Conduction and Radiation

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Lecture No. # 17

Transmissivity

The first problem which was the temperature of the earth, we already saw the solution to the problem in yesterday's class. So, basically the sun is considered to be a blackbody, whose outer surface is at 5800 Kelvin, that is not the actual temperature. The temperature of the sun millions of Kelvin at its core, the outer surface of the sun has a temperature equal to 5800 Kelvin, that is enough for us; from there the radiation is coming, it is falling on all the planet, that is why we are able to have sun light, day light, this thing and because of that, the earth is having a good temperature at which we can survive and all that. So, I told you, we had discussions about this in previous class, in one of the earlier classes. So, you have to take the surface temperature to be 5800 or 600 Kelvin, find out the blackbody emissive power of the sun, that is outer surface of the sun; sigma T s to the power of 4 divided by pi, you will get I intensity watts per meter square per steradian, keep it.

Now, work out the solid angle; solid angle is always calculated with respect to the receiving area. So, the receiving area is the earth. So, it receives because it is from sphere to sphere, if you if you cut a, if you have a plain cutting, so, it is only pi r square or pi d square by 4. So, the area which you have to consider is pi d square by 4 for the earth, pi d square by 4 for the sun.

Now, the receiving area is pi d square by 4 for the earth multiplied by the Cos theta divided by the distance square, that will give you the d omega. Now, once you have the solid angle, then once you have the intensity. So, I d omega Cos theta, what else is there? Into? So, that will give you the. So, multiplied by yeah. So, that will give you the q, q incident, q incident must be equal to sigma T e to the power of 4 into 4 pi r square, because the area of emission of the earth will be 4 pi r square; once you do that you are able to get the equivalent temperature. So, the earth's temperature came out be some 279 Kelvin, but there is a technical flaw in what we have done, because the earth is not a blackbody, it has got a albido, that is it has got a reflectivity; if if you consider that you will get a temperature which is slightly different from 271, 279. In the second problem most of you have done, but for the sake of completeness.

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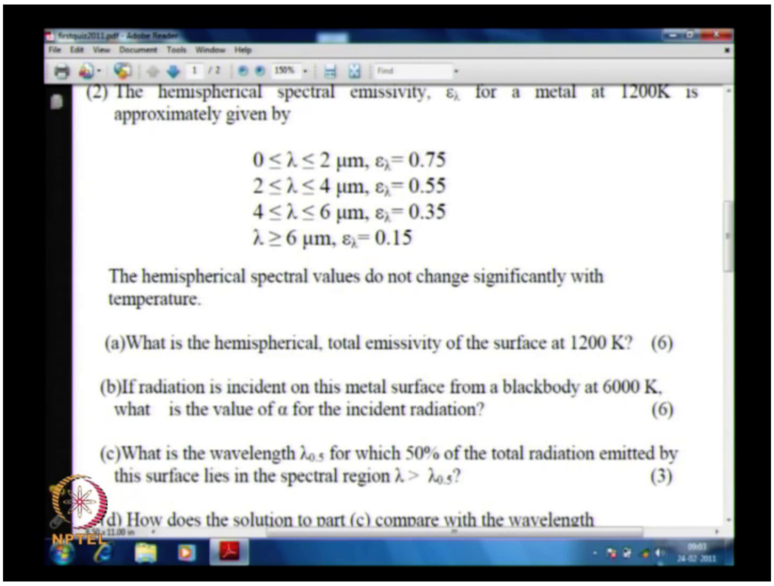

So, I will go through this again; this is the spectral hemispherical spectral emissivity So, the first step is to plot it like this, epsilon lambda versus lambda.

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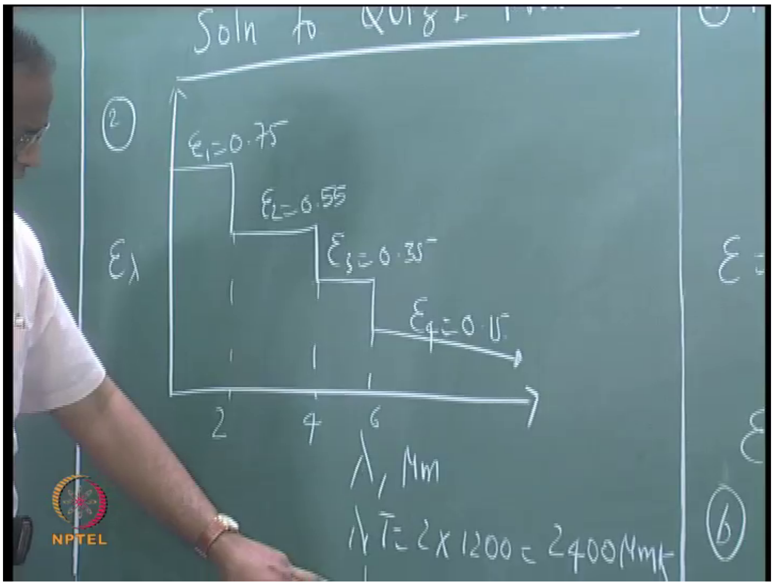

Then evaluate, there are 3, lambda 1, lambda 2, lambda 3. So, calculate lambda 1 T, lambda 2 T, lambda 3 T. This T corresponds to the 1200 Kelvin, which is the temperature of the surface.

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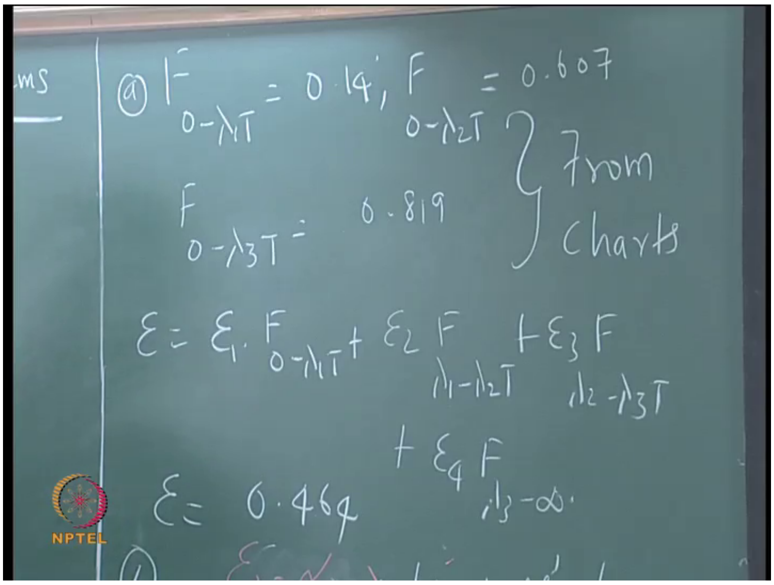

So, now from the F function charts. So, this is. So, from the charts, you calculate the F values and then you have the formula. So, epsilon is, epsilon 1 into F of 0 to lambda plus epsilon 2 F of lambda 1 to lambda 2 epsilon 3 lambda 2 to lambda 3 and this goes up to infinity. So, this is lambda 3 to infinity, which means 1 minus F of lambda 3 T, that F of lambda 3, all that, we have found out; this is 1 minus 0.819, if you had all that, you will get emissivity equal to 0.464.

