Conduction and Radiation
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Lecture No. # 10
Emissivity

So, we will look at how to characterize surfaces, which departs or deviates from blackbody behavior. So yesterday, we looked that some pictorial representation of I b lambda, I b lambda versus lambda and then, this I b lambda, I b lambda versus lambda, I b versus lambda and then, I b versus theta.

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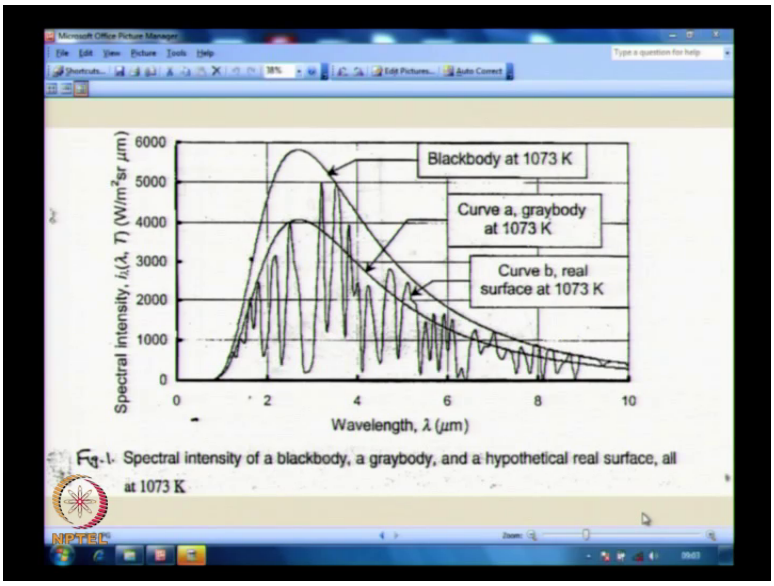

We are looking at this spectral intensity of a blackbody, gray body and hypothetical real surface all at about 800 degree centigrade, which is which is same as 1073 Kelvin. So, the top most curves is a blackbody at 1073. So, that follows the Planck's distribution. Then, there is a hypothetical surface which corresponds to curve A, which is a gray body.

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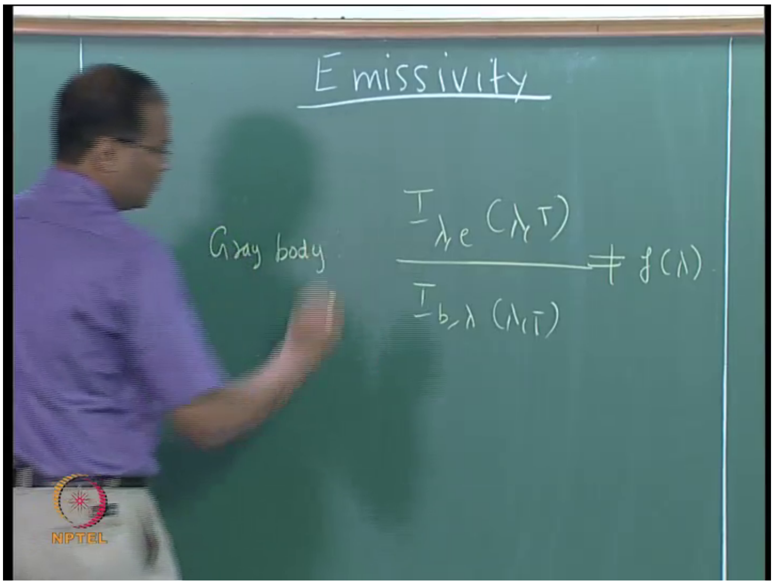

A gray body is 1 in which I lambda e, watch I am using a I lambda e, what is e means? Emission; so, you can also I lambda er, that is I lambda e reflected; I lambda t r, that means I lambda transmitted; I lambda abs, not the abs in the cars, I lambda abs is I lambda absorbed. So, like that we can characterize of course, this fellow is the king this fellow is king denominator, because you will not allowed to numerator to exceed him. Therefore, this fellow is always less than equal to 1. So, this gives you, we are already looking at the dimensionless quantity and I am putting it under the heading of emissivity. So, that the formal definition of emissivity will follow before that we look at some qualitative aspect and then, we formally (( )) we formally and mathematically define emissivity.

The curve b is a real surface, which is a got a zigzag radiation. The curve is jagged that means, it got a very tortuous path. It is very difficult to characterize it, even some of you some of you may take optimization course with me. But it is very difficult to interpolate put a function and all that cure fitting, it is very painful. But the area under the curve, if you take the area under the curve, you can replace it with equalent gray body.

