Introduction to Atmospheric Science
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Lecture - 34
Physics of scattering, emission and absorption contd

Okay good morning so I think in yesterday's class we were looking at the physics of the scattering, absorption, emission processes okay. Scattering is basically reflection from a volume so if radiation is reflected from a surface you call it as reflection and the non-dimensional value of that is reflectivity that is how much is reflected/how much is incident that is reflectivity.

But this scattering is basically from a volume and so therefore there is some directionality associated with it correct. So it need not be the same in all the directions then it is called anisotroping or anisotropic scattering. If the scattering is uniform in all the directions, it is isotropic scattering. Rayleigh scattering generally is isotropic scattering okay. Rayleigh scattering is applicable for small size particles, smoke and dust and other things in the atmosphere and the small particles.

Yesterday, we saw that the kappa lambda of red/kappa lambda of blue is all that. We figured out that the blue is scattered about 3.44 times more compared to that of red. This is evidenced by the predominantly blue color of the sky okay. Then, the logical question comes why is the sky is not violet? It is theoretically supposed to be violet but the human eye is not capable of detecting the violet that very well.

So we are able to see blue more clearly so as opposed to red we get this blue color. Sometimes we also get this red color because of all these you have seen that Chinook wind and this thing and sometime because of aerosols and all that reflectivity and all that radiative properties you get some red skies also. You have seen that red skies right okay. So yesterday we were looking at scattering.

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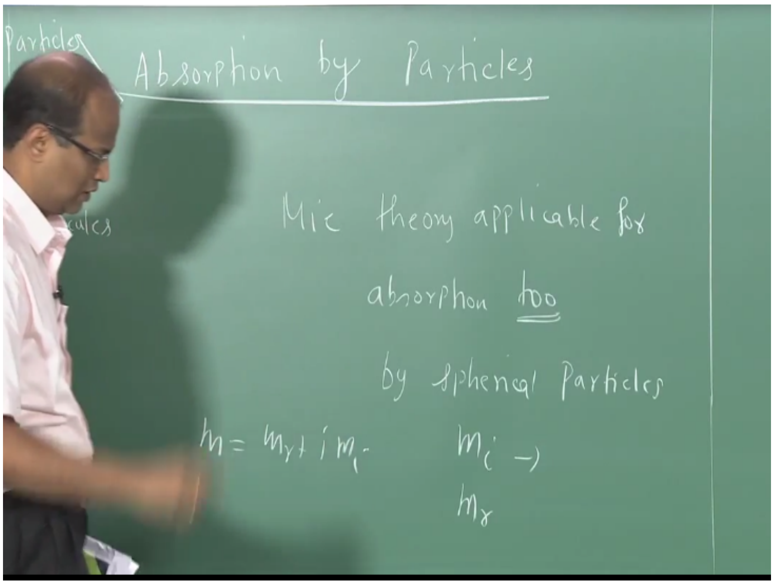

Now we have to look at absorption. So the absorption can be first okay. Please remember that particles are different from these gas molecules. This particle can be smoke, the particle can be rain, the particle can be ice, the particle can be snow and so on. Gas molecule is basically the air okay which consist of whatever nitrogen+oxygen and all that okay. So now let us look at absorption by particles.

The Mie theory is applicable for absorption too by spherical particles. So you will ask a question sir what about non-spherical particle? That question you should not ask in the first course. Non-spherical particle is a nightmare, so people have developed. There are some algorithms available on the internet developed by (()) (03:13) which is called the T-matrix algorithm which is basically for if you are doing that cutting edge research in radiative heat transfer in the atmosphere.

Then, you will ask those questions how do we handle a size distribution? How do we handle non-spherical particles? First, we will start with simple stuff; spherical particles Mie theory is applicable. So we did like this right, so m was equal to mr+i mi, it is not mi+i mr, this correct okay.

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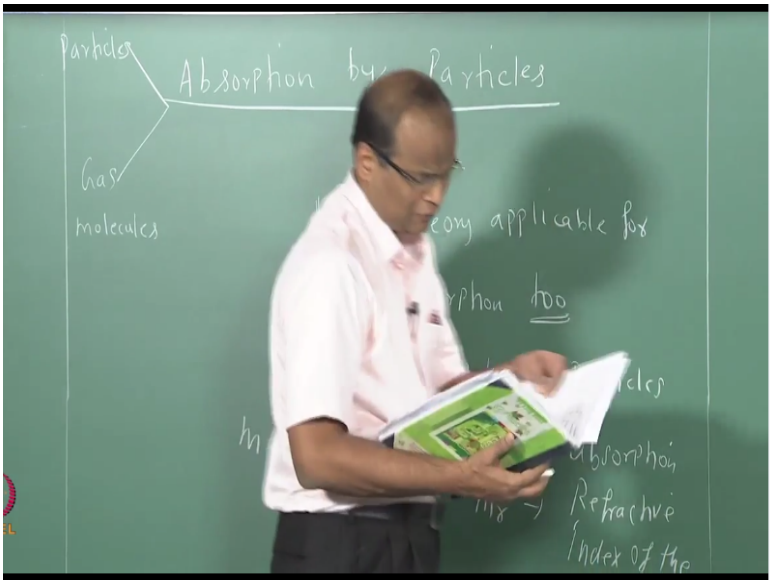

So i is absorption, mr is refractive index of the medium correct. Now what did I say yesterday? Correct yeah, yeah, refractive index that denotes scattering and we saw for a particular case of mi=0 and mr=1.5 I gave you a plot yesterday correct scattering efficiency.

