Elements of Solar Energy Conversion
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Lecture – 05

Hello and welcome back to this course of Elements of Solar Energy Conversion. And we are at the 5th lecture.

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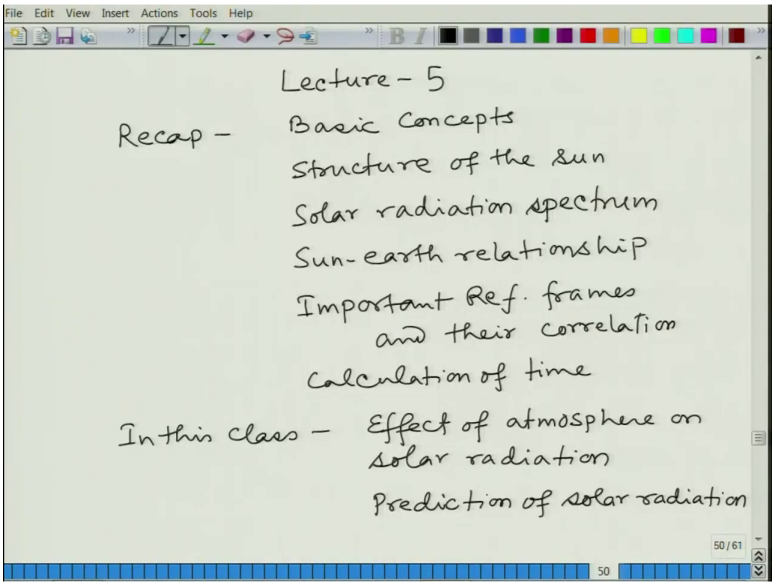

So, we are here at lecture 5. So, far what did we see? So, just to recap we have seen the basic concepts, the structure of the sun, the solar radiation spectrum ok. And then we have started looking at the sun earth relationships ok. And then we have looked at several important reference frames, and their correlation; reference frames and their correlation this we have seen.

And, in the last class what we saw, it was the calculation of time. So, the original motivation of calculation of time is the apparent motion of the sun and from there we have converted that time into our watch time and how they are related that we have looked at ok. So, now, in this class what we are going to see is the effect of atmosphere on solar radiation.

So, effect of atmosphere on solar radiation that will be the first thing we will look at and the next thing that we are going to look at is the prediction of. So, whenever you need to install a new device somewhere for a particular purpose you need to predict what kind of radiation it is going to see and then only you can estimate what would be the power output from that device ok.

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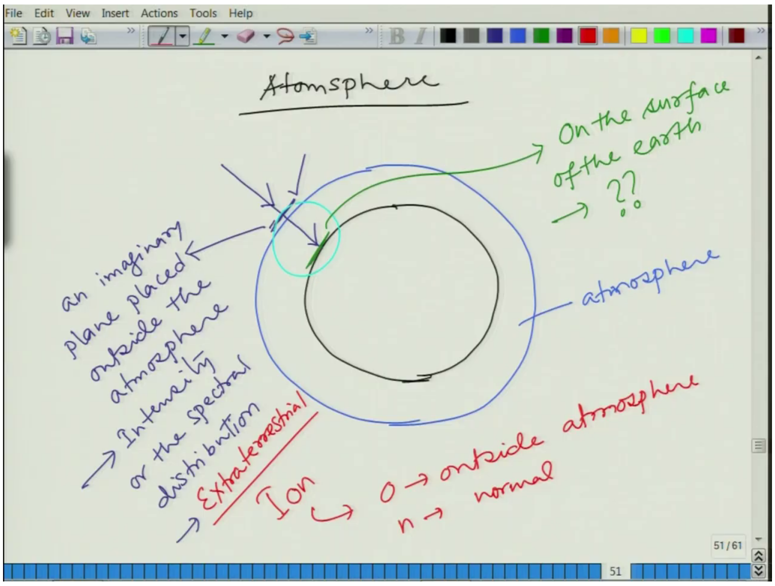

So, let us take the effect of atmosphere first. So, you can think of the atmosphere which is a specialty of our planet, which is allowing us from I mean allowing us to survive in this celestial atmosphere or celestial environment. So, this atmosphere you can think of the earth to be a sphere ok. And the atmosphere is covering the whole of earth as another concentric sphere ok.

So, this is our atmosphere right. And whenever we have talked about the solar radiation so, far we have talked about the outside the atmosphere ok. So, we have taken a plane outside the atmosphere and we have seen what is the radiation intensity, what is the spectral distribution of that intensity and all those things.

So, this is a so, this is an imaginary plane placed outside the atmosphere. So, whatever value we have taken there such as the intensity or the spectral distribution, everything on this particular plane we call it extraterrestrial.

There are too many hour in the spelling of extraterrestrial so, please note that ok. So, that means, extra means out and terrestrial means earth. So, it is out of the atmosphere of the earth ok. Now, but this particular thing is very interesting; however, what we actually get is something on the face of the earth ok. So, ultimately what we need is somewhere here.