Why did you want to do that gray body is a very powerful engineering approximation, which helps you to analyze very quickly and efficiently. And second, even if you have this variation, we do not have the competence or sometime, we are not aware of the numerical methods to handle this. So, this gray body assumption is widely used in engineering practice. So, this as far as this variation with respect to lambda is concerned. Now, the next thing is we have to see the variation with respect to open with.

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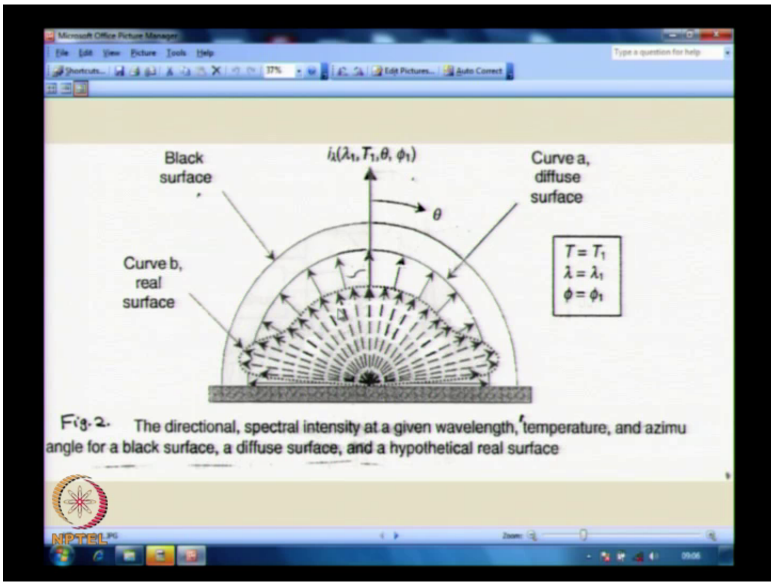

Now, look at figure 2 which gives you the directional spectral intensity, I lambda emission at given wavelength temperature and azimuthally angle for black surface, diffuse surface and hypothetical real surface. There are three surfaces there, so this is the black surface. So, the zenith angle is with respect to the vertical theta.

So, for purposes of drawing this graphs, T is T 1 fixed lambda equal to lambda 1 fixed p is equal to p 1 fixed. So, there are four parameters basically; wavelength, temperature, zenith angle, azimuthal angle. Now, temperature wavelength, azimuthal angle we fixed. We are studying the variation of I lambda with respect to theta only. Now, when we do that, already we said that the blackbody emission is independent of all the angles. So, it must be independent of the zenith angle also.

So, if this is the gives you the magnitude. So, this gives you the magnitude of the I b lambda. So, you will get a semicircle because it going to be the same for all angels point number 1 agreed. Now, next fellow comes who is below him. He is also not this fellow also has a characteristics as as characteristic distribution, in which I lambda is not a function of theta. However, at any theta you will have a value less than that corresponding to the black body, because the blackbody is the king. are you getting the point.

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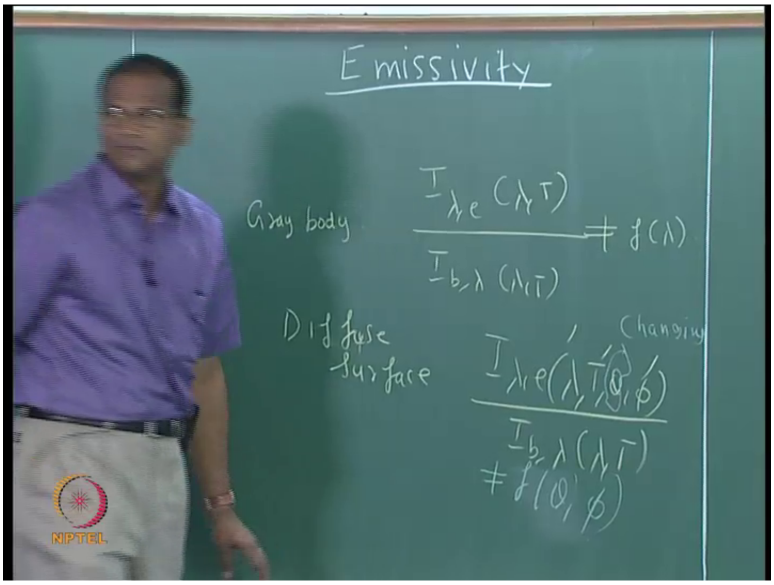

So, this leads us to concept of a diffuse surface. This quiet deep denominator I am not using theta pi. Theta pi it does not matter, I b lambda is independent of theta p, I do not have to use this.