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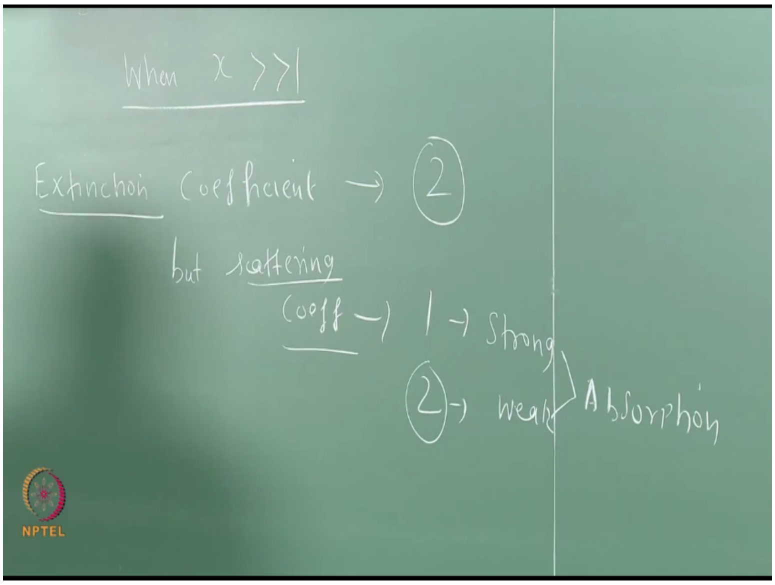

So let us see the limit of when x>>1, the extinction coefficient approaches the value of 2 okay but the scattering coefficient ranges from as below as 1 in the case of what are these two? Okay first those people who miss the continuity from yesterday's lecture. Extinction means when the radiation is passing through the gas volume what is coming out we are seeing.

What is coming out and is relation to what is coming in. If what is coming out is exactly equal to what is coming in there is no extinction, there is no scattering, there is no absorption that is happening here okay because water vapour is there but it is very less. So in this room so this air is radiatively transparent but you fill this with combustion products of IC engines of furnace gases, it is the game changes because CO_2 and H_2O okay.

So they are highly absorbing so what is coming out is different, is lower than what is coming in. So assuming that emission is not considered, let us not consider emission. So if that is the case, so this extinction consists of 2 processes, the scattering and the absorption. When $x>>1$, the extinction coefficient approaches 2 but scattering coefficient approaches 1 or 2, whenever the absorption is very strong the scattering coefficient approaches 1.

When the absorption is very weak, the scattering coefficient is 2. There is nothing wrong in what I am saying. So if you are awake you will understand what I am saying. When there is weak absorption, all of the extinction is contributed by scattering. So this is the same as this. So scattering becomes equal to extinction if it is weak absorption okay.

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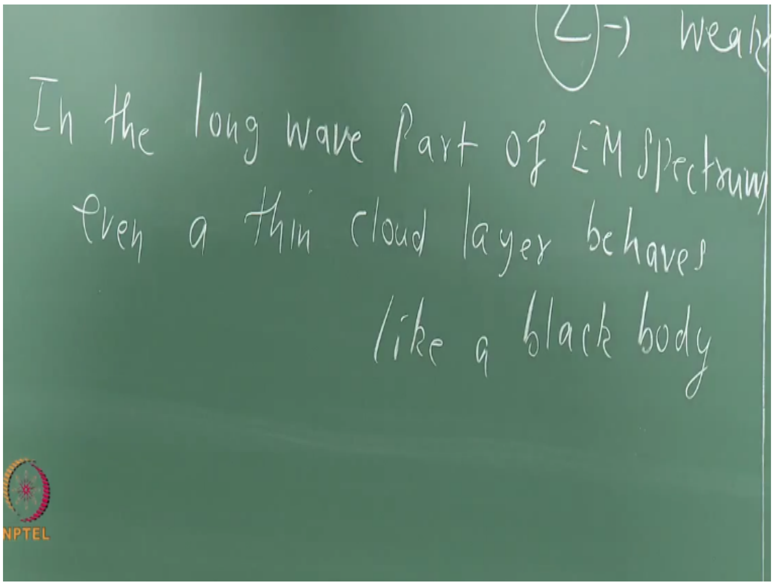

In the long wave part of the spectrum, the point is in the long wave part of the spectrum that means what is the long wave part of the spectrum is radiation coming back from the earth. What is coming into the earth is short wave okay mostly IR. In the long wave part of the spectrum even if thin cloud layer behaves like a black body. So what does it do because of that? Heat absorbed and then in the cloud is like this.

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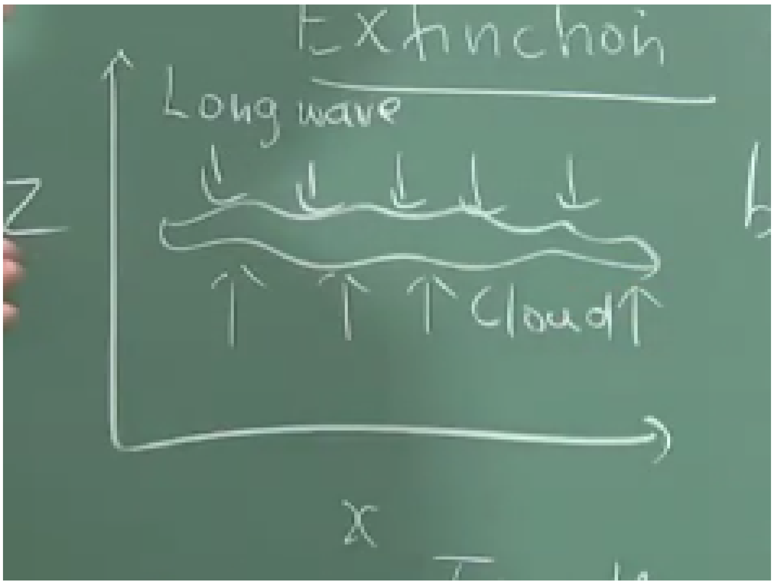

The long wave can come from the top also right but amount maybe less, is also possible for it to come from above these clouds. Clouds can be up 10 so even if a thin layer of cloud can heavily absorb radiation coming both from above and below in the long wave part of the spectrum.