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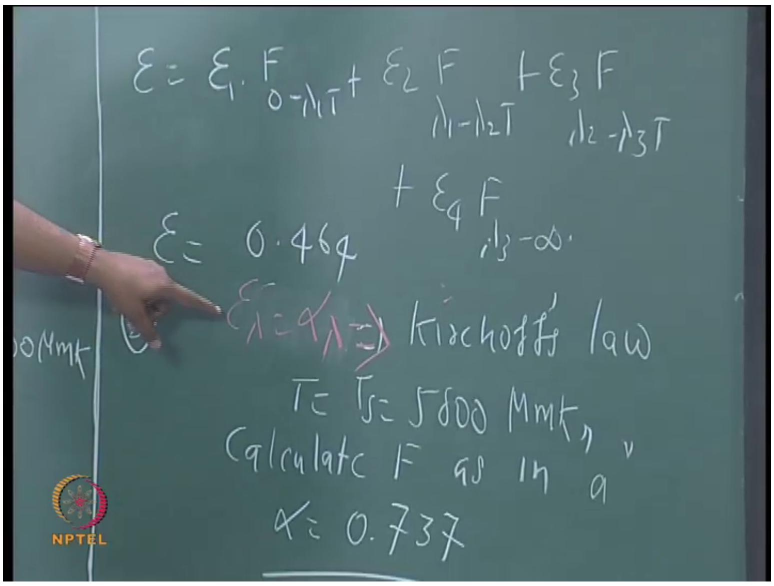

Now, if you calculate calculate the absorptivity, to calculate the absorptivity, you have to use the temperature corresponding to the temperature of the sun; but it is perfect to use epsilon lambda is equal to alpha lambda, because it is a, I told you it is gray diffuse surface, I told you it is diffuse surface. So, from the, from the Kirchhoff's law, you know that emissivity is equal to absorptive, that is spectral; but you should not make the mistake of calculating T t taking T to be 1200 Kelvin, then you will again calculate alpha also equal to 0.464, it is not which is not correct. Alpha, alpha is basically the absorptive of the incident radiation. So, the incident radiation is coming from somewhere, from where? It is coming from the sun.

So, we have to take temperature of the sun; otherwise I should give you information on I lambda i, I will say no, it increases from 0 to 4000 watts per meter square, decreases, increases, since I have not given the distribution, you have to use the blackbody function and then. So, repeat the same procedure, except that, you will use ha ha except that, you will use 5800 Kelvin, now we got the alpha. So, 6 marks plus 6 marks 12, 12 marks; then we will go through the other portion, little more carefully, because lot of few were blinking yesterday, how we got that lambda greater than lambda, what is the optimal resolution? What is that? Yeah.

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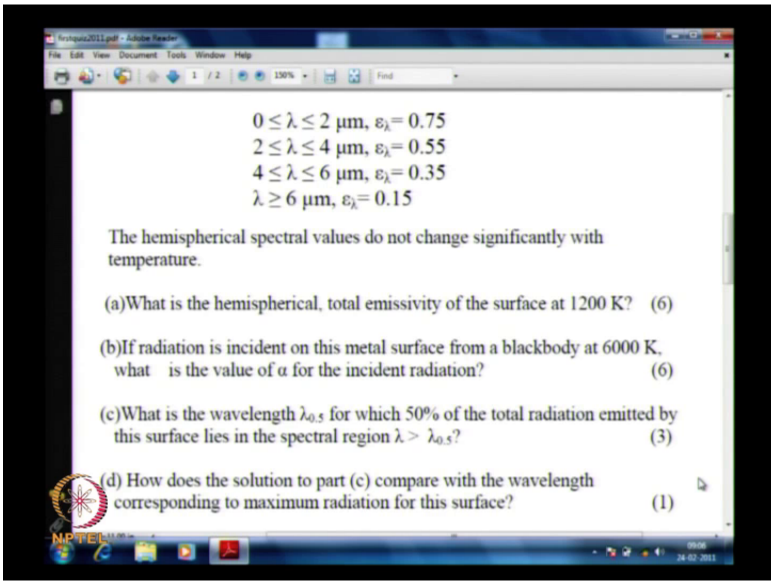

So, the part c of the question is what is a wave length for which 50 percent of the Total radiation emitted by this surface lies in the spectral region lambda greater than lambda 0.5. Now, can this be shown? Difficult, ok.

Now, all of you have this F function chart, all of you have this F function chart. So, when I said lambda, when I say, when I asked the question what is a wave length for which 50 percent of the radiation is emitted, all of you thought that I you must go to the column number, last column, column number 5 and find out the blackbody fraction, and find out where it is 05. So, it is not 0.5 exactly, at 4000 micrometer Kelvin, it is 0.48, at 4200 it is 0.51 5 1 6. So, you thought it's you are very intelligent and interpolated, and then, very intelligently, interpolated and got the answer, you said some 4100, something. So, therefore, lambda into this thing is for 4000, something; T is given to be 1200 Kelvin therefore, this is 0.5. That is perfectly, that is perfectly okay, if you have a blackbody or if you have a grey body; but the funda now is, this fellow is having a funny distribution. So, though the F function remains the same as a blackbody, it is contribution varies in the various wave length band, because epsilon 1 is not equal to epsilon 2 is not equal to epsilon 3.

So, you must first understand the futility of an exercise, where simply you took 0.5 in the last column and said no no this is 50 percent, are you getting the point? What that, that is correct for a blackbody as well as for a grey body, not. So, the body under consideration is what? Blue body? What it is a, it is called a non, it is called a non grey body, it is non grey, it is not grey, it is not the color, non grey means that fellow is having a distribution that is epsilon is the function of lambda ok.