Now, what is the diffuse surface I lambda e, so for that curve for drawing that graph or curve, these fellows are fixed. And this fellow is changing, even though this fellow is changing, denominator is fixed. This ratio is always same, because both are concentric circles there. So, this is not a function of theta.

Now, I can draw a curve, where 1 more curve, where instead of p is fixed, I can put theta is fixed and say that azimuthal angle is varying. Therefore, I should have a general case, where this not a function of theta. Do not ask me, sir you have not shown me. I have to draw another figure 3 with the azimuthal angle, it is under stood similarly, and we can draw 1 more curve. Therefore, now if simultaneously I say; if I say that a body is simultaneously gray and diffuse then, this dimensionless ratio this emissivity whatever it is functional dependence on lambda theta p and all knocked out.

So, this dimensionless ratio is the emissivity becomes the function only of temperature. Then, if I do my engineering analysis, weather you want to do it using your own code and consul or fluent or whatever you say that I am working with the very narrow temperature lane. Therefore, epsilon is not a function of theta then, we can go home peace of mind, that emissivity is not a function of any varies. But so many approximates are involved in reaching that level, reaching to that stage and you must be aware of the assumptions, which are behind it.

Now, why do you use this gray diffuse approximation? It is useful engineering approximation, still many engineering materials confirmed to this gray diffuse behavior and it helps us do the radiative transfer calculations very fast, it also helps us to combined radiation convection and conduction very easily.

Therefore, the gray diffuse approximation is a very useful, potent and frequently used what do I say, approximation in engineering practice of a radiation

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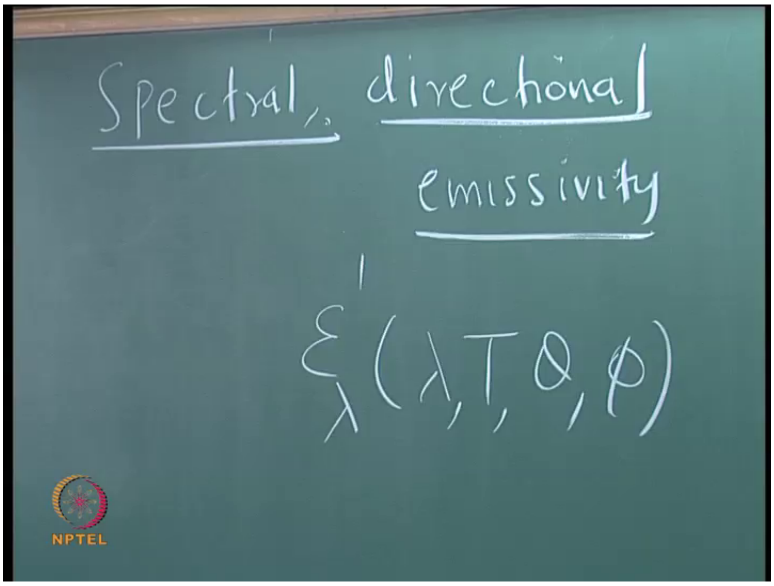

Now, we formally define all these emissivity spectral directional emissivity. The symbol for this is epsilon is the Greek symbol for the emissivity; epsilon lambda means a spectral quantity; epsilon lambda dash means directional quantity. This should be a function of we saw that all the drama and all that should be a function of lambda. So, it is lambda after that lambda T. (( )) So, the directional spectral, so spectral directional emissivity.

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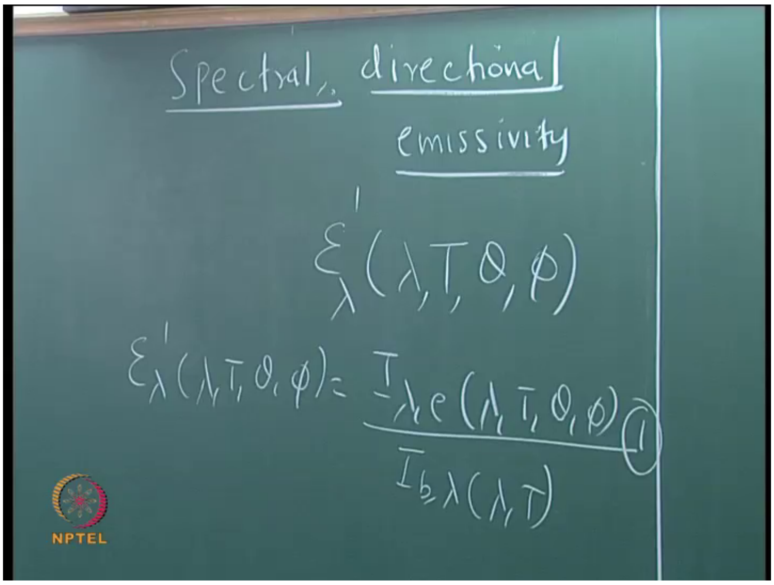