So it will almost behave like a black body. Clouds will become a game changer okay. On an average 40% of the atmosphere is covered with clouds generally around 40% of the atmosphere is covered with clouds all the time. This is the average, you do not tell now it is clear sky and all that. If it is clear sky here somewhere it is cloudy so I am talking about the average okay.

Now this is as far as absorption by particles is concerned because cloud is basically consisting of water molecules, ice, everything will be there. So if it is sufficiently high, the cloud will be full of ice when you go in aeroplane you can see. After it lands you can see that condensation and you can see some particles. In fact, these ice particles can create lot of trouble.

It went into the Pitot tube and changed all that AF 447 and it went into a storm that story I have already told you right. The Air France flight okay, I will tell later okay. So now we have to see absorption and emission by gas molecules.

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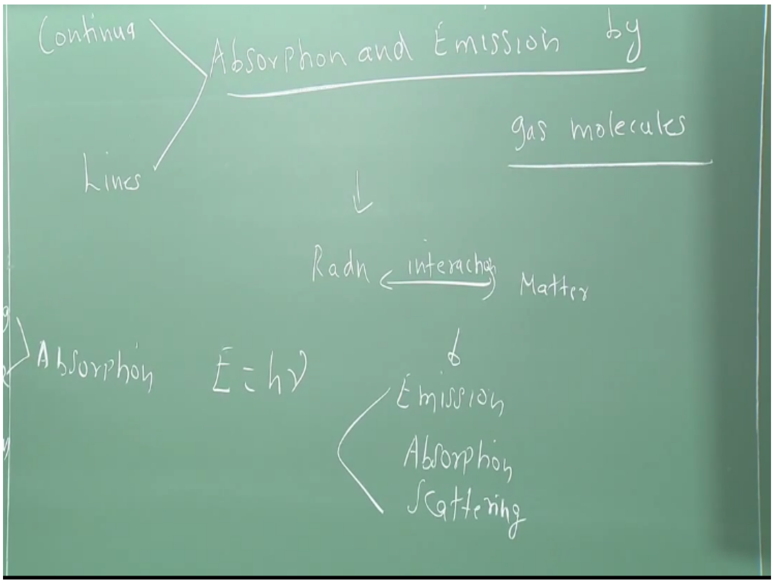

So this is you have to consider what is the absorption and emission from clear sky basically of the constituents of the atmosphere. So when radiation interacts with matter according to the photon theory what happens is some emission, absorption, radiation is absorbed, scattered or emitted and each photon contains energy.

When radiation interacts with matter not only with particle with any matter that you have already studied in physics and this takes place in according to this famous E=h nu okay. So now we have to talk about 2 things called absorption continua and absorption lines okay. Absorption line means that fixed bands it absorbs, it does not absorb, it absorbs, it does not absorb.

I have already shown you at 11 kilometers above the earth and then 0 kilometers above the earth what is the fate of the radiation which is going through the earth's atmosphere we saw that right and I told you that the incoming part of the spectrum there is very little absorption and then towards the later part you have got absorption by H2O, CO2 and all that and I have explained to this is the principle region for the greenhouse effect okay.

So now you have to distinguish between absorption continua and absorption lines.

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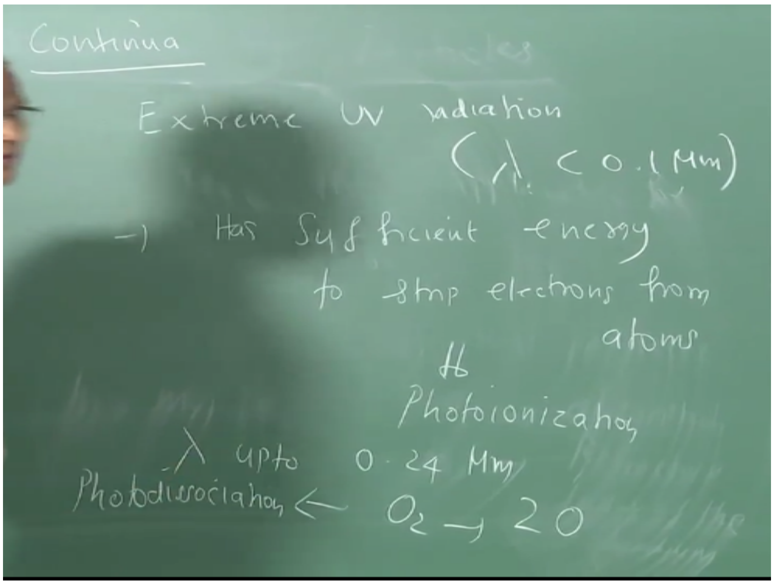

So let us see extreme UV radiation, compared to infrared UV will have high energy or low energy? High energy okay so high energy radiation interacts with matter; it is capable of causing some reactions is called photo ionization and photo disassociation. This is how ozone is formed. So the next 5 minutes basically what we are going to see is how ozone is formed and all that and so those things we will take a look.