Therefore, you have to, now, I have to make an assumption, I do not know where that 50 percent lies, I do not know where the 50 percent lie. So, but now, I, my intelligent guess is since the Wien's displacement law gives me 2 8 9 8 micro meter Kelvin is the maximum.

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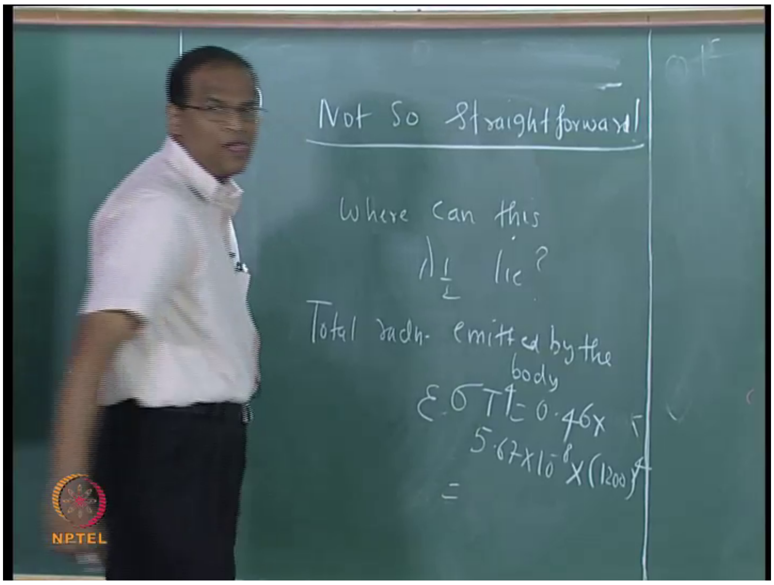

So, what see is not so straight forward, that is a first thing; first thing you have to recognize, it is not straight forward, it is not simply taking the last column and giving. Therefore, so, it it may involve some tedious iterations, suppose, I make it very painful 0 lambda less than 1.2 is 0.75, 1.2 to 1.8 is 0.71, 6 8 5, if I do like this you are finish; but now, so, where can this lambda half lie? What is this lambda half? That is F of 0 to lambda half, no no it is not even this, it is not even this. What what does it mean? where first first, we have to find out what this lambda half is, Total radiation emitted by the body, epsilon, correct? What is this? 0.46? 0.46 yeah. What is this? All this is not required for working at the problem, but we will do for the sake of completeness; per meter square.

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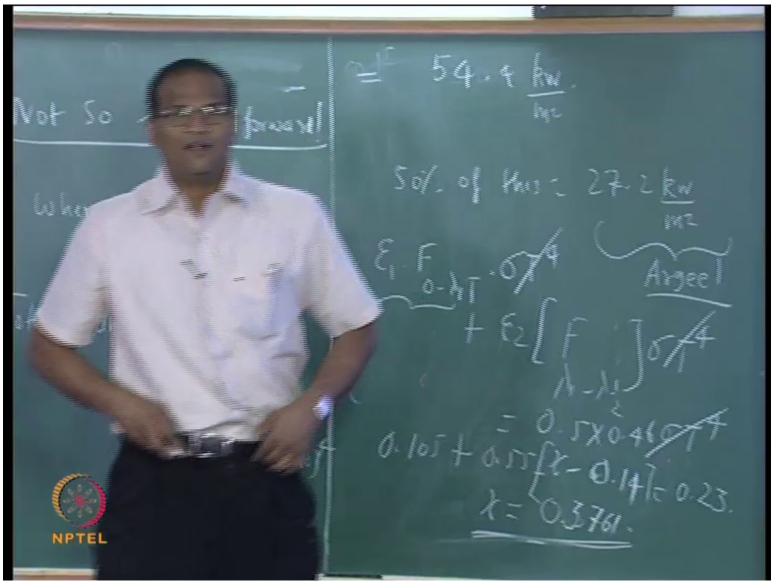

Now, now, what I want is, is it, right, whatever, I have written? Deepak, is it okay? So, what happens to this? I am not going to use this, Vikram r g. So, that is not going to, that is not going to use 27.2; if some people are want to be clinically perfect, please keep this 27.2, multiply each of this term into sigma T to the power of 4 and proceed; then it will give you the same; but the danger there is, when you do sigma T to the power 4, you may make some more mistakes.

Now, now, I am assuming that I expect this fellow to lie between 2 and 4. How can I make such an assumption? Are you getting the point? How many of you are not able to follow my line of argument? I am saying that the buck stops with epsilon two; that means, I am expecting that 50 percent interval to be between 2 and 4, it is reasonable to assume because the temperature is 1200, wien's displacement law gives me lambda max T approximately 3000, 3000 by 1200 is 2.5, correct? So, around 2.5 it is speaking. So, I expect, when it is speaking, I expect that between 2 and 4, I can get this 50 percent, I may be wrong, if I, if I do not get that I will go to epsilon 2 or epsilon 3, are you getting the point? Fine.

Now, can you do this? So, this will be a, what will, what is the first term? 0.105 plus epsilon 2 is 0.55, what is epsilon lambda 1 lambda 2? Not 0.2, I do not know lambda half, right; 0.607. I can solve for the x. So, x turns out to be point, is it?

Student: (( )).

6 0 7 minus x, it is correct.

Student: Lambda 2.

It is right, correct. So, x is, x is how much?

Student: Point (( ))

Yeah yeah. So, 0.607 minus x is alright.

Student: (( )).

No, no, wait, fine. x minus 0.6, yeah, yeah algebraic ok. So, x equal to 0.376, go to the F function chart, go to the F function chart, point out where you get this 0.376. So, you have to interpolate between, yeah what is the problem?

Student: (( ))

What what what?

Student: x should be greater than 0.607.

X is greater than 0.607, why?

Student: (( )) greater than lambda one.

No no no no just hang on. No that is not 0.607, 0.1402. Huh. 0.14026. There may be mistake here, let us, what is the F of 0 to lambda 1? ah

Student: 0.143.

So, what what (( )) ,it will be x minus?

Student: 0.14 (( )).

Ah I made so many mistakes, x minus,

Student: 0.14 (( )),

Hey Umesh, now is it okay?