So, on the surface of the earth what are the characteristic of solar radiation? That we are getting that is our question, actually that is the one that we are going to be harvesting using our solar energy device ok. So, what happens in this thing; when it passes through the atmosphere what difference does it make? That is very important and that is what we are going to look at now ok.

So, before we move on let me just say that this extraterrestrial thing we have represented with Ion, you remember in couple of classes ago we have seen this I e o means outside atmosphere and n means normal ok. So, that means, the normal intensity outside the atmosphere.

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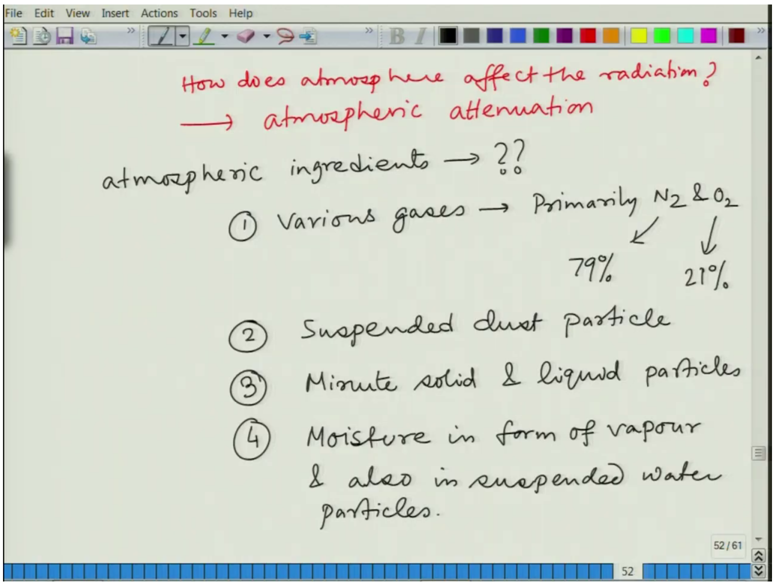

Now, how does atmosphere affect the radiation? That is the question we are going to look at now. And it is often called atmospheric attenuation; because, it will actually attenuate or reduce the intensity of the solar radiation that is why it is called atmospheric attenuation ok.

Now, what does our atmosphere consist of as atmospheric ingredients? What does it have? First of all it has various gases right. And primarily it is nitrogen and oxygen right. So, approximately 79 percent of atmosphere is made up of nitrogen and 21 percent oxygen.

The rest are very small amount so, this is a rough estimate you can say that it is majorly nitrogen, and then the next important component is oxygen, and that is why life is surviving on the earth.

So, that is the major constituent of our atmosphere. What next? We have suspended dust particles ok. Whenever, you leave some surface unattended for few days you will see that there is a layer of dust accumulating on that surface right, from where does it come it is coming from the atmosphere.

So, atmosphere is full of this dust particles ok. And the next thing we have minute solid and liquid particles. They have different sources, but you have even the metallic particle, and this liquid from the car exhaust so, from some industry exhaust or just the moisture that is coming out from the ocean to the atmosphere that is also there ok. In particle form and then the moisture in vapour form. Moisture in form of vapour and also in suspended water particles ok.

So, these are the major components of the atmosphere ok. So, if you are a hypothetical rider sitting on a particular ray which is coming from the sun. Up to the edge of the atmosphere there will not you will not see much change ok, its a huge vacuum that you are coming through unless you encounter some celestial body or celestial particles you will not see any change in the characteristic or intensity or even direction of the radiation right.

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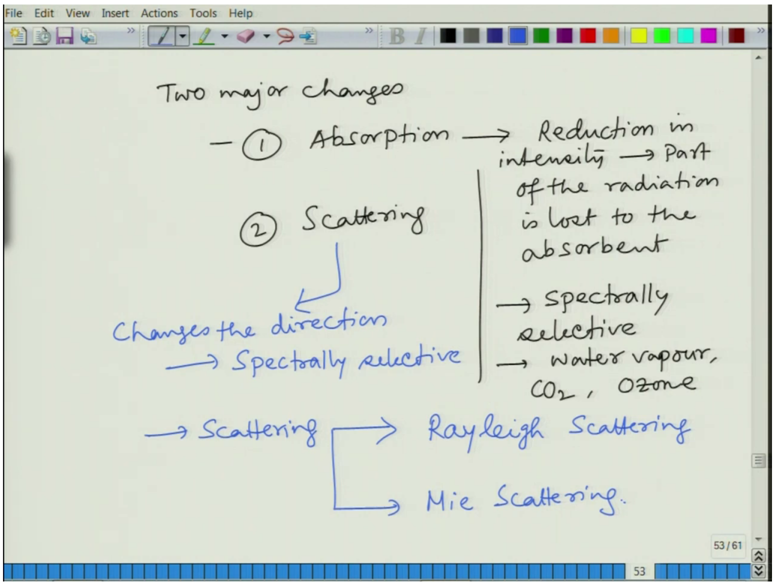

But whenever you are moving in the atmosphere there will be several issues that you will find those are majorly of two kinds. Two major changes that you see within the atmosphere. 1 is absorption ok and the 2 is scattering ok. So, these are the two major issues that the solar radiation will see. Now, what is absorption? Absorption is the reduction in intensity ok.