So has sufficient energy to strip electrons form atoms so this is called photo ionization okay. So lambda up to 0.24 micrometer O2!=20 okay, O2 can be broken up, what does it mean? O2 molecule is broken down into O2 atom. So this is called photo disassociation it is taking place by light okay. This will not keep quite. If you have this free oxygen atoms, 3 of them can combine together and form ozone okay so that is the reverse reaction.

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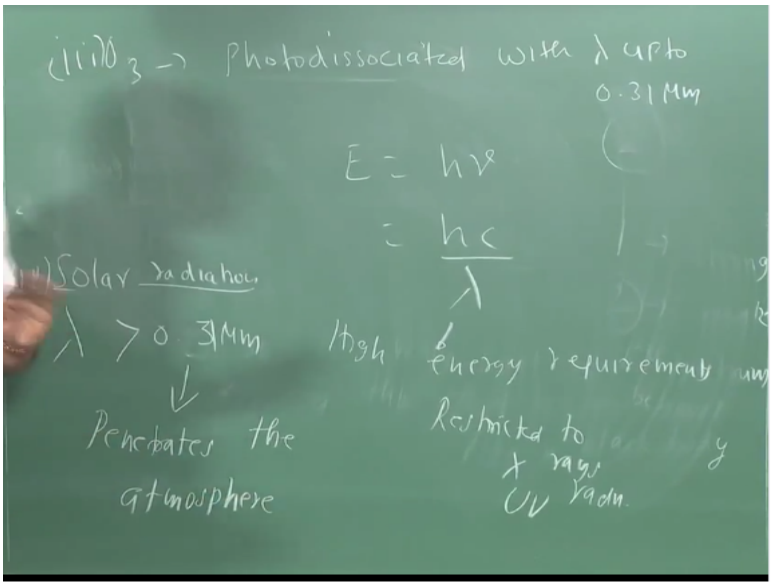

What are the forward and reverse reactions that are taking place? Okay. What is the use of studying all these? How does it affect us? If you look at a black body distribution from the sun okay the sun's photosphere is the temperature of 5800 kelvin. I can prove that between 0.4 and 0.7 micrometer, which is in the visible part of the spectrum 37% of the radiation is concentrated.

We can do the math, you can do IV lambda plotted and total area under the curve. There is only 2% of the sun's radiation which is in the ultraviolet portion of the spectrum okay. The total is 2% but ultraviolet radiation is extremely lethal to human beings okay. So this photo dissociation of ozone 3O becomes O3 and O3 is again becoming and OO becoming O3.

This photo dissociation which takes place up to 0.31 is responsible for holding up for ensuring that the 2% of the ultraviolet radiation stays there, it is busy with the photo ionization and dissociation reaction so that the ultraviolet radiation does not reach the earth surface. The moment you are burning the CFC and so on, if you are using that refrigerant chlorofluorocarbons what they do is they deplete the ozone in the atmosphere.

If you deplete the ozone in the atmosphere, this radiation up to 0.31 micrometers, there is not enough ozone in that atmosphere to engage this radiation, so all of its energy is not used up in this O3 and because O3 is depleted therefore because of this ozone hole, the ultraviolet radiation appears. This ultraviolet radiation is extremely harmful to human being. Therefore, they set up this Montreal protocol I think in 1994.

Was it somewhere but it is before 2014, so they set it up. They decided that CFC will be banned and now satellite imagery clearly shows. I showed you some ozone hole depletion in the first few classes if you remember maybe you slept or maybe you were awake I do not know. You just recall and rewind so I showed you ozone hole and all that. Now satellite imagery shows that legislation has really paid off.

Now we are having healthy ozone in the atmosphere and we are saved from this lethal ultraviolet radiation, which will enter the earth surface okay, okay. All of these require lot of energy and therefore all these reactions require lot of energy and E=h nu=hc/lambda, all these are restricted only to high energy reactions. Fortunately, the visible part of the spectrum does not have enough energy to cause this photo dissociation or ionization.

Is that okay? And what about lambda>0.3 micrometer, if that is the sequence I think you yeah you make it like this chapters <0.1, 0.24, up to 0.31, >0.31, solar radiation>0.31. What is happening? Very good, yes it will come. It penetrates to the earth surface. What you say it? Penetrates to the earth surface? Is it okay? That English is okay, okay. It penetrates the atmosphere okay.

So it is absorption continua. There is nothing like in 0.26 there is an absorption, 0.27 there is no absorption, so we do not talk of a continua up to 0.31 but after that the story starts. Different molecules behave differently because of their chemistry and their electronic structure and all that okay. That you will have to study deeply using a spectroscopy and all but their behaviour is like that.

