Conduction and Radiation

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Module No. # 01
Lecture No. # 16
Reflectivity

We will continue with our discussion on radiated surface properties. So, you have already seen two or three very important properties namely, emissivity and absorptivity. We will have to see reflectivity and then when you extend these properties to surfaces which are not opaque, that is surfaces which allow radiation to pass through them, for example, glass or the atmosphere and so on; you have to consider a very important property called, transmissivity.

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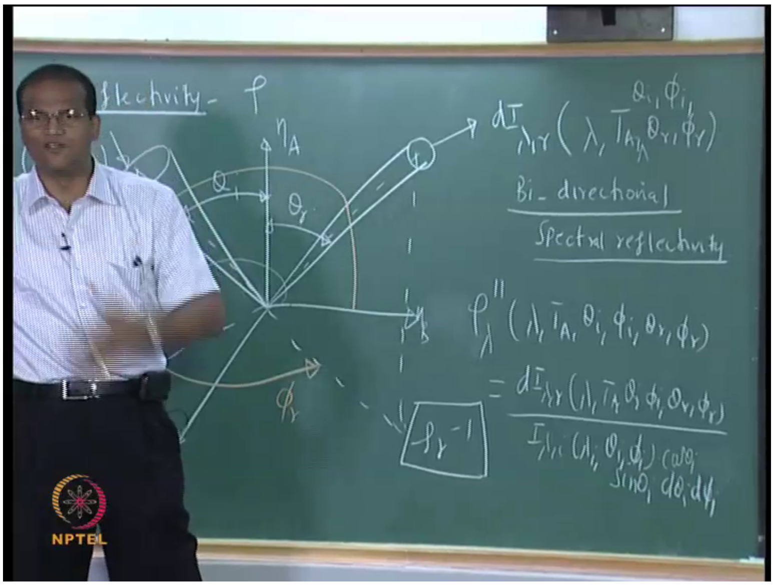

So, first we look at reflectivity. As the name suggest and also from the past experience where we have already worked out problems with reflectivity given alpha. We assumed an opaque surface and then alpha plus rho equal to one. Therefore, rho is equal to one minus alpha. If I give you the distribution of alpha lambda you can get rho lambda you have calculated rho that is reflectivity and so on. But, reflectivity is much more difficult than you thought; it is much more difficult and much more conceptually involved than you ever imagined, because radiation is coming on to a surface. This radiation coming on to a surface can be from one particular direction or this radiation coming on to a surface could be from the hemisphere above this surface. By the same token, you can look at the reflected radiation going out in a particular direction or the reflected direction going out in a hemispherical space above this surface.

Spectral is another story; spectral story remains as far as direction is concerned. So, you can have radiation incidence from a particular direction, you can find out how much is going out in a particular direction or you can look at radiation, which is coming from a particular direction and what is going out in the hemispherical space, or you can look at radiation impinging from hemispherical space above with and going out in a particular direction or finally, radiation impinging from hemispherical space above with and it reflecting in the hemispherical space above width.

To all this you had this spectral dependence. So, reflectivity is a very dangerous property. If you have to give or if you have to get really to the bottom of it is going to take a long time. So, I will just define the basic bidirectional reflectivity and then we will proceed to those reflectivities, which are of engineering significance, but reflectivity is a highly involved property. So, let us draw a picture and then things will become clear. Let us take the spherical coordinate system.

Alok, did you use the lift or (( ))

What are all these? Please, look at the figure. So, this is our spherical coordinate system. The incident radiation I lambda I is a function of lambda, theta i and phi i. Can you tell me theta i from this figure? What is theta i? Which is theta i? This one is correct. Now, this fellow is going out; d I lambda r, so this should be a function of lambda, the temperature of that surface, theta r and phi r. It should also be a function of theta i phi i, right? Because from theta i phi i only it is coming. Please watch them. So, please watch the orange chalk. What is that angle? Orange chalk. No, I am looking at the projection, suppose you shine light if the shadow falls on this and this is this x y plane. So, what is that angle?

Phi (( )) Phi of what? Phi R, Very good correct, phi R, is everybody through with this.

That is the azimuthal angle. What is the azimuthal angle? This one, the theta is angle. Now, can you draw phi i? So, I should take… We will use the green chalk. No, I think I have not completed it properly. It should be from here.