So, basically part of the radiation is lost to the absorbent ok. It may be a particle a dust particle it may be gas or moisture anything it may be, but that is what it will do, it will reduce the intensity ok.

And that particular thing is of course, spectrally selective. What do you mean by spectrally selective? Spectrally selective means that a particular part of radiation or the particular portion of spectrum will be absorbed more and the rest will be affected less, that is why we call it spectrally selective ok.

So, and they are majorly due to water vapour, carbon dioxide, ozone these kind of gases they are the major absorbance which affects the intensity of the radiation. And the second factor that is the scattering. What does it do? It changes the direction ok. Scattering means the radiation hits a particle and that is how it changes the direction of it and that is the scattering ok. Again this will be spectrally selective.

Which part of the spectrum will be affected by how much that depends on the particular scattering agent ok? So, now scattering we can again distinguish or we can classify it in two major types ok. One we call Rayleigh's scattering ok, the other one is called Mie scattering. So, what do they mean this Rayleigh's scattering and Mies scattering?

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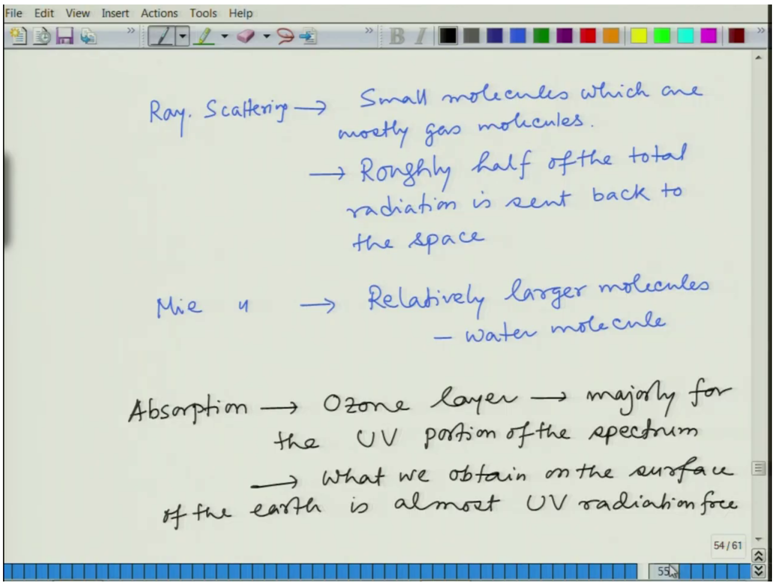

So, this Rayleigh's scattering is actually due to small molecules which are mostly the gas molecules ok. So, these gas molecules they affect the solar radiation, and by this Rayleigh scattering actually half of the approximately half of the total radiation is sent back to the space ok. So, scattering means change in direction, and it changes the direction by so, much that it never reaches the earth. So, if you feel in a summer day ok.

So, this is a very hot day so, much radiation we are getting from the sun actually whatever you would have gotten you are getting less than half of that ok. Because of this particular atmosphere and the Rayleigh scattering that is happening inside that atmosphere ok. So, half of that is sent back. And the Mie scattering we can go in details of this, but those fall outside the scope of this course. So, we will just touch upon these different scattering.

So, Mies scattering only does or happens by the relatively larger molecules such as water molecule ok, or some metal particle dust particle and all those things ok. And the absorption that is happened so, that is how the scattering works by Rayleigh and Mie scattering.

Now, absorption that is happen in the ozone layer, if you are familiar with the different layers in the atmosphere you would know that there is a ozone layer that is in the top part of the atmosphere. And there the absorption happens majorly for the U V or ultraviolet portion of the spectrum ok.

While we have talked about the solar radiation you have seen that there is a portion of solar radiation which falls in the ultraviolet region right. And that whole portion almost gets absorbed by the ozone layer ok. So, what we obtain on the surface of the earth is almost U V radiation free ok.

Because, it gets absorbed that is why we do not get U V radiation much. But we actually did lot of harm to the ozone layer while we initially started the refrigeration cycle to use the refrigeration cycle, particularly in America what happened they use some chemical which as the refrigerant.

And that gas went up to the atmosphere up in the atmosphere and affected the ozone layer. So, there were few large ozone holes and through that the UV portion came to the surface of the earth. In that case, there were lot of issues of skin cancer and other things, and that is why they have stopped all the that particular refrigerant ok.