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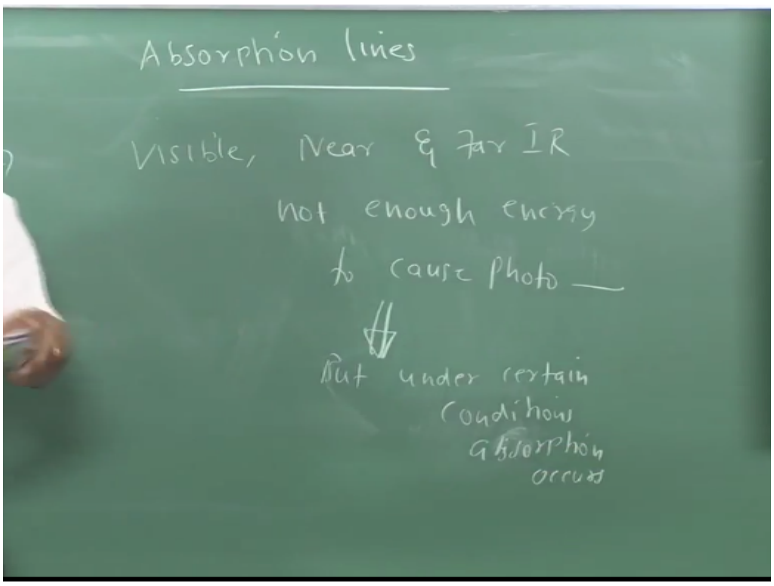

Let us look at this absorption lines. So visible, near, and far IR okay. These are the types of radiation which we are considering, not enough energy to cause this photo dash that is photo ionization or photo dissociation. Then should you be happy and not consider them? No, unfortunately under certain conditions and for specified wavelength interval they absorb okay. Not they absorb, they will be absorbed okay. Absorption occurs so we need to look at this okay.

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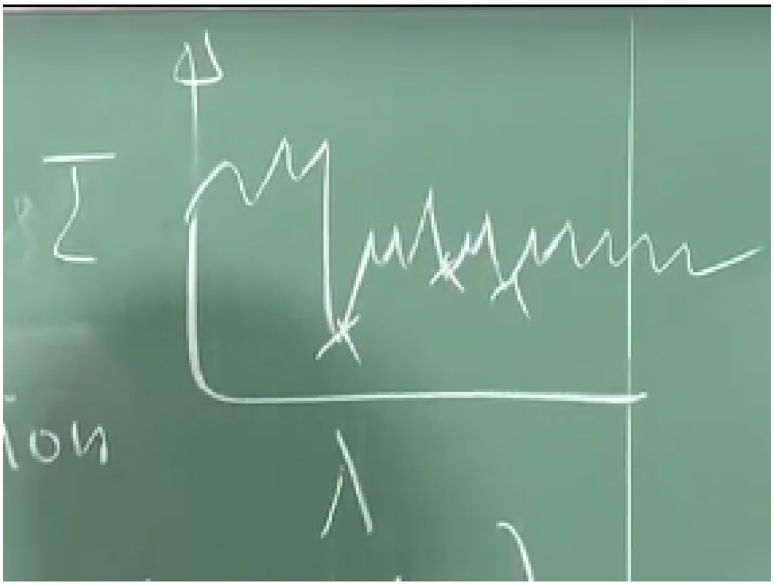

So we talk about a line spectrum we say like this right, intensity versus lambda, so where it is absorbing? Whenever the intensity dips correct, whenever the intensity dips it is absorbing. So these are called the absorption lines but the funda is so these involve orbital rotation, vibration, translation energy of the molecules, all these physics you studied all these but now these absorption lines are not direct delta function.

Are you getting the point? It is not that 2.11 micrometers it absorbs and 2.12 it is 0 and 2.10 it is 0. So there is a broadening of this absorption lines. Does it make sense?

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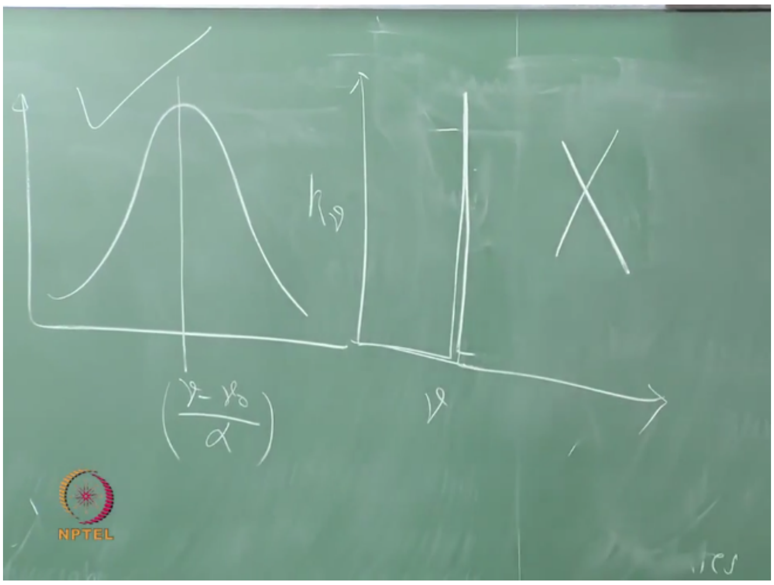

What I am saying is if you look at the absorption, so if you take the kappa lambda or kappa nu okay. Actually, we can call it as nu0; nu0 is the central wave number at which it absorbs maximum. So dimensionless abscissa nu-nu0/alpha where alpha is the half width of the absorption line, therefore it has absorption like this. Is it okay? So that is the story, got it. It is not happening like that.

Now there are 2 types of broadening that we have to see. So there is a broadening then you say sir you drew like this what is the resolution? I am considering all lambdas here. If you make it fine resolution, then the story will be clear. If you break it out into 0.01 per micrometer or 0.000001 micrometer if you have that resolution, then all these things will become clear.

So we have to look at broadening of absorption lines. Though it is little theoretical it leads us to the development of what is called the HITRAN database. So I expect some of you may do, your masters or Ph. D in atmospheric science so this will be a good background. So okay broadening or in climate science or something.