How do we define this spectral directional emissivity or directional spectral emissivity? So, use enquires the equation number carefully. So, the directional spectral emissivity divided by epsilon lambda given by epsilon lambda dash is a ratio of the ratio of the spectral; ratio of the spectral directional; intensity of emission of a real body; of a real surface; divided by the spectral radiation intensity of a blackbody at that wavelength and that temperature in the same direction. So, expectedly or expected epsilon lambda dash is a dimensionless ratio, which varies between 0 and 1.

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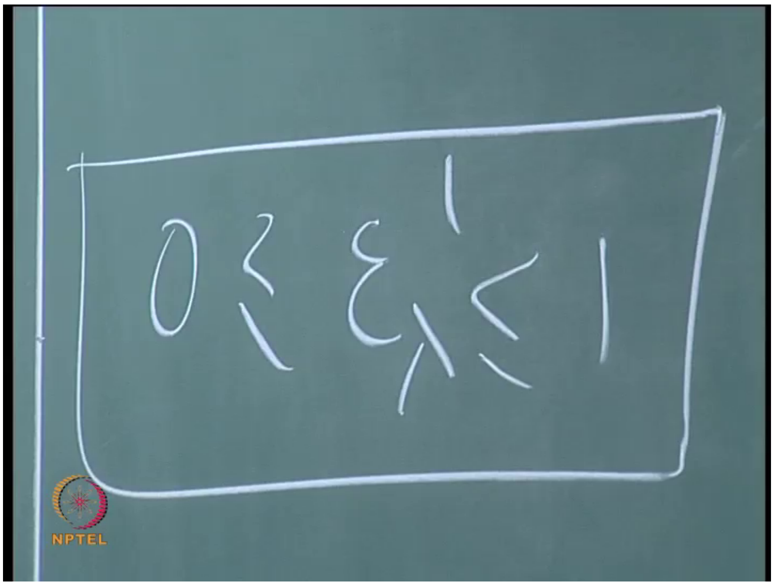

Therefore, so it is like your c g p a out of 10. If you get 10 it is like blackbody, so it varies between 0 and 1. It is give you a non-dimensional way of telling you the efficiency of emission. How efficient it is? So if you say how efficient it is you need a benchmark; you need a datum; you need a standard. What is a standard blackbody? So, corresponding to a blackbody, how efficiently this fellow is emitting. Now, we will have to work out this maths.

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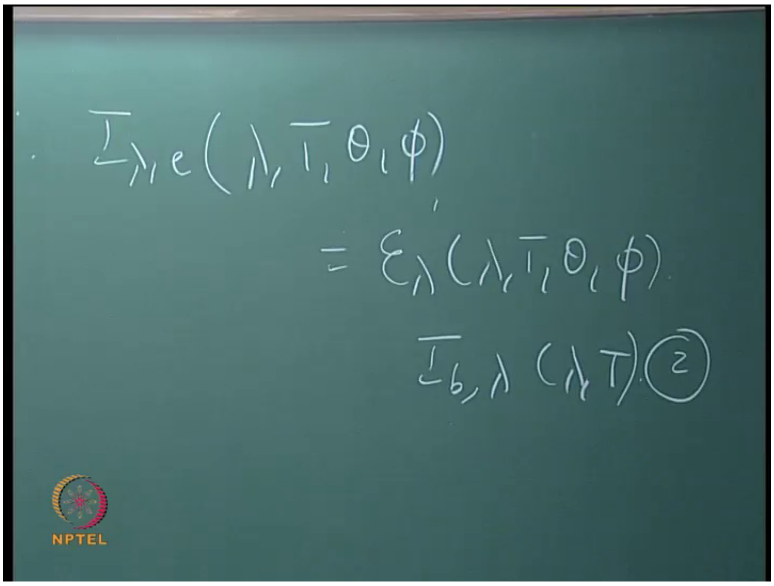

Now therefore, I lambda I am just re-writing. I will call it equation 2 for a given temperature wavelength and the given direction if somebody gives me epsilon lambda dash, either from theory or from experiments, I can use a Planck's distributions and get the I b lambda, multiply epsilon lambda dash by I b lambda and find out what is I lambda e.

