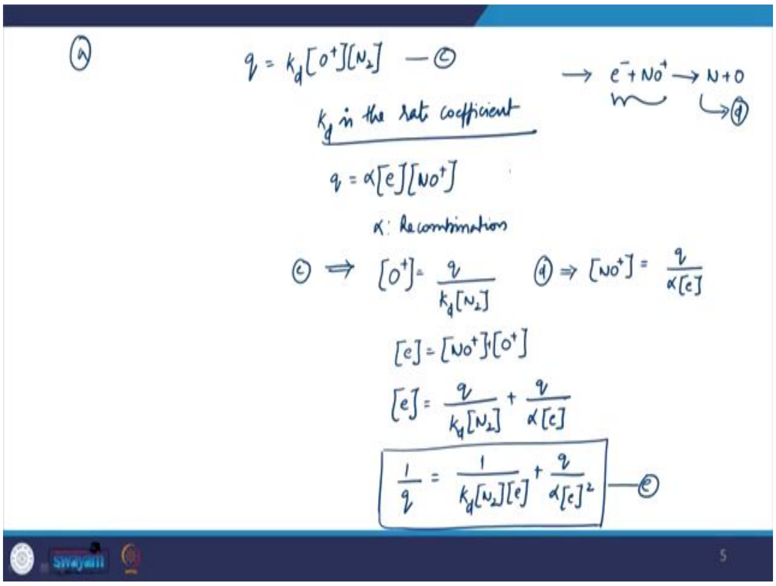


Let us say we have equation a by which electrons are removed from the ionosphere. So, it removes ions from a unit volume is the rate at which it removes the ions per unit volume is equal to the rate at which they are produced. So, let us say q is the production rate, now the rate at which the ions are removed by the channel of process a; will be equal to the rate at which the electrons or ions are produced. So, we always make the plasma approximation valid; that means, there are always equal number of electrons and ions in a cubical volume wherever you take.

So, if it is the case the q is k d times O plus N 2. So, where k d is the rate coefficient. So, electrons are produced also at the rate q; will disappear by the reaction. So, let us say now the electrons will we have already seen. If this process continuous electrons plus NO plus will give you N plus O right. Let us say let us call this as equation c and this as d.

So, now you write the rate at which electrons are lost is q is equals to alpha times e times NO plus. Now, what is alpha? k d is the rate coefficient by which process a will happen and alpha is the recombination coefficient. So, it tells you how much amount of recombination will happen,given the species that appear on the left hand side. So, well alpha so, from equation c we can write the density of O plus is q by k d times N 2.

And from d we can write the NO plus density as q by alpha times e. So, I have just taken two processes and these two processes will just make molecular ions available in the ionosphere. And molecular ions have more tendency to recombine with electrons at a much faster speed. So, now, if you impose charge neutrality at this point. So, what we have been able to do is, we have been able to in terms of reaction rate coefficients.

And the recombination rate coefficients we been able to write the density of O plus; the ion density that is trying to recombine or the ion density that is trying to create molecular ions by the ion atom rearrangement process. Then the density of NO plus is an indication of the number of electrons that can be taken care or that can be removed from the ionosphere, by the dissociative recombination reaction.

If you combine these two or if you impose charge neutrality or let us say quasi neutrality, we can say that the total electron density at any given moment will be equal to the concentration of NO plus, plus the concentration of O plus; that means, total negative charge is equal to the total positive charge. So, we can write that the electron density is now, q by k d N 2 plus q by alpha times e or 1 by q is 1 by k d N 2 times e plus q by alpha e square. So, let us call this equation as t. So, let us call this equation as e.

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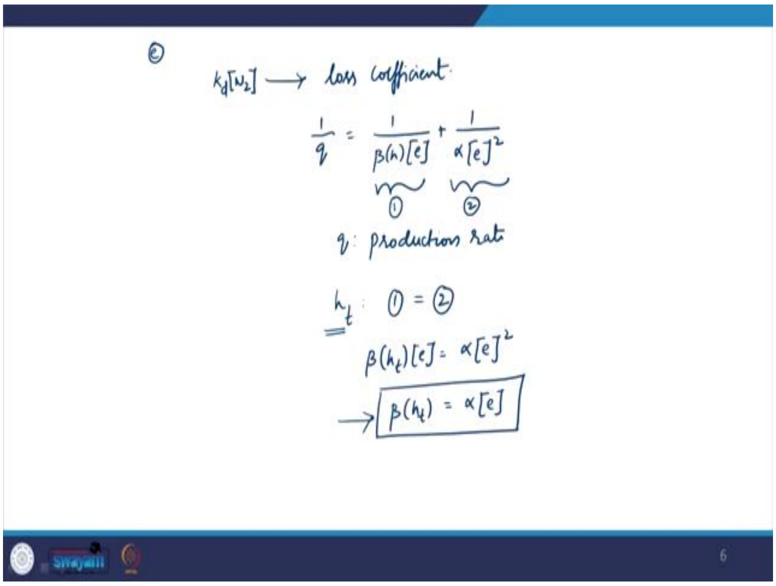


Now, so, in this expression in e in the expression e k d times N 2 represents the loss coefficient , which has the same height dependence as N 2. So, N 2 has an exponential dk as you go up.