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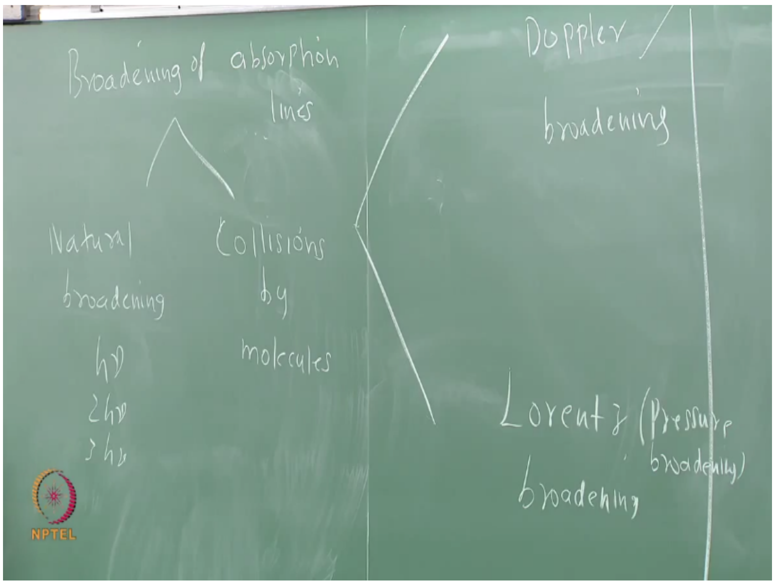

Why is this broadening taking place? One is basically because of why natural broadening is taking place? You are having only h nu, 2 h nu and so on okay but we cannot dictate, h nu is very small. So this is inconsequential. The other thing is collisions. So the collisions by molecules and the motions of the gas molecules cause this broadening.

This broadening is basically 2 types, Doppler and Lorentz broadening. You know what is Doppler shift right. The shifting of frequencies at which molecules experience by virtue of the random motions, to or away from a particular source. You know the frequency increases when motor bike, the teachers must have taught you right and the motor bike comes towards you, you feel that sound this is increasing and then going away, like that away or from a source what is happening to this shifting of frequency that is the Doppler broadening okay.

So the Lorentz broadening is basically also the pressure broadening. So anyway for the sake of completeness I will give you the equations but I am not going to ask questions on this in exam, this is little advanced but anyway since we are discussing it I thought I might actually give you the formula.

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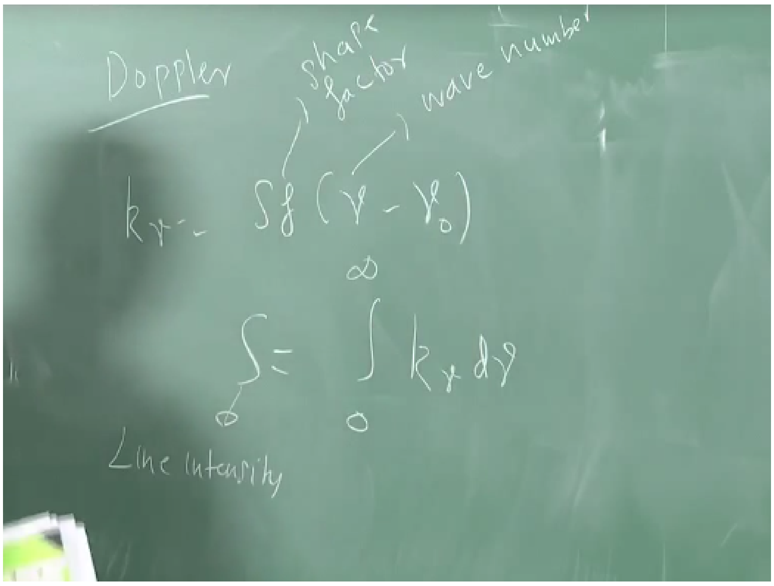

So Doppler is basically okay so S is basically the line intensity, I think nu is the wave number, nu0 is the wave number at the center of the band okay, d nu you have okay and f is the shape factor okay.

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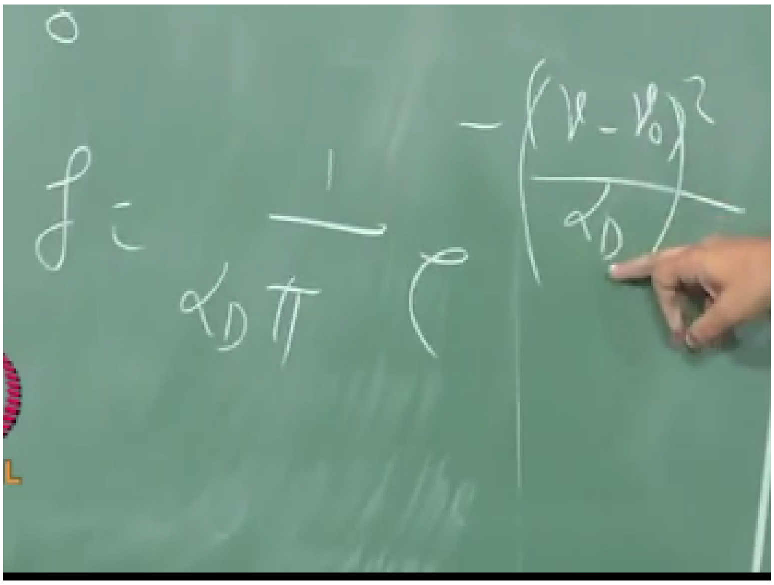

So now f is given by so this f the shape factor is given by the Gaussian e to the power of –nu-nu0 whole square/alpha d square. Is it okay? So it is like your normal distribution right e to the power of x-mu/2 sigma whole square probability right Gaussian distribution or normal distribution but now it gets murkier and murkier because now I have to define alpha D right correct.