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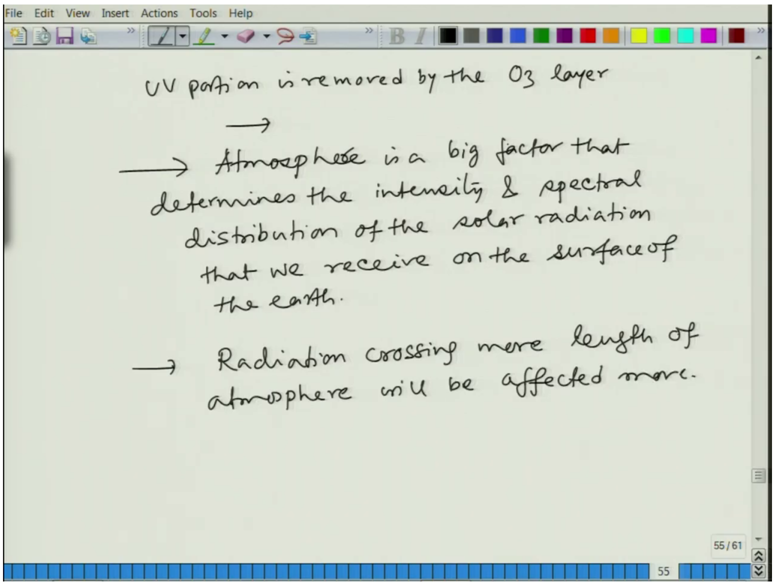

So, basically U V portion is removed by the ozone layer. And that is why we can survive otherwise life would have been very different on earth ok. So, these are the major changes that the atmosphere does on the solar radiation ok. So, what we can say that atmosphere is a big factor that determines the intensity and spectral distribution of the solar radiation that we receive on the surface of the earth ok.

So, in the same breath what we can also say that the radiation that is crossing more amount of atmosphere will be affected more right. So, radiation crossing more length let us say length of atmosphere will be affected more. Do you agree ok?

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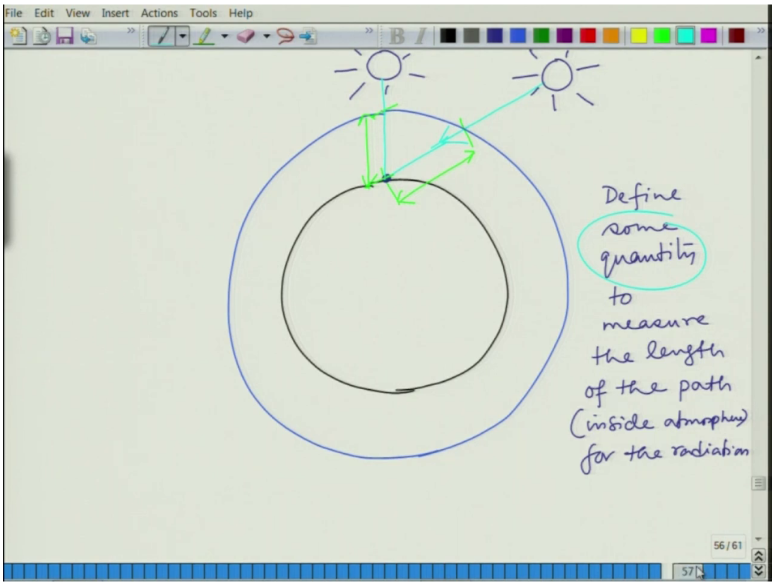

So, if that is the case, then we can you can appreciate the following figure. Again this is the earth and let us say this is the atmosphere. Of course, we are exaggerating the atmosphere much because; the earth diameter would be about 12,800 kilometers ok. So, this is about let me not put that in the figure because then it will not make with scale. So, its about 12,800 kilometers and with respect to that the height of the atmosphere is only about 10 kilometers.

So, its a very tiny coating you can say on the top of a large ball ok. So, here we are exaggerating it for the purpose of demonstration. Now, you can see that suppose you are an observer here ok. Now, if the sun with respect to you is here ok. So, the sun ray that is coming directly to you is this one right ok.

So, the amount of atmosphere it is seeing is this right ok. The sun is going through the atmosphere for this length. Now, compare that with sorry compare that with the solar position which is here ok. Now, if you consider a ray coming from there will be this and the amount of atmosphere it is seeing is this much right.

So, of course, these two lengths are not same ok. So, we have to somehow define. So, we need to define some quantity to measure the length of the path inside atmosphere for the radiation ok. Because, that is what will determine the intensity ok. So, we need some quantity let us say or let us see what would be that quantity, but you can appreciate that we need to define it right.