So, k d N 2 also has a similar height dependence as N 2. So, we can now conveniently write this as in terms of the scale height dependence or the high dependence as 1 by q is 1 by beta h times e beta h is k d N 2 plus 1 by alpha e square. Now so, the resulting electron concentration at any given height will depend on the relative contributions of these two .

So, what are these two? Let us just look at these two. So, q by alpha this one is the recombination term and this one is the production term for the molecular ions. So, let us say q is the production rate, q is the rate at which electrons are produced, alpha is the rate at which electrons are recombining to give neutral species; e is the electron density.

So, it is natural to expect that the resulting electron density at any given height will depend on the balance between the terms. Let us call this term as 1 and let us call this term as 2. On the balance between 1 and 2 how they contribute towards the total production rate. So, let us we can say that at a particular height h t we can say that at this height term 1 will be equal to term 2

So, let us say beta now h being taken at the limit ht times electron density becomes equal to alpha times e square. So, beta of ht is alpha times e. So, this is the balance between the production of molecule ions and the recombination rates. So, at shorter distances what will generally happen at shorter distances above the peak q decreases upwards proportional to the concentration of oxygen being ionized.

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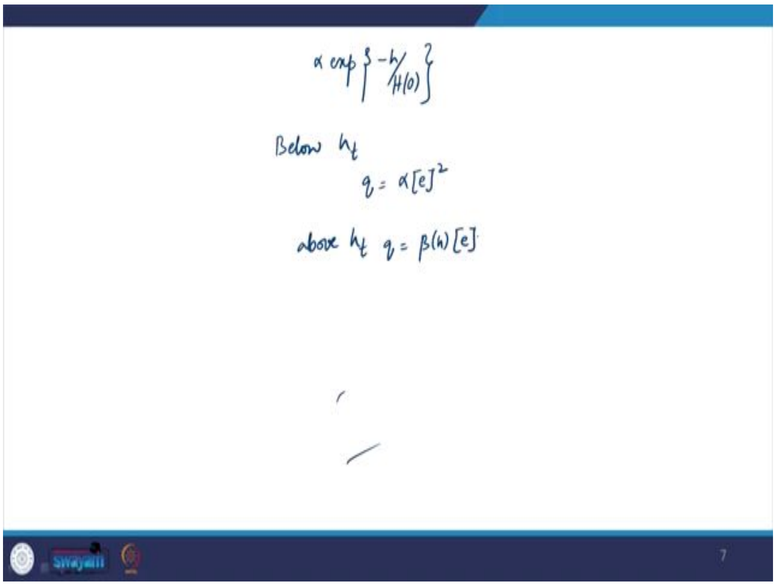


So; that means, q will be the at very shorter distances it will be proportional to exponential minus h divided by the scale height of oxygen. So, let us say below h t. So, we have seen that above ht at the height ht this is the equality both of them are equal below ht we can say that, only this term will be dominant term number 1 that means.

So, below ht we can write q is equal to alpha times e square and above h t we can write q is equals to beta h times e. So, the h t is the height where both these processes are equal. Now let us look at these parameters graphically let us say how do they look like. Let us try to look graphically how this expressions will look like. Let us say we plot the production rate first, let us say we have below h t.