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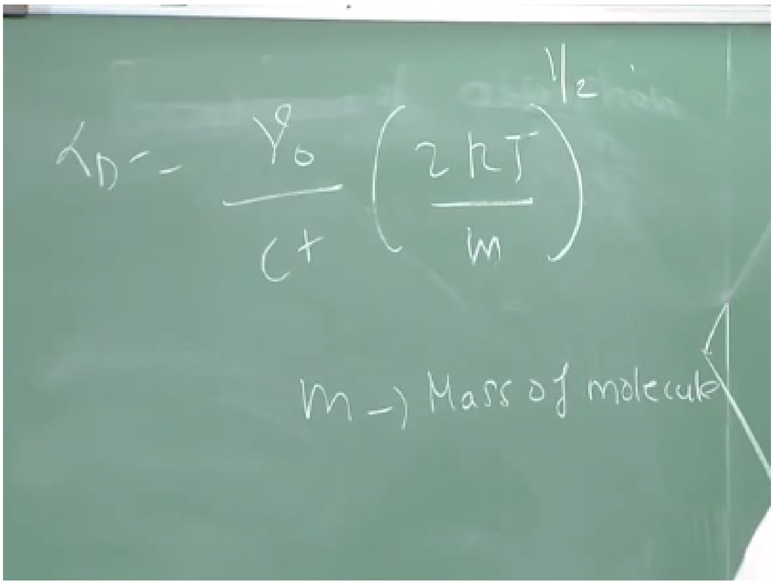

Yeah you know all this, nu0 is the central wave number, c+ is the velocity of light in vacuum, k is the Boltzmann constant 1.3 (()) (30:42) to the power of -23 joules per kelvin, T is the absolute temperature, m is the mass of the molecule. So if you know the temperature of the molecule and mass of the molecule and the central band you should be in a position to get the alpha D, once you get the alpha D this nu-nu0/alpha D this thing you can get the f.

So you will find out the f for each value of nu and then you will integrate this and get the whole thing. Only after getting this you will be in a position to get this kappa nu or kappa lambda, which was where in our Di lambda/Dh=-kappa lambda* look at yesterday's notes, Di lambda/Dh=-kappa lambda and something. I am now telling you a procedure to get the kappa lambda.

And it is not so straight forward because there is integration involved and you need to know this value of f. You need to know this value of f and this thing and from this you have to get this S and this varies so for a particular band of 2 micrometers then you have to say 1.88, 1.89, 1.9 or 1.97, 1.971, 1.972 so you need to have data for all of this okay. So there are some data bases available I will tell you all this.

But after so we have to complete this in another 7 or 8 minutes. We have to do the TCF today. I will stop at 10:40 okay.

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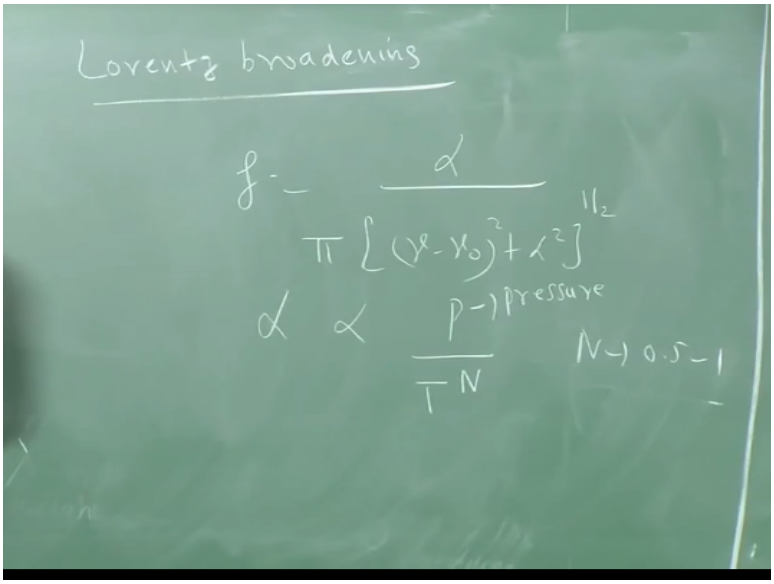

So the Lorentz broadening alpha is proportional to P/T to the power N, the N varies from so P is the pressure okay. So you have to take care of this Lorentz broadening as well as Doppler broadening in your calculation of this kappa nu.

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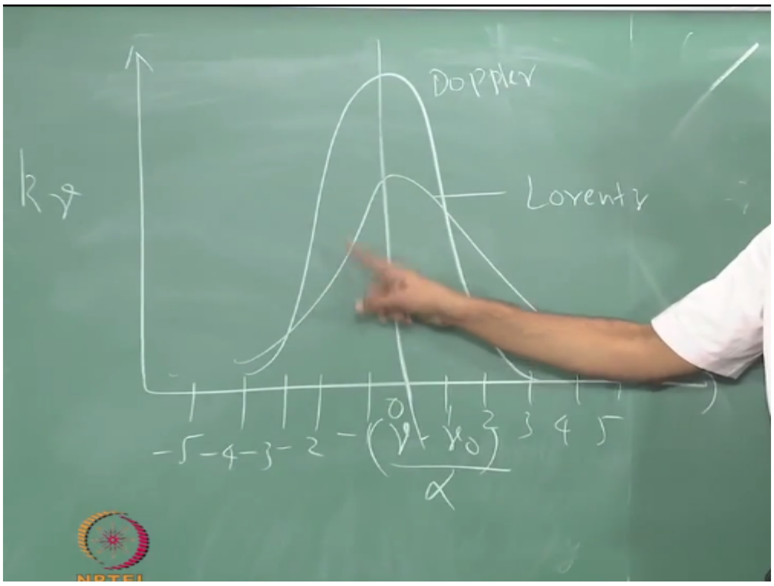

So basically it is like this. This is the Doppler; this is the Lorentz. So this will have units of 0, this will have not units right divisions.