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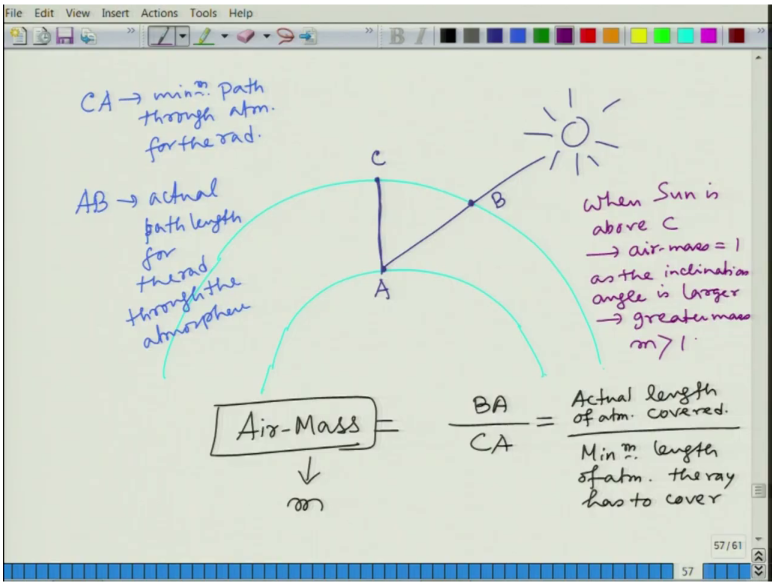

Now, let us say we take just portion of it we do not need to draw the whole thing this is the earth and this is the atmosphere ok. Now, let us say this point is A and this point is B and just above just the vertical direction the end of atmosphere is designated by point C ok. Now, let us say this is the solar position ok.

Now, we can say that this CA this is the minimum path through atmosphere for the radiation ok. Because, wherever be the sun CA that minimum path it has to cover right, because that is the normal distance. So, now, AB is the actual distance or actual path length for the radiation through the atmosphere ok.

So, what we can we are after some metric to define this. So, what we do? We define this particular quantity which we called air mass ok. So, air mass is defined by the this particular quantity this is BA divided by CA ok. So, BA is what? The actual length of atmosphere covered ok. And the denominator CA is the same thing, but minimum length of atmosphere the ray has to cover ok.

So, this is what we called air mass ok. And air mass is designated by the symbol m. So, its a ratio of the length it will not have any unit as you know, but the name is air mass ok, because the amount of air that it has to cover we want to measure that; that is why the name is air mass even though it is a ratio of the lengths ok.

So, you can see here that when sun is above C ok. You will have air mass equal to 1 right, because then both the denominator and numerator will be CA. And as the inclination angle is larger you have greater air mass ok. So, m greater than 1 ok; so, that is the concept of air mass. Now, how we can determine the value of air mass ok.

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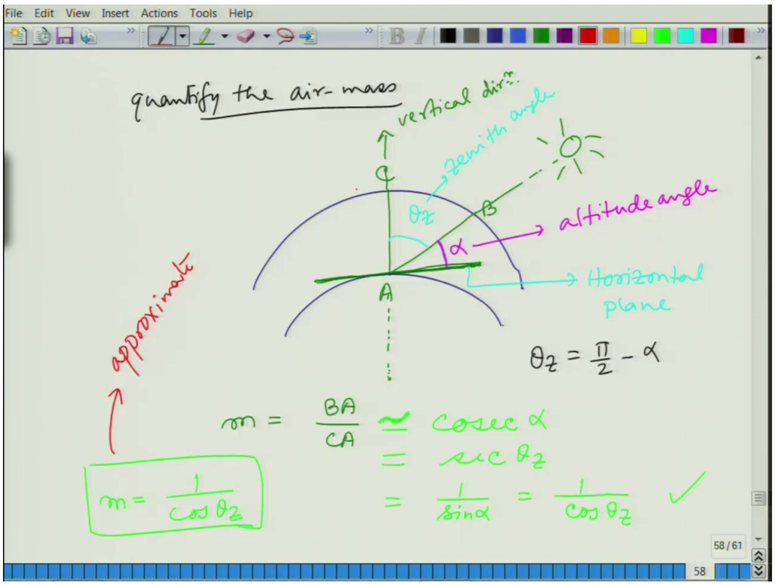

So, quantify the air mass ok. So, now, let me draw that figure again or maybe just the atmospheric part. So, here we have CB and A ok. And this is what can you tell me? This particular plane this is the horizontal plane right, because this is the center of the earth ok. If you connect that to the observer location and extend that this is the vertical direction.

This is vertical direction and the plane perpendicular to that is the horizontal plane. So, basically this is our horizontal plane ok. So, now, this B is representing the direction of the sun ray ok. So, can you tell me what would be this angle? This angle will be the zenith angle right. You have seen this already that the angle between the ray and the vertical direction is the zenith angle ok.

And what angle will you tell this? This angle or let me use separate colour. So, this angle is our alpha which is the altitude angle ok. This is zenith angle. So, just from the construction of the definition you know that this theta z will be pi by 2 minus alpha. Zenith angle is complementary to the altitude angle right.