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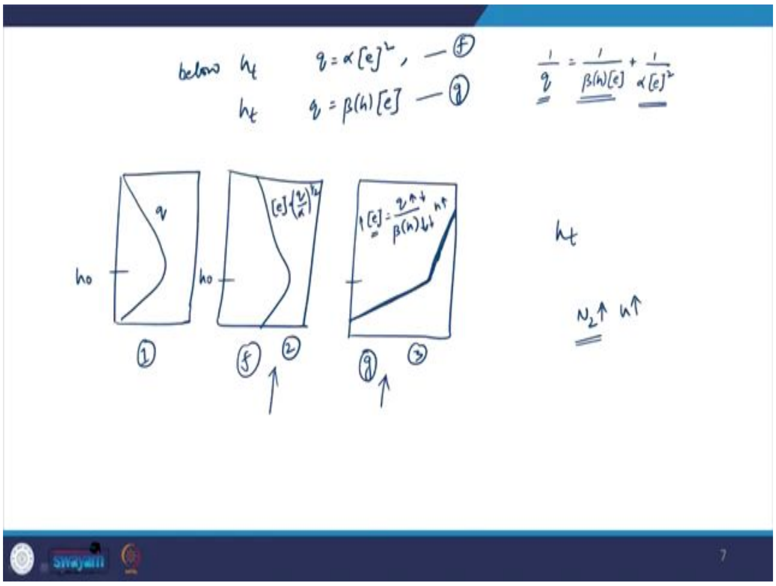


Production rate is also given by

$$\frac{1}{q} = \frac{1}{K_d[N_2][e]} + \frac{1}{\alpha[e]^2}$$

Where $K_d$ = reaction rate coefficient and α = recombination rate.

We have q is equals to alpha times e square and above ht we have q is equals to beta h times the electron density. Let us say if you see the q the production rate it will look something like this. So, let us say this is h naught, h naught is the peak of production.

So, this will look something like this. Let us call this as panel 1 then the other parameter that is important for us is the electron density. So, electron density will look something like where h naught is again identified as the. So, this is q the rate of production then this is electron density, which is equals to q by alpha raised to the power of half let us call this as 2.

Let us say then the other parameter that we should look at graphically is, the electron density above as per this expression let us say. So, let us we call this as f let us say we call this as g, f and g. So this is f and g will looks something like this where. Now electron density can be written as q by beta h let us call this as 3.

What I have done is I have drawn the production rate q as a function of height. The electron density as a function of height assuming that the electron density is following the equation that is given by f. And again the electron density following the equation that is given by g.

So, if f alone so, the original expression that we had these two terms 1 by q is 1 by beta h times the electron density plus 1 by alpha times e square. So, if the total production or the total electron density is alone by this process, then the electron density will look like this. If the total production is by this process then the electron density will look like this; but these two processes are equal at a height h t.

So, if f alone is applicable throughout then the electron distribution will look like the what is you see in two. And if g alone is responsible then you will see the curve given in three. So, below the peak production q increases upwards and beta h decreases upwards why does the beta h decreases upwards? Beta h decreases upwards because of the decrease in the nitrogen density N 2 density will decrease as a function of height.

So, what you see here is beta H is indicative of the decreasing N 2 density, but beta H is appearing in the denominator. So, electron density will increase as beta h is decreasing right. So, this decreases the electron density increase that is what you see here you see that the electron density is increasing at a particular speed. And at the same time q with height let us say with height is increasing beta h will decrease; q is also increasing. So, combining these two increases .

And decrease electron density will increase at a particular point. But after that point let us say so, what you see here is a increase. If the slope of this increase is slightly different that is because after this particular height h naught you see that q is decreasing with respect to height beta h is decreasing at all heights.

So, the second equation is this one is decreasing of course, and this one is again decreasing now. So, the resulting electron density change will look something like this. Now, let us say at very short distances above the peak q decreases upwards proportional to the concentration of oxygen being ionized. So, it will be proportional to exponential oxygen being ionized.

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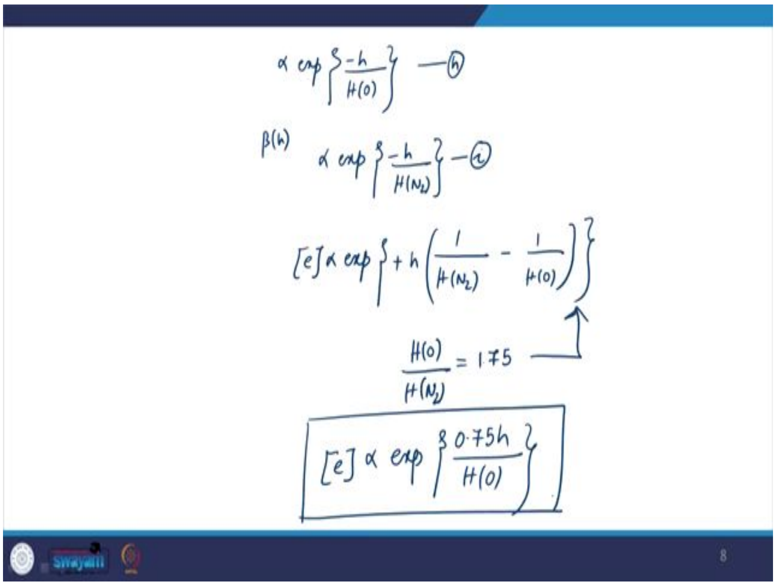


Electron density in ionosphere

$$[e] \propto \exp\left[\frac{0.75h}{H(o)}\right]$$

So, it will depend on the scale height of oxygen. Let us call this as equation h. And beta of h decreases proportional to the concentration of nitrogen exponential minus h by scale height of nitrogen let us call this equation as i. Now since beta h decrease is more rapid than q beta H appears to be the dominator I mean its it seems dominant the electron density curve.