Let us check 0.2, 0.2311 divided by, so, it should be fine, 3 7 6 1, is it correct? yeah. So, if you look at 0.3761, go to F function chart, take the last column corresponding to 0.3761, you back calculate lambda into t. So, what should be the answer?

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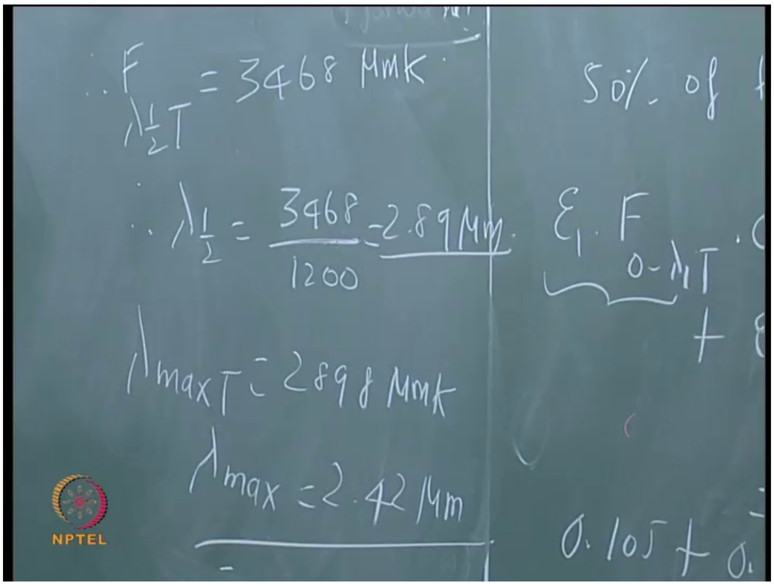

Equal to 3000, 3000, what is it?

Student: (( )).

3400 and?

Student: (( )).

58.

Student: (( )).

Ok.

Student: lambda max is 2.48.

Point (( )).

Student: 4.

Point (( )).

I wanted you to write that, this lambda half and lambda max are close to each other; some people have written 2.89 is greater than 2.4, therefore, lambda half is greater than lambda max and; but from, in in the whole spectrum of 0 to infinity, one was 2.89, one was 2.41, I do not know, why you are not able to see the similarity, but you want to see only the difference. Ok.

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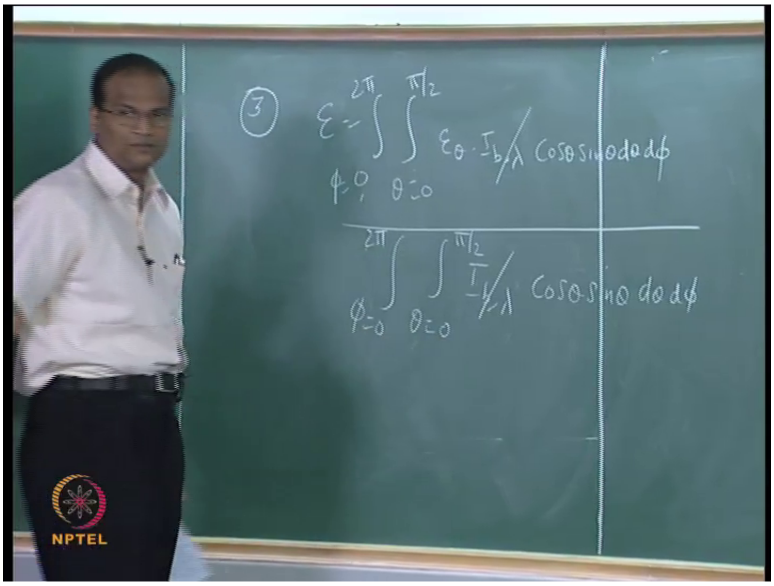

Now, third question, yeah, it was a straight forward question. So, there was a small typo, this came as 45, it is supposed to be 60 to 90. So, this is a directionally. So, can this fellow be knocked off? And one integration with respect to phi will give 2 pi in both the numerator and denominator; that can also be removed ok

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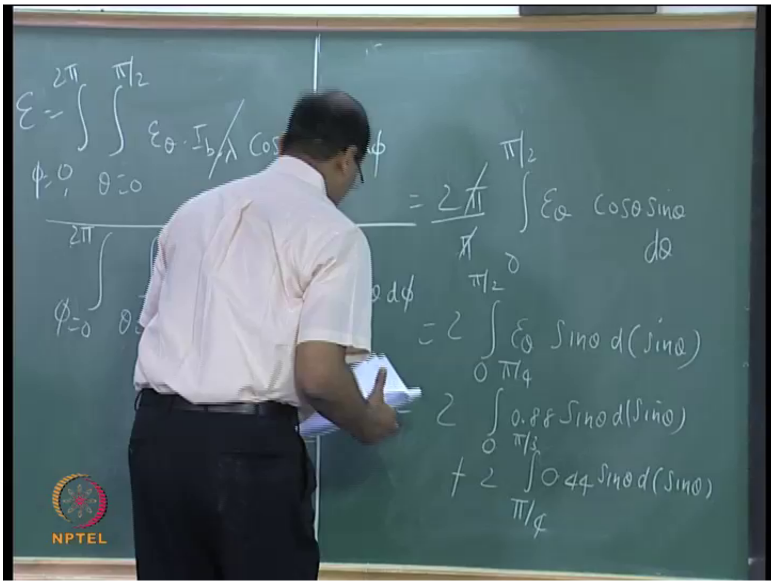

So, 2 pi by, is it correct? Divided by 2 pi in both the, I am making a mistake, I am making a mistake, I am making a mistake, I am making a mistake. Only 1 pi. There is only 1 pi in the denominator because its solid angle, pi radian, pi steradian. I am writing this explicitly so that, all of you remember that when you when you are converting this spectral directional into what is it?

Student: (( )).

Into Total quantity, the 2 will be there, the 2 will be there. So long as it is azimuthally isotropic, I gave you, the surface is isotropic in the phi direction, that is there is no change in this direction, we can give one more dependence on that, we can say that epsilon is a function of phi also, then you make things complicated, but that is that will be basically an academic exercise. Very few surfaces have both dependence on zenith and azimuthally angle. So, this is like this. Now, straight forward, it is pretty straight forward. So, epsilon theta sin theta d of sin theta, there are several ways of doing it, some people are doing it sin theta Cos theta sin 2 theta by 2 and then all that. So, now, you can substitute. So, this is basically. So, 0.88, the next is 0.44, now, plus.