Now, if we want to know what would be and here what we can. So, basically air mass is nothing, but you are BA over CA right. Now, here we can assume that this is so what we can assume is that this particular angle or this particular air mass will be the cosecant of alpha ok. Because, this you can think of a construction of a right angle triangle with this B A C, where the right angle will be at C ok.

So, this I should write this is an approximation ok. So, this will be cosecant of alpha and that is same as second of theta z right. So, just from the simple trigonometry and this you can also write 1 over sin alpha or 1 over cos theta z ok. Just by constructing a right angle triangle between BA and C you can write this ok.

So, basically m equal to 1 over cos theta z that is the definition most often we use. But you have to remember that this is approximate because, this BA and C, they do not form a right angle triangle rather B and C they are basically a curve line it is not a straight line ok.

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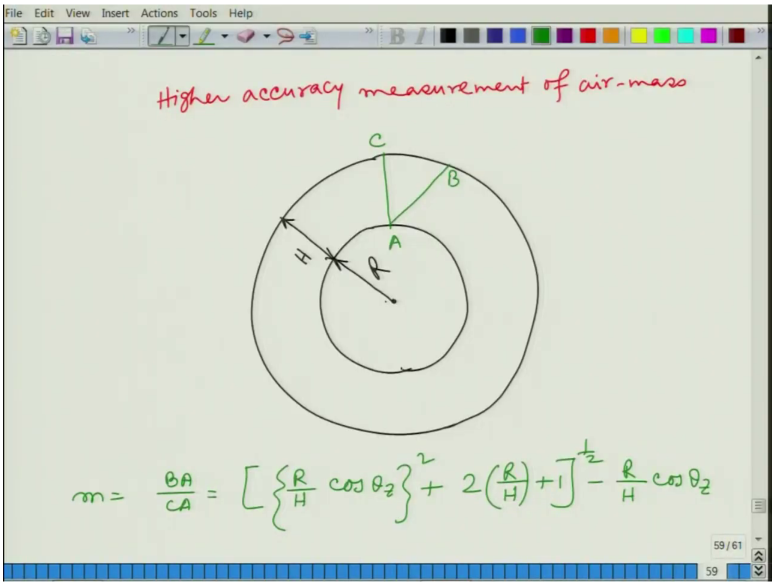

So, if you want higher accuracy so higher accuracy measurement of air mass that would require the curvilinear path between B and A ok. So, in that case what we can. So, let me draw it first because the curvature we need to consider, we need to take what are the values of if this is the radius of the earth, and if this is the height of the atmosphere H and R, then you can get then other things stay the same this is BC and A.

So, air mass which is BA over CA you can write in terms of I am not going to derive it, but if you are interested in higher accuracy; what you can use is this particular expression ok. So, this will give you little more accurate value of the air mass, but 1 over cos theta z is the most common form of air mass that we use for any engineering purpose that will serve you, serve your purpose ok.

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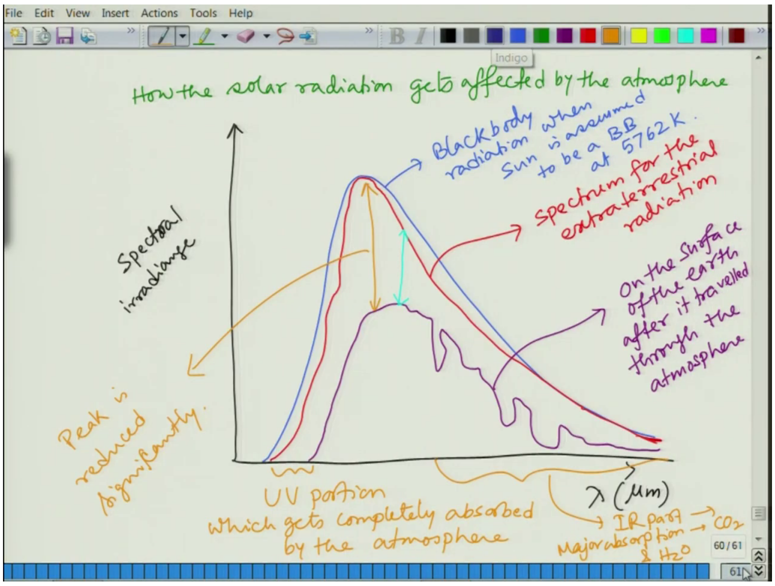

So, that is the first thing that we wanted to talk about was the air mass. And now, we will see how the solar radiation gets affected by the atmosphere? So, we have talked about the factors that are affecting the solar radiation. Now, we will see what would be the result of that ok. So, let us look at this solar spectrum once again ok, here we have the wavelength lambda in micrometer and here we have spectral irradiance spectral irradiance ok.