(( )) What about this? I have drawn the other normal here. What about this phi i? Phi i; this is that phi i. From here we are always mentioning from here. So, this projection is falling here this is phi i. So, I lambda I is incident from a particular angle theta i phi i. The reflected can take place in any direction. We are looking at reflection from an angle theta r phi r.

Now, please note as oppose to the absorptivity, there is a significance departure here, because I am putting the reflected as d I lambda, because this theta r phi r is a small direction. There is a small solid angle in this big 360 degrees over the hemisphere therefore, I expect the reflected component to be small as oppose to the incident. Therefore, I call it as d I lambda r. Now, I have to define the bidirectional spectral reflectivity. What is this bidirectional spectral reflectivity? It is directional-directional spectral reflectivity, incoming is from theta i phi i, outgoing is theta r phi r; it is still spectral. So, it is directional-directional, therefore, it is being rho lambda dash-dash. (( )) Dash dash It is rho lambda dash-dash. (( )) by (( )) I lambda.

No, I lambda is finite radiation which is coming in, but since we are not considering whatever is going out in the full hemisphere, in a particular direction, I expect that to be a very small quantity as suppose to I lambda I. Therefore, I call it d lambda r, because it can go equally in all the direction, unless it is a very specula surface or something. Consistent with my understanding that if it is a diffused surface or whatever; if it is a surface, which can reflect in all the direction what is coming out in a particular direction will be much smaller compared to this, therefore, I call it d I. Is that clear to everybody?

Now, therefore, I define this rho lambda and I will remove this fellow divided by… Please note that the denominator, I am taking the cos theta (Refer Slide Time: 10:44), because projected area, I am also multiplying by d omega i, which is the elemental solid angle.

This is the elemental solid angle subtended in the reflected direction of theta r phi r. if you do not like this; Under directional, you can talk about a directional-directional reflectivity that is which we saw. It is actually bidirectional spectral reflectivity, but it is usually called BDRF in capital that is bidirectional reflectivity. This is what the optics people, physics people will call. So, it is a direction to direction; from theta i phi i to theta r phi r.

I can have direction to hemispherical, correct; from a particular theta i phi i into the hemisphere above it. I can have a hemispherical to a directional. Finally, I can have a hemispherical to hemispherical and that is of engineering importance for us. So, what will be the symbol for this? Rho lambda, very good, rho lambda is expected to be a function of lambda and then temperature of the absorbing surface. I lambda r or I lambda reflected should be a function of lambda T A all lambda. If you want you can put theta i phi i also here, so cos theta i. that I lambda reflected in the numerator that I lambda reflected can be written in terms of I lambda I multiplied by rho lambda dash, where rho lambda dash can be directional to hemispherical or hemispherical to directional.

And that rho lambda dash can be connected to rho lambda double dash, which is directional to directional. To cut a long story short, if you know the bi-directional reflectivity rho lambda double dash, it is possible for you to accomplish the integration and calculate the numerator. If you know the directional distribution of the incident radiation I lambda I you can calculate the denominator. With this we can straight away get the rho lambda.

So, if alpha lambda information is not available to you and if rho lambda double dash information that is bi-directional reflectivity is given to you; you can calculate rho lambda and if it is an opaque surface; one minus rho lambda can be taken to be alpha lambda. So, from alpha you can go to rho, from rho you can go to alpha, and all those manipulations we can do, but however, the things get little complicated, if we suddenly say that tau is not zero; it is not opaque. From there is only one more reflectivity, which is involved, which is basically the hemispherical total reflectivity.