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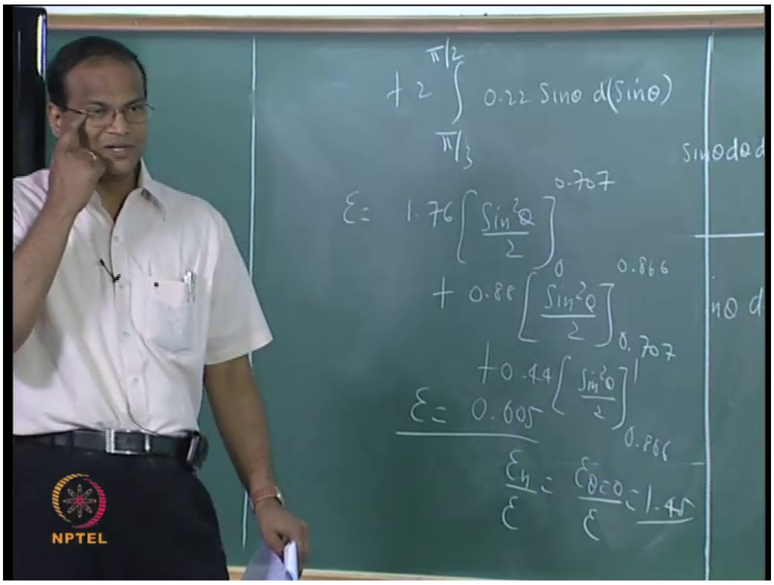

Now, plus, it looks like a very innocuous, a very simple problem, but many of you just got rid of the 2, and you got a nice answer of 0.305 or 3 0 2, the answer is 0.6605 or something, somewhere the 2 was followed. So, pretty straight forward. So, this is 1.76. So, I substitute for sin theta 0.6, something.

Student: (( )).

6 0 5 and I, so, this is the, this is the hemispherical?

Student: (( )).

This is Total hemispherical emissivity.

Now, I asked you the ratio of the normal emissivity; normal emissivity is Cos Cos of 0 that is 1, that is the highest, that is 0.88, right? So, ratio is epsilon, 1.45. So, 5 marks for this and 1 marks for this; many of you have got it right, but basically, some of you have miss that factor of 2.

The last question is a practical problem which involve energy balance, right? So, what is the radiation heating a roof, it could be an asbestos roof, or it could be a conflict roof, or whatever.

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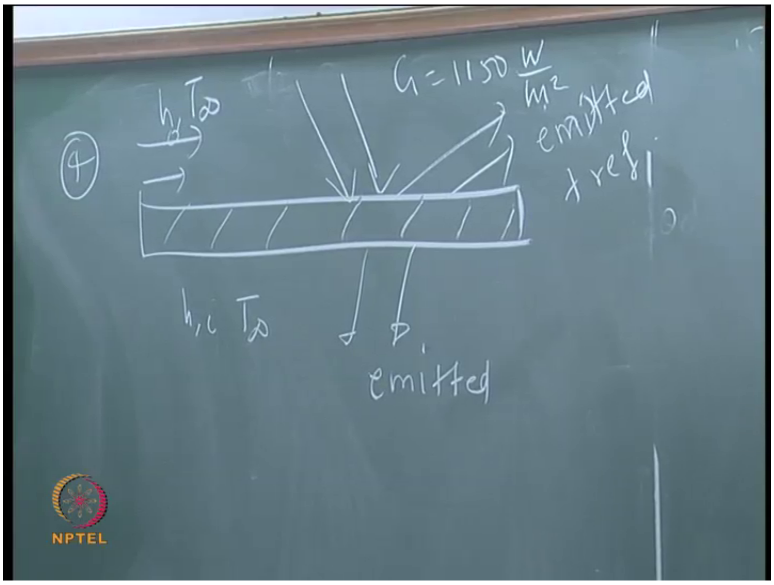

So, for example, if you have. So, there is a convection on the inside, outside, there is also a convection on the inside, but outside convection is because of wind, inside it is because of natural convection. In fact, if it is a roof, you do not expect much natural convection on the inside, because if it is heated at the top, to say your room heated at the top, the hot air will stay here, but somehow I have given you 8, so that I wanted to check whether you are able to add 24 watts per meter square per Kelvin to 8 watts per meter square per Kelvin and. Otherwise, it is this is go stably stratified, that is if the hot air remains at there is top, it is stable, it will not over return because hot air is lighter.

So, now now there is an incident radiation. So, what is a G? I or G is 1150; out of this, there is a emitted plus reflected, here you have emitted. Now, you do the energy balance.

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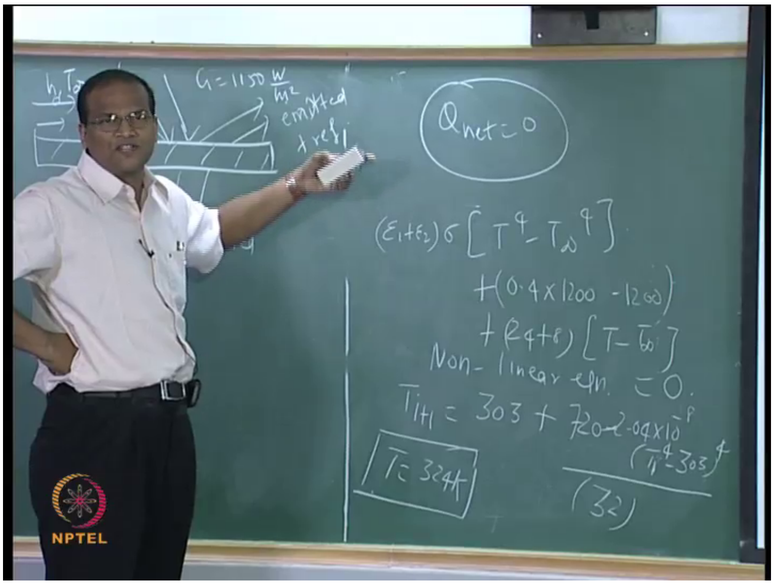

So, basically, Q net is equal to 0, if Q net is not equal to 0, then Q net will be equal to m c p d T by d time of the plane; then the d T by d time will be non 0, it will increase or decrease depending on the complex interplay between the various factors, that is not the subject of this problem; your model something where d d T t T increases and decreases with T the time, that is the impulsions heater, we have already done that, this is not the goal here, the goal is to find the steady state temperature. ok

So, the governing equation will not be a differential equation, it will simple non-linear algebraic equation. So, basically 2 epsilon sigma plus, did I give 300 or 303? I will just put it as T infinity first equal to 0, right the net emitted, the net emitted plus whatever is reflected minus whatever is incident plus whatever is converted must be equal to 0. If everything is going, where is the source? The source is, this minus 1150; rather, 0.4 into 1150 minus 1150 which is nothing but, any problem? I gave.