So, we have seen that we have started from the most basic approximation which is the black body radiation ok. So, the black body radiation and again this is not up to the scale, I just want to give you the qualitative comparison between the different plots. So, black body radiation when sun is assumed to be a black body at 5762 Kelvin right this we have seen in earlier classes.

And from there we have seen what we get at the extraterrestrial level ok. So, there are certain variations and all, but we reach the peak quite accurately and in the later stage it matches quite closely to the blackbody radiation.

So, this is the spectrum for the extra terrace trial radiation. So, we have seen that there are some variations from the blackbody radiation, but its matches closely, but with the atmosphere playing a role the things get significantly changed. First of all let me just draw it first ok.

So, again this is qualitative, but this is the spectrum that you get on the surface of the earth after it traveled through the atmosphere ok. So, this in at any wavelength this is the difference that the atmosphere is making to the solar radiation ok.

Now, few things I want to draw your attention to first of all this particular portion; this particular portion is majorly the UV portion right. So, this is the ultraviolet portion which gets almost completely absorbed by the atmosphere ok.

And the intensity is also hugely dropped. So, the overall intensity so the in the peak region also you can see the peak is reduced very significantly ok. And another feature you notice here that a beyond the visible range where when you are in the infrared range; that means, in this part of the wavelength. So, there are significant reduction in intensity at certain portions ok.

So, this part in the IR part the major absorption happens due to carbon dioxide and water vapour ok. And because of that because this infrared portion is spectrally selective to the absorption of CO 2 and H 2 O; that is why this portion gets affected significantly, even though the visible portion is not affected that much ok. So, this gives you a qualitative picture of what you would expect when the atmospheric conditions are taken care of ok.

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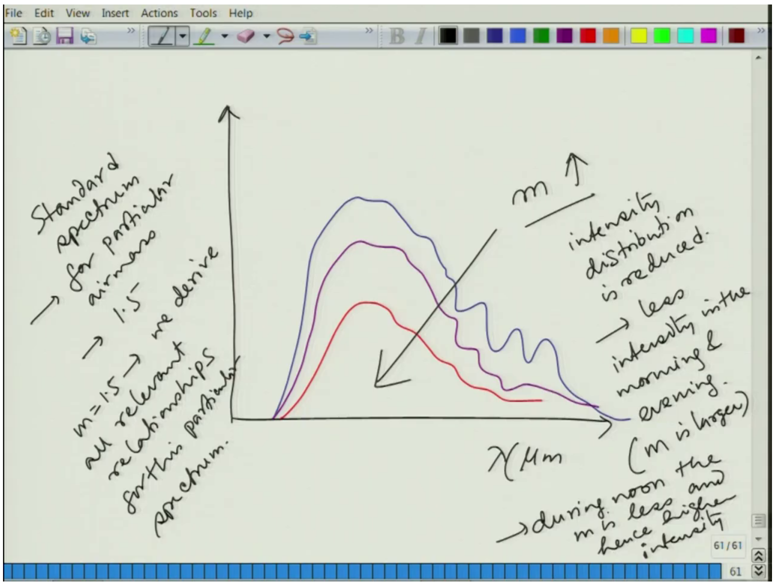

Now, you can see now let me go to the next page. Now you can see that for so, just the same thing you can see that the air mass will actually determine how much you will get ok. So, the intensity and other things will be dependent on air mass ok. So, you can see that in this direction the m is increasing ok. So, rather when m is increasing your intensity distribution; intensity distribution is reduced ok. That is why you get less intensity at the in the morning and in the evening.

So, less intensity in the morning and evening because the sun is closer to the horizon and as air mass depends on the altitude angle that is why in the morning and evening air mass is much larger. So, for morning and evening m is larger ok. And during noon the m is less and hence we get higher intensity ok.

So, that gives you a total clear picture of the air mass. And whenever we talk about the standard spectrum then we have to define the air mass. So, whenever we call a standard spectrum we do for a particularly or a particular air mass, and that value is 1.5. So, when m is 1.5 we derive all our relationship all relevant relationships for this particular spectrum that is why we call it a standard spectrum ok. So, we have looked at the effect of atmosphere on the solar radiation and what is air mass and how does it affect the situation ok.