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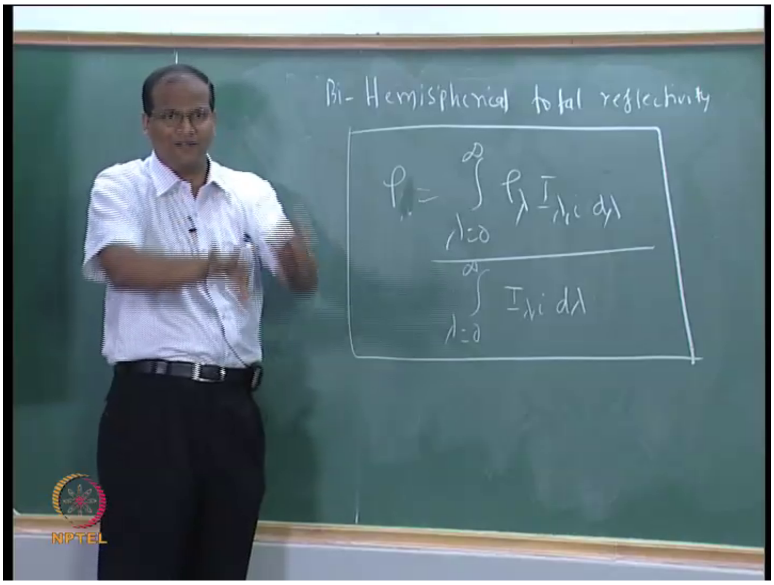

Let us do one more and then I will work out the question paper. Before that you want to write the directional total reflectivity or you will get rid of that. You do not want that. Let us go to this straight away. So, rho is equal to… There may be I lambda I into cos theta and that cos theta may come in the numerator and denominator. Since, cos theta and d lambda are not related the cos theta can be pulled out in the numerator and denominator. We can remove it. Before that there is one thing and I should have rho double dash know. Hemispherical with respect to (( )).

So, this is a I did not want to go deep into this, because by the time this class is over you will all get confused. I can have a directional-directional total reflectivity I can have a directional total I can have a directional-directional or hemispherical directional; correct. So, that is why I can have rho double dash, rho dash and all that. Then you may have an issue with whether from direction to hemisphere or hemisphere to direction, what is relationship and so it gets messy. So, that is as for as total reflectivity is concerned.

Now, this is very simple. If you know rho lambda then you can get the rho. But, if you know if you do not know the if you do not know I lambda, suppose, I do not give you the distribution, but I say that the incident radiation is from a black body at 5800 Kelvin then you can convert into E b lambda, d lambda and use f function chart and use the alpha lambda and take one minus alpha lambda is rho lambda and calculate rho. Or, if I give you rho lambda double dash, then you can do all the integrations and get up to rho lambda. Then calculate rho, then if it is opaque surface alpha is one minus rho. Or if I give a problem in which I give you rho lambda as well as tau lambda. Then alpha plus rho plus tau is equal to one, you can calculate alpha is it.

So, you should seamlessly go from one property to another property. So, this is as far as reflectivity is concerned. Now, what is a story for a surface, which is not opaque, which allows some radiation to pass through? Such a surface is called participating medium; glass is an example, lenses, filters, atmosphere and combustion chamber filled with gases. In all these cases, where you cannot assume as a medium is opaque, so there is a transmissivity involved. that is why we cannot simply put alpha plus rho equal to one. So, alpha plus rho plus tau is equal to one.

Therefore, you have to do the same story; spectral transmissivity, total transmissivity, hemispherical total transmissivity, we will quickly go through those derivations and then we will see then we will work out some problems on. I told you know about tinted glass, sun control film, if you put tinted glass whether it helps in reducing the incoming radiation, I mean the radiation which is transmitted. So, we will stop here and we will quickly see the solution to the quiz paper. So, first you want to have the papers and then you can take a break for three minutes. I will distribute the paper and then, ok.

Now, the intensity associated with the solar radiation is E S divided by pi which is 20.42. Some people have done it very correctly. I do not know whether you anticipated, may be you looked at the old question paper or four years back I gave this question, I do not know, but basically in these sorts of questions, I cannot change any data. I cannot change the diameter of the earth or the diameter of sun. So, some questions have to get repeated. I keep saying that we do not repeat, but this question we cannot change anything. So, from next time onwards, I should ask you to calculate the equivalent temperature of Venus, Mars, of course, Pluto is out of solar system right now. Pluto is not there, it is supposed to be part of something else.

Now, I is there, now just calculate the solid angle and find out what is the radiation which is incident and what is the power, which is coming on to the earth. Under equilibrium, whatever is going out must be equal to whatever it is coming. Earth is black; therefore, sigma T e to the power of four of the earth must be equal to whatever is incident. Therefore, T e is equal to q divided by sigma whole to the power of one fourth that is a story.