Student: (( )).

Ah.

Student: (( )).

My notes, I had 2 epsilon and all that, then when I was typing, I changed; you do not believe. So, this is before setting the paper. So, I have 2 epsilon and all that, and 1150 then I changed 1150 to 1200 and, but I got the answer for 1200 also; this is the way we set papers, fine.

Now, this is the non-linear equation. So, T I plus 1 plus. So, let us start with T I is equal to 310. So, it will drive it. So, that will drive it, right side. So, you will have 303 plus 720 minus whatever. So, in 3 or 4 iterations, we get, after the third or fourth iteration. So, if you got some other answer…

Student: (( )).

32.

Student: 32 (( )).

Ya ya ya, correct.

Now, how will you redesign this for a solar collector, is this clear to everybody? So, we have done with a quiz now. So, if you have started iterating, I would have given 5 or 6 marks regardless, whether you got the right answer or, and if you have got something close 323, 324, 325, you would have got 10 marks. Ok.

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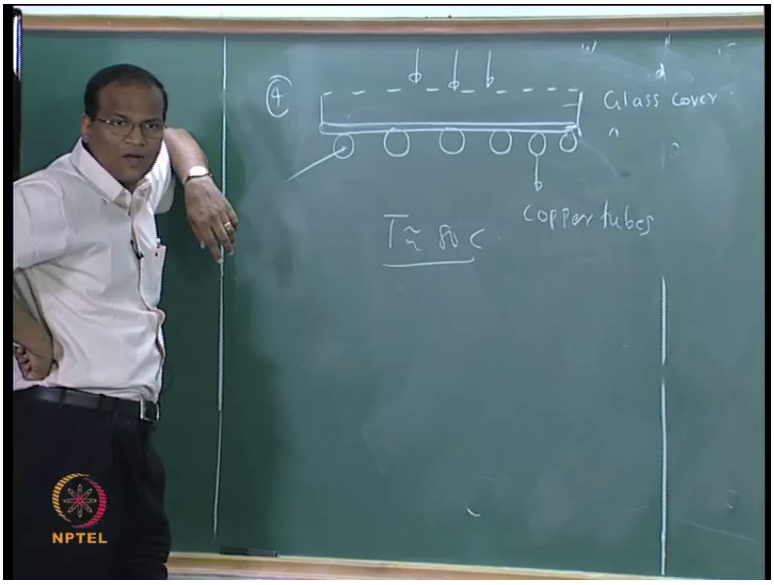

Now. So, what the, what the solar people will try to do is, they will try to put some…

Student: (( )).

That is, that is one thing, non selective surface, already emissivity is low, they will have something, where absorptivity is 0.6, they may increase it further, they will put there, will be a glass cover; so that, you can reduce the convection, what they will do is, then you probably, they make it like this, then they will have copper tubes in those, copper tubes, we will send water and then, you will get heated water. So, the maximum temperature will be around.

Student: (( )).

T will be around 80 degrees. ok .

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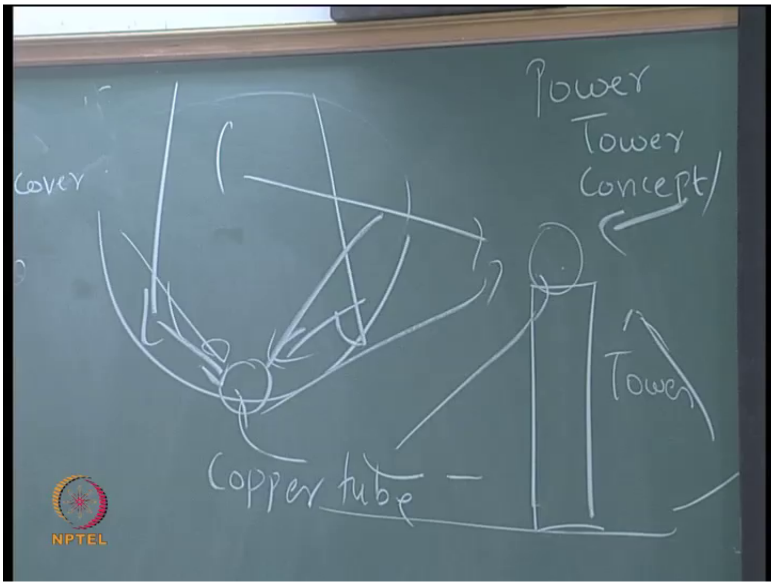

So, if they want more, then probably, they will have do something like this. So, they will have what is a concentrator, and then this will go up, this temperature will go up, this is basically called a line focus because, it is like this; if you want to get, if you want to improve further, so, probably you will have something here, this is the ground, this is the Tower, you will have all these fellows like this, you will track all of them, all these fellows will will send the radiation up, using this motors during the time of the day, during the season, you will track all this, dual degree students must have studied this in many courses, this is called power tower concept. So, you can put, you can get very high temperatures here, when you send the fluid here, the thermic fluid or fluid here, it will get heated up and that fluid can can can be used in secondary heat exchanger, where water is converted into steam, you can run a power plant, there is a plant called solar one in Barstow, California; they are also developing something called Rajasthan energy developed agency is trying to build, but they have been saying this for a long time, it takes it takes lot of area, it, and there are lots of issues maintenance issues, and all those things, and then because, you have all these motors right, for tracking all these and so, they frequently give rise to problem; this is one set of people who are working on this, there is other set of people electrical engineer and physicists for directly working on thin films and they will directly do the solar portable deck conversion.