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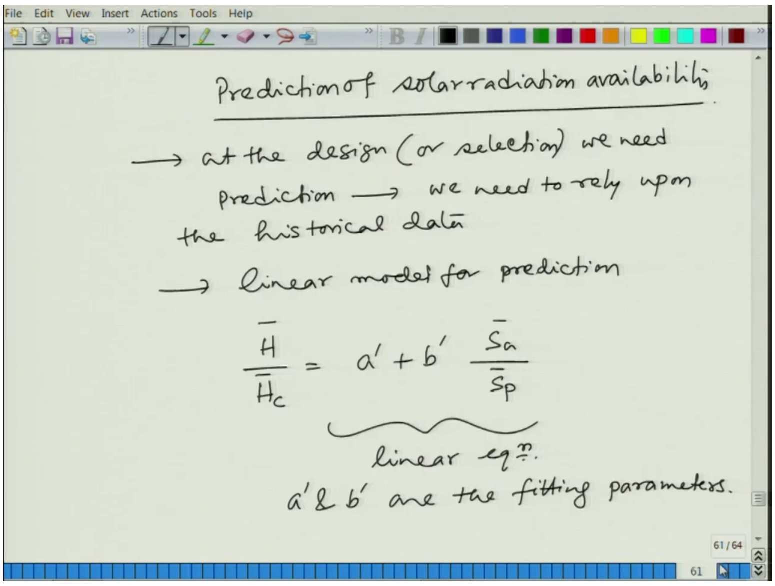

So, let us now go to the next portion of this lecture where we are going to talk about the prediction of solar radiation availability ok. Why do you need this? Suppose you are trying to place a solar panel on your rooftop ok. You want to know that how much power it will give throughout the year right. Because, I mean you have to know whether it will serve the purpose for which you are placing that solar panel ok.

And maybe suppose you want to reduce your electricity bill in the summer because at that time your electricity bill is higher and you want to place a solar panel, which will be particularly effective for those summer months, where you use run your air conditioner ok. If that is the case then you would like to know how much solar radiation will be available on your rooftop or to the panel that you are using right.

So, that is why you need to predict it at the design stage itself design or here you can say selection when you are selecting the panel or selection stage, we need prediction and that prediction will come only from historical data right. You have to know on your rooftop how much solar radiation was available throughout few years few decades maybe the larger the sample set you have the better will be your prediction ok.

So, we need to rely upon the historical data ok. And what is the most basic form of prediction equation? That is the linear model ok. So, here our course is not going to cover all the possible variations, but we are give we are going to give you the flavor of all the different aspects that are going to affect your design or understanding of solar energy conversion. So, we are going to use a linear model for this prediction ok.

So, what let us just straight away write a prediction equation then we will explain each term of it ok. So, let me first write it then we will talk what does it mean ok. First of all this is a prediction equation I have written and you can see that this is a straight line equation linear equation ok; where a prime and b prime are the fitting parameters ok. And that will depend on the data ok.

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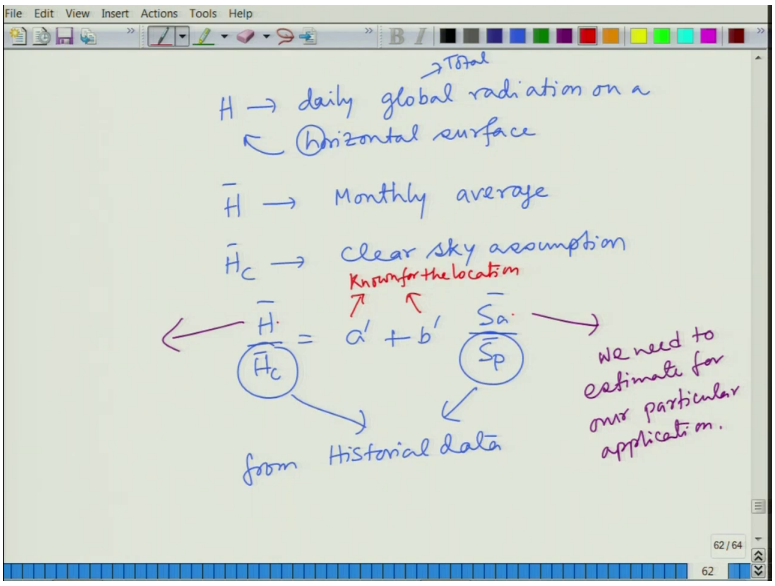

So, and what are the other things we have? This H bar is so, before I use the bar let me just say what H stands for. So, these are very standard notation we are going to use in this course. So, we need to know what it means. So, it means the daily global radiation on a horizontal surface ok; so, this horizontal this is represented through this H.

We will see that when we are talking about different tilt of a solar collector then the whole scenario will change ok, but the most basic thing is the horizontal one and that is how the prediction is always based upon. So, and this daily global; global means its total ok. Total that means both diffuse radiation as well as direct radiation we will talk about it in a while.

So, and this daily means throughout the day how much total radiation a horizontal surface is getting. And whenever you put a bar on top of that; that means, its the monthly average. So, for a month you calculate this H for all individual days and then you average them up that is called monthly average. And whenever we put a subscript C it means that we are doing that under a clear sky assumption ok.

So, what we get in this equation; what we get in this equation? That both these denominators we are getting from historical data ok. And the numerator both this one and this one we are we need to estimate for our particular application ok. And these are known for the location. So, H bar and S bar H bar and S; S a bar these things we are going to estimate while the historical data and the coefficients are known ok. So, we will start from here in the next lecture.

Thank you very much for your attention.