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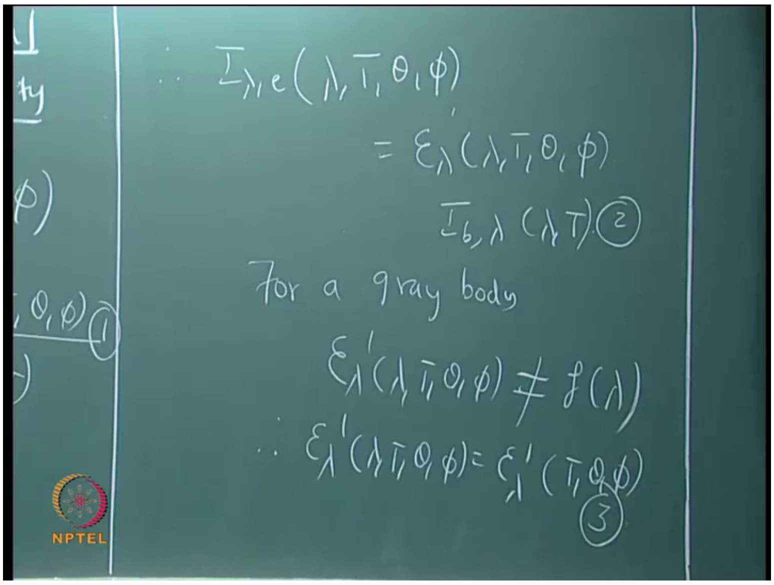

This equation can be used to experimentally determine epsilon lambda dash, if you want to do an experiment. That means, you have a complicated experiment, where you have a real surface, where you have a blackbody all that, so it can be used to determine epsilon lambda dash or more realistically or more practically, if somebody give an epsilon lambda dash equation 2. Let us you calculate I lambda e.

For a gray body, (( )) therefore, so for gray body this epsilon lambda dash is independent of lambda, the fact that epsilon lambda dash the fact that epsilon lambda dash is not a function of lambda, does not change the fact. That it is a spectral quantity. It is still is a spectral quantity. It has a value at every wavelength unfortunately or fortunately that value is same for all the wavelengths. It still has spectral quantity, what do you mean by saying that it is a spectral quantity, that integration with respect to lambda is not done, so it is spectral.

If integration with lambda is not done, it is called as spectral if integration with respect to angle is not done, it is called directional. Even though you removed the function dependent on lambda, I still call it as epsilon lambda dash. So, it is still a spectral quantity.

There could be surfaces, which will which need not exhibit gray body behavior, for all angles. For particular zenith and azimuthal angle it can exhibit gray body behavior. In other angles, it may not exhibit gray body behavior. That, we will have to see that depends on its nature. In your angle of interest, if it is gray body behavior, if it is exhibits gray body behavior, you are fortunate and lucky your analyses become easier. Now, we will have to work on this further.

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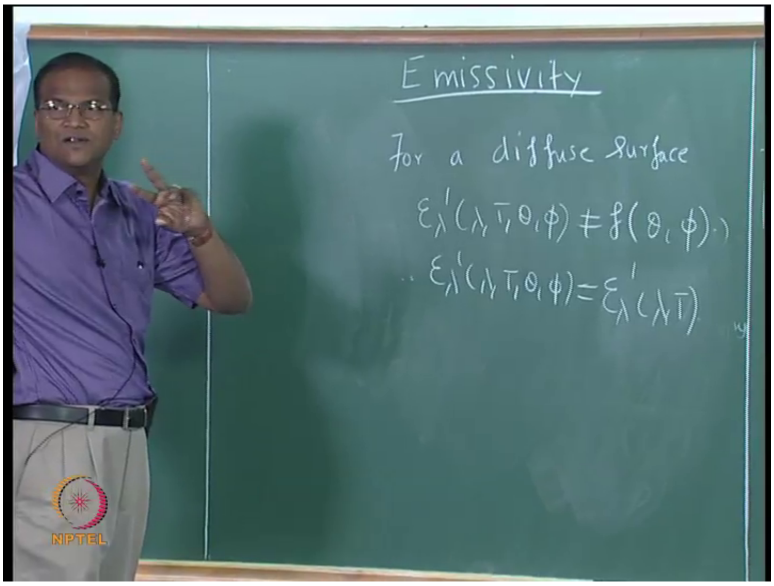

How do we so how does the epsilon lambda dash look like for a diffuse body. You can say for gray body or for a gray surface is not a function of (( )) theta phi. Therefore, now diffuse is the with respect to angle and gray is with respect to lambda. So, for a gray diffuse body for a gray diffuse surface is a function of (( )) only.