Well, because this is again thermodynamics, then second law, then we cannot produce more, it is impossible to conflict device which operating in a cycle, all those laws will be applicable. So, we can directly use portable type, but the Costs are very high. So, here there are other reasons, the other problems like initial investment is high and maintenance issues and so on; but they can supplement, you cannot have, it is very difficult to get 3000 megawatt or a 4000 megawatt plant with all these, use amongst areas required, but the single for a Ramagondam super thermal power plant, you got 5 into 5 into 5 megawatts, 2500 hundred megawatts in 3 kilo meter by 3 kilo meter, to whole plant, township, everything, we are able to generate thousands of megawatts.

So, coal is also solar energy only, everything is solar energy, correct? Wind is also solar energy, correct? It is not really renewable because, because the sun is not an inexhaustible source of power, but anyway, when you say it is renewable, it is basically, you are looking at the scale, time scale; for our life, for our time scale, it is renewable, in a Cosmological time scale, it is not.

So now, we will get rid of this and then we will get back to our Transmissivity; that is the last property which we have to study; I will define Transmissivity and then tomorrow's class we will work out two problems and wind up our discussion on properties.

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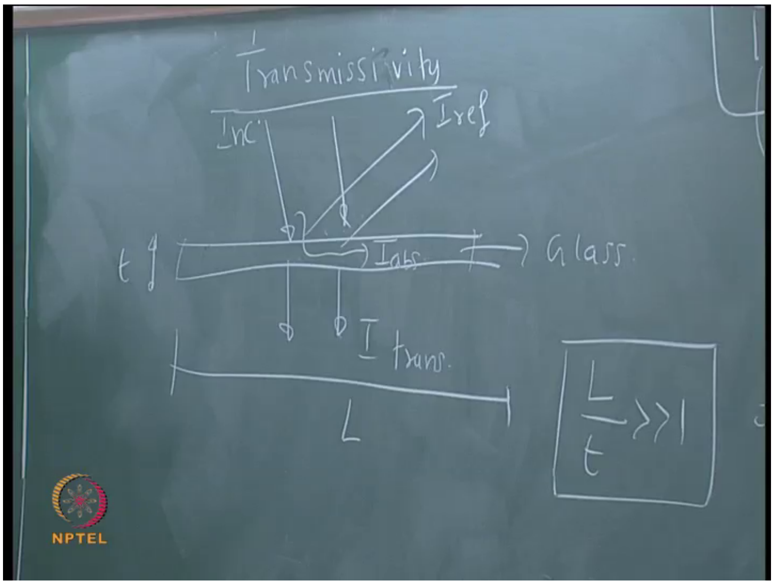

Ok. So, now, no spelling mistake? Right, Transmissivity, for example, if we consider, if we consider glass, what is the story of the radiation falling on this, falling on thisd falling on this? Did we say I for falling, incoming is I? Oh I i and say incident, good. So, what is a fate of the radiation which is falling on this? Do not worry about the emission, what can happen to this?

Student: (( )).

Reflected, then absorbed is it goes inside. Now, as for as glass is concerned, it is not opaque. So, some will go through ok.

So, for a transparent medium, or a semi-transparent medium, or a medium which is not opaque, there is a possibility that the radiation will go through, penetrate the medium and come out of it. Therefore, an additional property enters, which is basically, is the Transmissivity.

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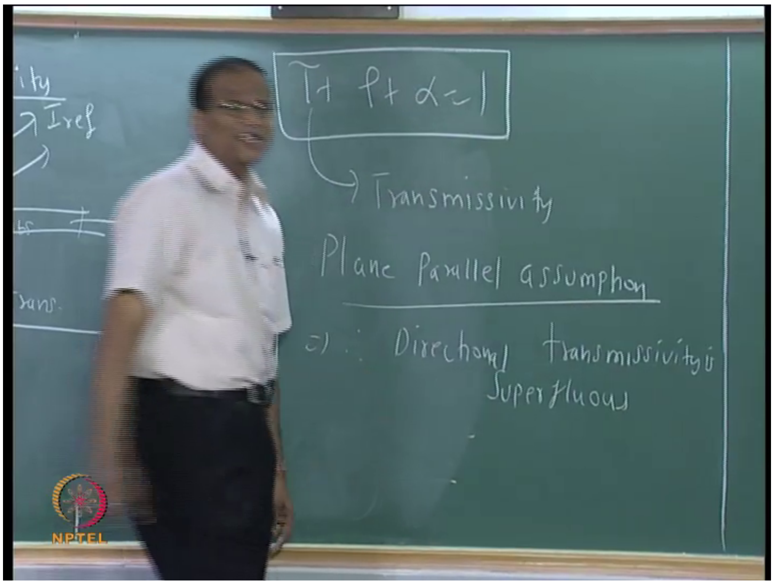

We already saw that this tau, it is also a dimension less property, it can also have a, it also has the limit 0 to 1, it is opaque surface, it is having tau equal to 0, if it is, if it has got hundred percent transmittance; for example, glass, some some surfaces will have ninety percent plus in certain positions of the spectrum, then the tau will be equal to 1; and just like our emissivity, absorptivity and reflectivity, this fellow can also misbehave, does mean, it can vary with respect to lambda, it can vary with respect to theta. So, it can lead to complexity.

But we are talking about thin media, a thin layer of, a thin layer of glass, a lens, or a prism, or a filter, or the atmosphere. Now, suddenly I am saying, I am equating a glass to atmosphere, how can I consider atmosphere to be thin? Can I consider atmosphere to be thin? Again, it it depends on the relative scale, compared to the radius of the earth, the diameter of the earth from the problem is, quiz problem is how much?

Student: (( ))

Radius of earth is 6378 kilometers. The radius of the earth is 6378 kilometers, the atmosphere may be 78 to 80 kilometers. So, the height of the atmosphere divided by the diameter radius is so small, therefore, the atmosphere can also be consider as thin; what is the advantage? Then I can consider it to be one dimensional, I can consider all the properties to vary only with the height or z; that makes matters very simple; if everything is a function only of z, then I kill the variation of Transmissivity with respect to direction. So, the concept of a directional Transmissivity becomes redundant for a one dimensional medium or a plain parallel medium. Because it is so easy to work with that, we stick to that assumption and say that most of the time we are interested in plain parallel assumption, that, that does not lead to savior error. Ok.