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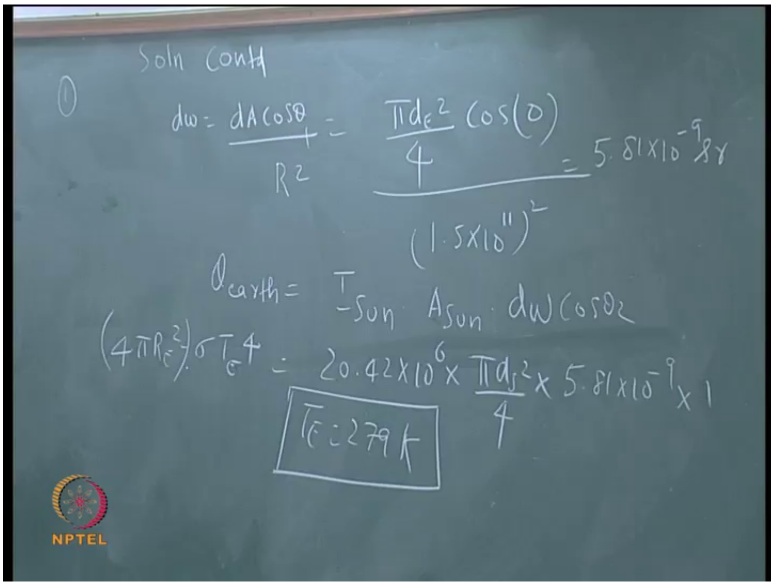

Now, the solid angle what is that d A? It is area of the receiving surface, and who is receiving? Earth, so pi d E square by four; that is the projected area. the beauty of this problem is even if it is a sphere what it receives from the sun depends on the pi r square or the pi d square by four, but when it emits, it will emit from four pi r square. That is why some people fail to recognize this four; they got orbit temperature like 557 Kelvin, 450 Kelvin, and 557 Kelvin and so on.

The earth is the projected area as far as incoming is concerned is pi r square, but when it is emitting it is four pi r square. So, pi d square by 4 cos 0, divided by, is a very small 5.8 1 10 to the power of minus nine steradian. This is d omega, q earth is equal to I sun, Please look at the board; I am spending lot of time on this because other problems all of you have done, most of you have done the other problem. I sun, we know and we just calculated. Area of the sun; what is the area of the sun again? As seen by (( )) is pi d A square by four. As seen, it is not four pi, it is because as seen by this. We are looking at solid angle. (( )) one that be incorrect (( )). Why? It is correct; pi d square divided by four multiplied by this.

So, this is basically, No, this is into zero, no way. So, this must be equal to… is it right? Sigma T to the power of four is a black body radiation of the earth multiplied by the total area, which is emitting. It is emitting in four pi r square from the surface area. So, this 20.42, we calculated; this pi d square is basically, it is a projected area for both the earth and the sun. If you do that p is, If you calculate the albedo what will be the final temperature you are getting?

We get (( )) 255, 258, (( )) but not 285. 280? (( )) Are we getting 288? If you calculate the albedo, the reflectivity, the answer will change. This is the solution to the first problem. So, if you have calculated T and got some incorrect answer I have given you four marks; if not done anything I cannot give mark. If you have got the correct answer you will get eight marks.

Second problem and third problem is all straight forward. So, second problem you have to use f function chart. So, you have to calculate lambda T s. So, you have to use f function chart and then proceed. So, you are getting epsilon is 0.46. Six marks for getting this and most of you have got it. There may be some small change, some of you have got 0.46 for 0.47, I have ignored all that, but if you have got 0.36 and instead of 0.74, you have got 0.46 that means, you made a mistake. So, proportionately, I have reduced some marks.

Now, the other part of the question is people I mean you went wrong. If I twist slightly, then you are in trouble. The part c, I told you what is the wavelength lambda 0.5, for which 50 percent of the total radiation emitted by the surface, lies within the spectral region lambda greater than equal to lambda 0.5. That was the question I asked. So, I am not so dumb man. I know you can read the tables and take 0.5 from there and say lambda T is 4100. Why will I ask such a dumb question? That is only for a black body.