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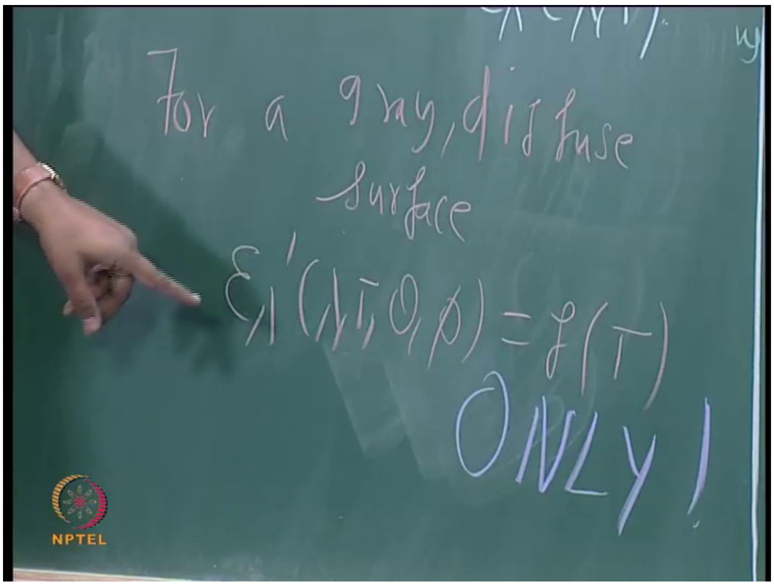

Very powerful approximation pain is considerably reduced. So, if you just go to your data book or somewhere or if you have some reference, if somebody tells you aluminum oxide paint, black pain, black board paint, wood. Emissivity has a function of temperature and somebody says confirmed it is gray diffuse, you do not have to worry, how it is varies with respect to lambda, how it is varies with respect to theta.

So, I retreat the points why do we want to do this approximation, because many surfaces exhibit this number 1 number 2. Even though we have sophisticated database available people many competent people are not there or people are competent they are not willing to do this analysis and radiative already making somebody, some students are working radiation it is difficult. Then, you say that epsilon lambda, alpha lambda, row lambda all these are functions of theta and this thing then, you have to quadrature in all the angels. You should have a quadrature or a multi- integration with respect to theta integration, respect to phi and all these becomes very painful becomes very challenging.

So, very few so radiation is a craft; radiation is not even a science. Radiation is a craft followed by very few, very few people in the world. Many of them from the Russia or Poland and those kinds of places US, some professors are there, j jack Howell Siegel have you seen the book radiative heat transfer Siegel and Howell. It is 1 of the references listed u T Austin, professor j r Howell. He is also editor for the general heat transfer. So, India with there are 3 or 4 people professor s p venkateshan, me and professor subhash mishra from IT guwahati 3 4 people who can we cannot say that, we are experts, but we are trying to do some we are trying to do some work some radiation gas radiation, I work on atmospheric radiation and all that. So, not that problems are not there enough is such problems are there, but people are interested in other things.

So finally, for a diffuse gray surface epsilon lambda dash is a function of T only. But now, there are surfaces where this gray diffuse approximation is not valid, so from epsilon lambda dash, we have to finally, go to we have to get rid of the lambda and get rid of that dash. If we have to get rid of the dash, we have to do integration with respect to theta and phi. You want to get rid of the lambda that is epsilon lambda you have to do integration with respect to lambda. So, if you want to finally, get the overall emissivity epsilon, which we are used in a basic heat transfer course.

Me 317 in IIT madras or in other courses or you have used from a data book that epsilon is getting that epsilon is a long story. So, many integrations have been done. So, you will have to do the integration with respect to lambda, as well as with respect to theta and phi. So, first integration with respect to theta I am leaving it. Then, first integrating with lambda I am leaving it. Then integrating with respect to lambda and theta and getting the overall. All the 3 definitions, we will see and that complete on our discursion with basic properties, I mean emissivity.

In tomorrow's class we will use this derivations, which will go through and today's class I will work out some problems. Where epsilon is a function of lambda, epsilon is a function of lambda for many surfaces for example; epsilon should be different from alpha for which kind of surface. Suppose, alpha is called the absorptivity alpha s is called the solar absorptivity. So, if you are interested in solar collector, the alpha should be very high or low you want high absorptivity, but it alpha s means alpha corresponding to sun's temperature 5 thousand 800 Kelvin. Alpha corresponding that, but the body will get heated; its temperature will be seventy or eighty degrees. It is body will be about hundred degree centigrade. So, when it emits it will emits according to Wien's displacement law. It will emit in which portion of the spectrum (( )) 2 8 9 8 divided by 300 Kelvin or 400 Kelvin or will be 8 or 10 micrometer.