So, basically plain parallel assumption, what is this plain parallel assumption? If this is the thickness, this is the l for example, l by thickness is much much greater than 1. So, properties vary in, properties vary across this height only; therefore, therefore, directional Transmissivity is super flow or redundant, there is no need to worry about a directional Transmissivity, it makes life easy for us; example,

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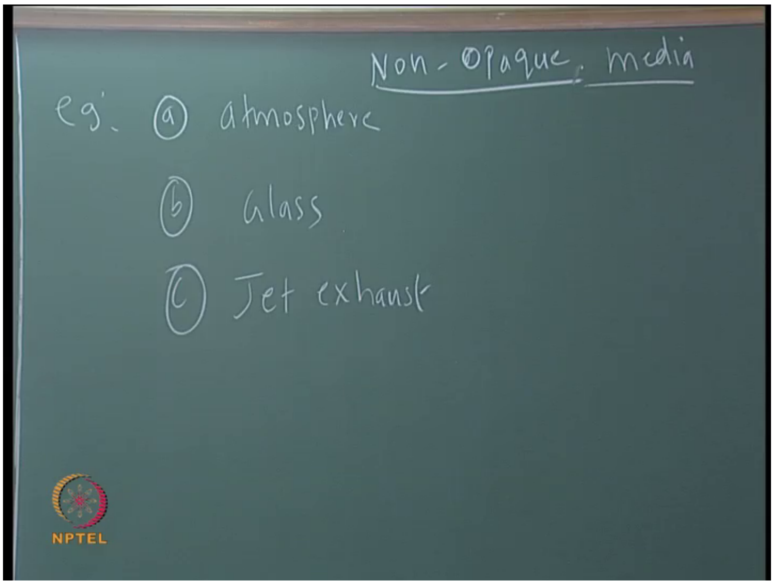

Example of atmosphere, glass, example of trans, examples of media which are not opaque, get exhaust, right? Non opaque what? Media, correct. We cannot say surface, non opaque media, some example the atmosphere, length, filter, this thing. So, the concept of a directional Transmissivity becomes redundant. So, we have to define spectral and total, then be done with it.

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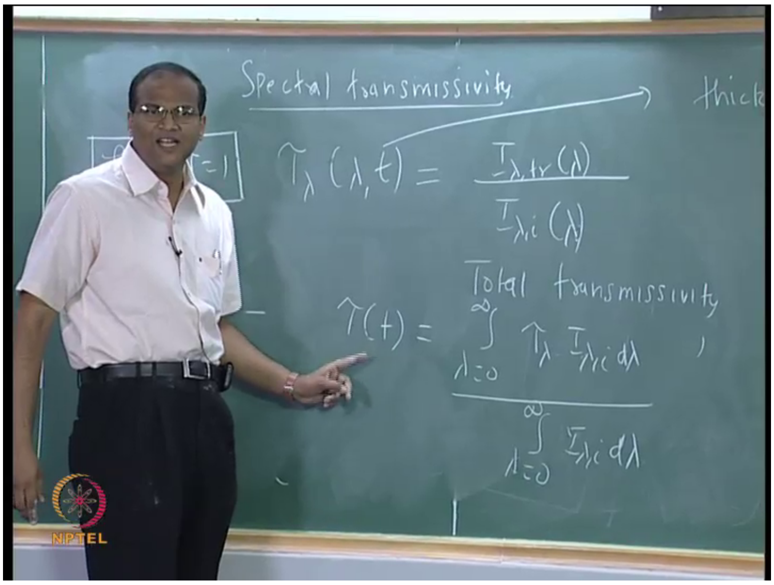

So spectral transmissivity. So, you want to put tau of, I want to use tau lambda, should be a function of lambda, and shall we put is as d or l thickness? t.

Student: t.

t, you want to use t. So, it is basically, I lambda I incident the denominator, numerator? Yeah, yeah. So, I lambda, fine. Can it be greater than 1? No, it cannot be greater than one, fine. Now so, what is this? What is t? Thickness, a medium which absorbs, which can scatter and it can also transmit is called a participating medium.

In a participating medium, the basic difference between a participating medium and the surfaces we considered so for are, basic difference is as far as surface is concerned, the reflection, absorption, they were all happening in the first, the first, the first few micro meters they were all surface phenomena; that is why, I said radiative surface properties, but in an atmosphere, the radiation penetrates deep into the atmosphere, it hesitates all these molecules, they may absorb this, they may scatter, that is they may reflect it may transmit; because of which, temperature being greater than 0, it can emit as a volumetrically, this is different from the emission of surface, where it was emitting from the surface; now this whole gas volume may emit, and it may scatter differently in different direction, that is called an isotropic scattering. So, the problem gets lot more messier.

And the governing equation is called the irradiative transfer equation, r T equation, which was first figured out by Subramanian Chandrasekhar; he only wrote the equation and solved it when he was just 29 years or something. So, that is the r T equation, what is r T e? Radiative transfer equation, r T e or or r T equation.

So, therefore, this is called a participating medium because it participates in the radiation volumetrically, the whole gas volume is participating; as oppose to the surface, where all the activity was restricted to the surface it can get absorb, but the absorption is very quick; I mean the absorption happens in the first few micro meters, right? In the, for the surfaces, right? Now Total Transmissivity. So, can I give an explanation for the Total Transmissivity? Tau, tau lambda divided by, you can put all these I lambda tau lambda or lambda T, all that, do the all that, put the bracket; divided by lambda equal to 0 to infinity I lambda i d lambda, very good.

Now, fine. Now, look at this, watch carefully, please look at the board, suppose I say that the incident radiation is coming from the sun, the incident radiation is coming from the sun, I am talking about a non grey surface, I give you this spectral distribution of rho, I give you the spectral distribution of alpha and I tell you that the radiation is coming from the sun, and keep quite; can you calculate this? Can you or can you not? Yes, how? You will first say tau equal to 1 minus alpha 1 minus open bracket alpha plus rho from whatever is given data or from the graphical distribution, you will recreate the graphical distribution for tau, and then for I lambda I, you will take e b lambda corresponding to this sun’s temperature. So, you will use the F function chart, you will re, you will re reproduce or create tau based on this, and then calculate the, calculate the tau. So, we will work out such a problem in tomorrow’s class; we will also work out a problem about the sun control film, how it works, I will stop now. So, you can work this out, for the, for the special case of irradiation from a blackbody, you know this; what will happen? One second, the special case of irradiation of a blackbody, lambda 0 to infinity tau lambda e b lambda divided by?

Student: (( ))

sigma T 4 4 by,

Student: Pi.

By pi.

Student: (( )).

Ah, if it is no, no, if I use I b lambda, it is by pi; if I use e b lambda (( )).