So, we can combine these two dependences and we write electron density is proportional to the rate at which oxygen is being offered and the rate at which nitrogen density is decreasing with respect to the height. So, you can write that exponential plus h times 1 by scale height of nitrogen minus 1 by scale height of oxygen. We know that the scale height of oxygen by the scale height N of let us say nitrogen there to the ratio of 1.75.

So, we will use this into the expression above we can write electron density, it will be proportional to the exponential 0.75 h; divided by scale height oxygen

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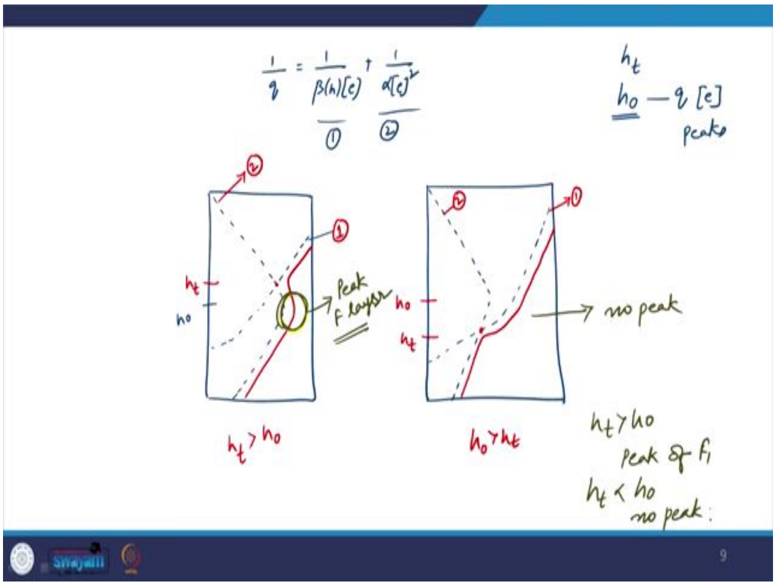


So, we have one height which is 1 by q is 1 by beta h electron density plus 1 by alpha e square. Now, if we combine these two plots. Let us say we have now two heights ht is the height where these two terms are equal. h naught is the height at which q or e peaks. Let us combine these two plots we have h t and h naught. Now we are going to look at the combined, let us say. So, going to look at this plus this.

Let us say we will call this as 1 and 2; 1 plus 2 and we will have to see what is the height ht in comparison with h naught and how does it decide whether F layer peak will emerge or not.

So, let us say we take h naught being the height. So, we have seen that this is one and the second one is. Now what you see? We can see that this is beta h, this one is 1 and this one is 2; what do you see? You see that at this point both of them are equal 1 is equal to 2.

So, we can call this as h t. So, now, we can say that h t is now lying above h naught. So, the combined one we can draw as this right. Now similarly let us see the possibility when h t will be greater than h naught. I will consider as similar situation, but just so, that these two are not equal at a particular point this is 1 and 2 .

So, here at this point these two are equal. So, this is now ht and here and this point this is the peak. So, this is h naught. So, here we say that h naught, is greater than ht. So, if you combine these two, the combined profile will look like this. So, again this is 1 and this is 2. So, in the ionosphere there is a transition from the height h naught to a height ht.

So that means, there  at a particular height the first term will be dominant after a particular height the second term will be dominant. So, we can say that here we will be able to clearly identify the ionospheric peak. So, let us say  this is the ionospheric peak. So, here you see a peak F layer. So, here no peak.

So, we say that the dependent the availability of the ionospheric peak you will just depend on the transition between h 0 and h t. So, we say that ht greater than h 0 gives you the peak of F1; h t less than h 0 no peak. So, this is about the composite F layer. So, when does the F layer form, when do you see the F1 layer when you do not see the F1 layer there is a basic idea here.

So, we can stop here. So, in today's class we have seen how the hydrogen ion density will increase with respect to the height after a particular altitude due to the availability of large amount of solar radiation. And then, we have seen what factors will decide whether the F1 layer, should appear or whether the F1 layer should not appear.