So, the emissivity corresponding to infrared must be low the absorptivity, corresponding to the solar incoming radiation must be high. So, if you are e that is alpha is high; epsilon is low, then it will start collecting. It will become like a greenhouse, but whereas you want exactly the opposite. If you want to design system, where you have to cut out the radiation, you want to inside to be cool and so on. Sometimes, you will put sun control films, you want to cut out, you want to or you want to use double pin glass, which is used in aircraft shatabdhi, rajadhani and all those screens.

So, depending on the application you can play with alpha and epsilon, which are functions of lambda. So, these are called selective emitters; selective absorbers. Unless, you are a stud in the spectral and directional properties and epsilon row alpha, you cannot be a good designer. You need to know this information, I cannot put some sheet and you should know, what is the corresponding to which portion of the spectrum and all that, so are you getting there is formalism involved. You have to fundals are there you have to know the fundals.

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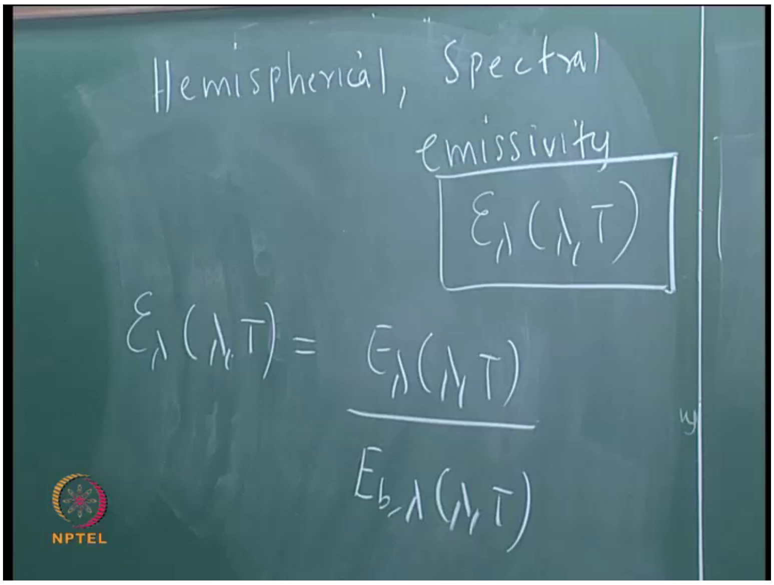

Now, first fellow is over now we will start integrating 1 by 1 hemispherical spectral emissivity. So, the hemispherical spectral emissivity is given by or we can do like this also is that spectral directional.

This is a surface, this at a particular temperature, you have to try out. You are trying to find out, what is radiation emission from this surface over hemispherical basket. If you want to do hemispherical basket, you have to do integration with respect to theta and phi. But over the hemispherical baskets, what is overall radiation at each and every wavelength over a hemisphere. That is why, I knocked off theta and phi in both the anyway denominator does not matter. I knocked off theta and phi in the numerator because I already done the integration.

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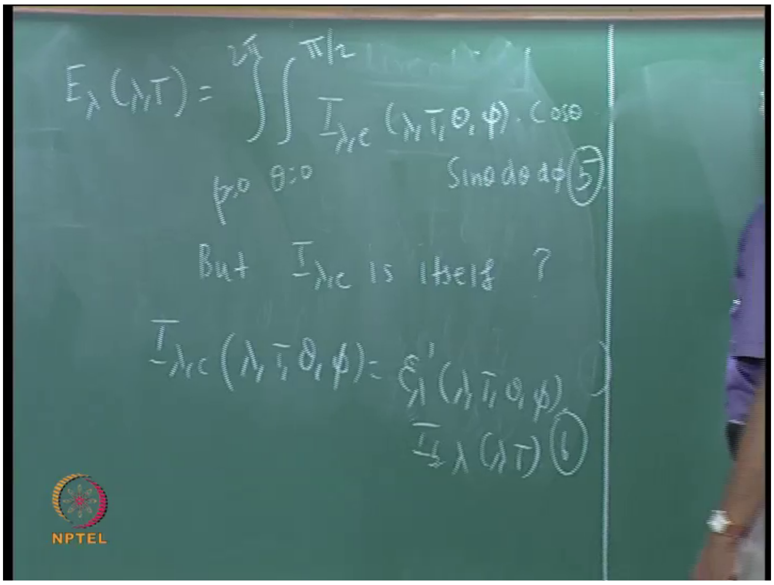

Now, what is the how do you what is the number for this? 4. How do you calculate the numerator? (( )) integration theta equal to 0 to (( )) phi equal to 0 to (( )) I lambda e cos theta sine theta D theta D 5. That, cos theta will come I lambda into cos theta number 5, but what is I lambda e itself, what is I lambda e itself from the direct from the definition of the spectral directional emissivity. But I lambda e itself what (( )) into Ib lambda.