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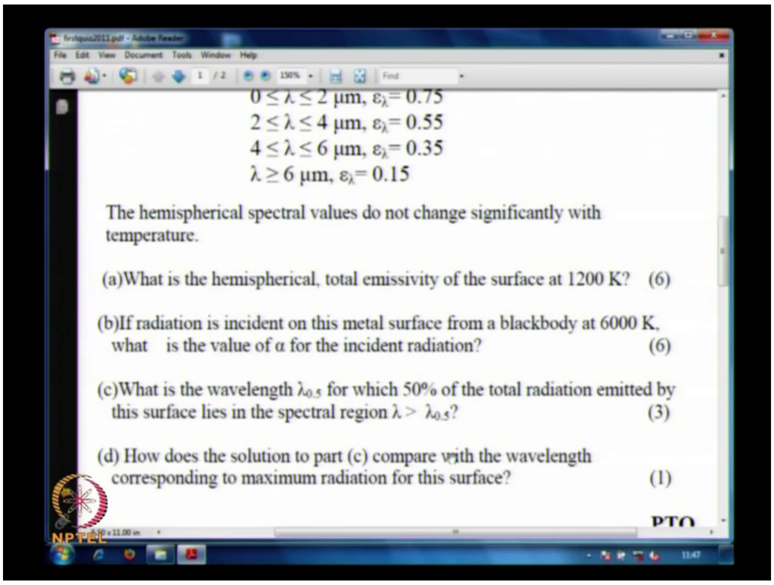

So, this body, there is already an emissivity. Are you getting that point? So, the total radiation emitted by the surface is epsilon sigma T E to the power of four that is 0.64 times sigma T W to the power of four. So, what I asked you was… What is a hemispherical total emissivity and that we have seen is 0.46. For part b, you can calculate that is 0.74. So, what is wavelength lambda 0.5 for which 50 percent of the total radiation lies in this spectral region; that means, what I am asking you is epsilon 1 F of 0 to lambda one T. What is this?

This is the overall epsilon. This is multiplied by the sigma T to the power of four. Here, also it is sigma T to the power of four, therefore, if you divide it becomes F. So, the right side, you will get something like 0.232. The first one epsilon one into this is 0.105 plus 0.55 into Now, corresponding to x, so lambda half t equal to 3468 micro meter. You can see from the table. If F is 0.3761, what should be the lambda T? Just look at the F function chart.

(( )) It is 3.5 micrometer. Therefore, 2.9 (( )) No, no no yeah fine x is point. So, lambda half is 2.89. Is that correct? Now, for people who have completely no idea what I have done, I making an assumption, I making a proposal that it will lie somewhere in between this. Why did I make an assumption that it will lie between two to four, because I know that the temperature is 12000 Kelvin. So, from Wein displacement law, 2898 by 1200 is about 2.5. Therefore, I am making an intelligent guess to start with; I am assuming that

50 percent of the radiation will be somewhere here (Refer Slide Time: 38:51). So, I am trying to see, if I stop somewhere at a particular value of lambda, I can find out what is f of 0 to lambda up to that place.

Now, I have to see what is that value of lambda at which this f of zero to lambda is equal to half of the total radiation, which is emitted by the whole surface? The total radiation emitted by the whole surface is a hemispherical total emissivity epsilon multiplied by sigma T to the power of four, which is epsilon is given by 0.464. I want 50 percent of that. So, I multiply by 0.5. So, 0.5 into emissivity into that sigma T to the power of four, I bring it to the left hand side. So, that left hand side is also instead of sigma t to the power four, it becomes f of zero to lambda t.

So, the first part I know the epsilon 1 0.575 into this and it gives you 0.105. Then epsilon two is 0.55 multiplied by it, it ends at basically four micrometer. I am getting 0.607 minus x and then x equal to 0.3761. Corresponding, to this value of F, I find out what is a lambda into T. So, that lambda into T turns out to be 3468, but I know T is equal to 1200. Therefore, lambda is 2.89 micrometer. If you do not like any of this, now find out what is a total radiation emitted by the body up to 2.89 micro meter. Calculate the emissivity, multiply by sigma T to the power of four. Find out the total radiation emitted by the body, which is emissivity into sigma T to the power of four, you will find that the ratio is half.