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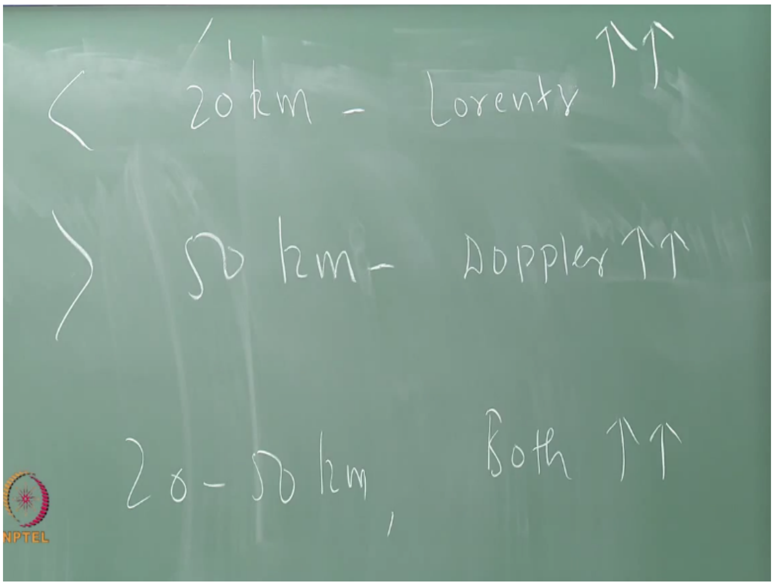

Forget about the mathematical formula, we want to solve the problem for absorption, if you want to find out the radiation through the one-dimensional participating media of the atmosphere, you need to look at absorption lines, forget about the absorption continua. Absorption continua are only up to 0.31 micrometer and only 2% of the radiation is in the 0.31, so the major concern is from 0.31 upwards.

When you say 0.31 upwards if you have water vapour, carbon dioxide, methane and all these things in the atmosphere, it is not a simple one value of kappa for you, kappa=some 0.1 for all lambdas unfortunately it is not so, it is a treacherous function of lambda and if you do deep how to get the kappa lambda itself what you can see that there are bands where there is heavy absorption followed by some portion of the spectrum where there is no absorption is because of the nature of these molecules, which are participating in this.

So if you want to get that absorptivity for each of this around is nu0, there seems to be a Gaussian distributions and all these functions have to be used, you have to numerically integrate and get the values of the kappa and then proceed with your and then you will have to integrate the equations all the equations and so on, so just to get the properties.

Now if your consideration is only <20 kilometers, the pressure broadening is very, very important because pressure broadening is taking place at the lower levels of the atmosphere because the density of the gas is very less therefore molecular collisions are very important, >50 kilometers basically there are no molecular collisions are less significant therefore the Doppler broadening will be more important.

But unfortunately if you want to study or include the stratosphere also, if you want to study between 20 and 50 kilometers then what you have to do is you have to take the planks, you have to take the kappa, there will be a Lorentz broadening, there will be a Doppler broadening then you have to do double integral convolution and all that and then take care of both the effects okay.

Therefore, calculation of kappa nu is not an easy joke. In radiative heat transfer of the atmosphere in RT of the atmosphere lot of effort takes place in getting this kappa nu and this kappa nu cannot be simply measured in the field, for certain values of nu laboratory measurements or side measurements using aircrafts and balloons are possible. Otherwise what people do is they have lot of models and with this limited laboratory scale you can have a cloud chamber in the lab.

My friend Prof. Tripathi, IIT Kanpur, civil engineering, he does these measurements. So you have a cloud chamber and then you do, seed it with some particles and this thing and then measure all these radiative properties. So you have limited laboratory or site experiments, you have a model, you match the model with the experiments and then from then on whatever the model predicts at kappa at those values of nu for which measurements are not available, the model is considered as the truth.

This is how the radiative heat transfer research has proceeded. Everything is not just based on a data book or some field data okay.

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So what about this information okay. The information on absorption is available on HITRAN, which is available on the internet, which is free for you. What is HITRAN? High resolution molecular transmission okay high resolution transmission T is coming first know. High resolution transmission absorption database. It is free for you on the internet. If you have time you just go to HITRAN so it is high resolution.

It is agreed upon by everybody. Researchers use this to get properties and this gives details about half width, central wave number, the Gaussian distribution, all these things it gives for various values of lambda. If you do not like this, you do not want to be so regress there is MODTRAN medium resolution transmission absorption. If you do not like this also there is a LOWTRAN low resolution.

All the Trans are available on the internet. Depending on the level of accuracy and the power of your computer and what is the level of detail to which you want to solve the problem depending on what type of sensors you have, you are doing remote sensing work and you can use this obviously. You can use these databases and get these properties. The story is not over, tomorrow you have to write the equation of transfer and then solve it.

When you solve you require properties, this database will give only the properties not the solution to the problem.