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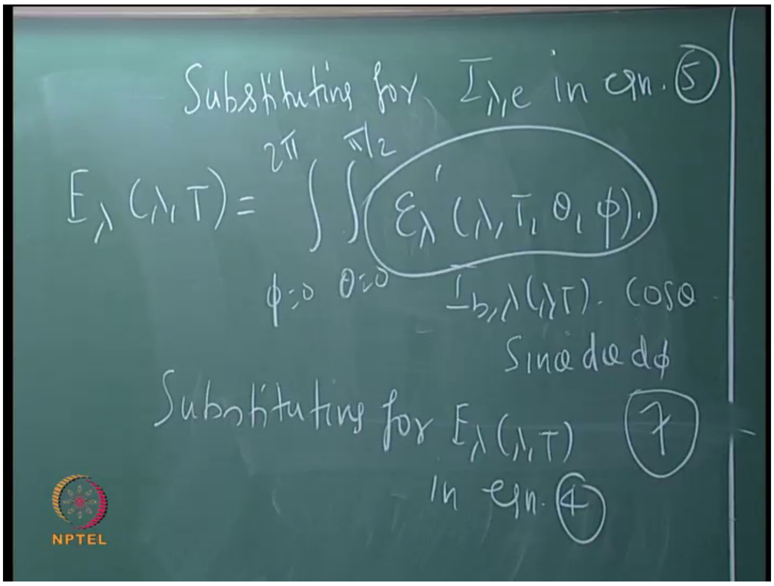

Now, we can substitute I lambda e in the equation 5, substituting for what is it I lambda e, what you get divided by what no but I am already able to see some silver thing I know

I b lambda is not a function of theta and phi, where still some manipulations possible, but before that look at the board is it clear up to this stage before that, what I will do is I can substitute for e lambda in original definitions of epsilon lambda.

You may just get the feeling, that I am going like this, but very simple my ultimate goal is I want to get this from this, if somebody gives me alpha epsilon lambda dash. How will I get epsilon lambda. So, I am using all the formulism involved. So, I am not going in circus. Actually for the first time, you may feel that it is confusing, but actually there is a there is a logic involved in this.

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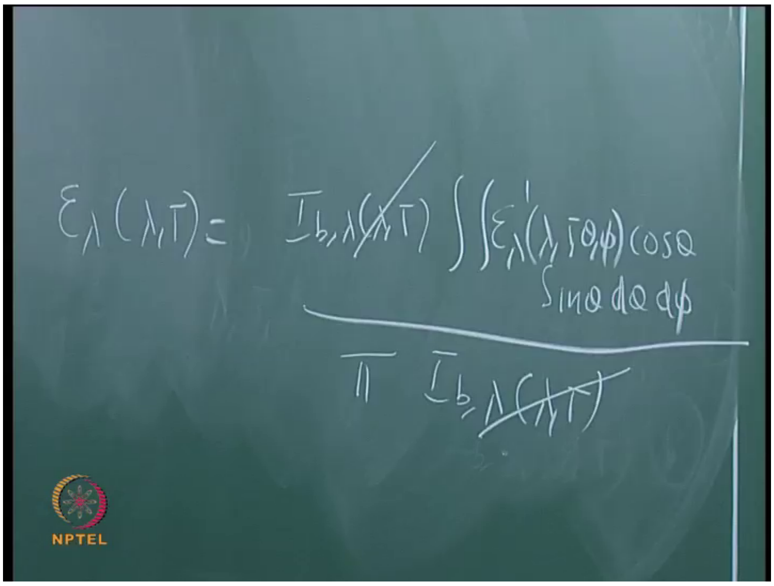

Now, substituting for e lambda in equation 4, we can do this. Shall I pull out the I b lambda, I can do that you have to do all this I. I will do that, what is the relationship between E b lambda and I b lambda (( )) can I cancel I b lambda from the numerator and the denominator.

What is the fundal? In this you tell me, epsilon lambda dash I will tell you epsilon lambda who will tell me epsilon lambda that is some physicists may gave me some people, who are otherwise jobless may do experiments; they will give me epsilon lambda dash so I will use it and solve my engineering problems.

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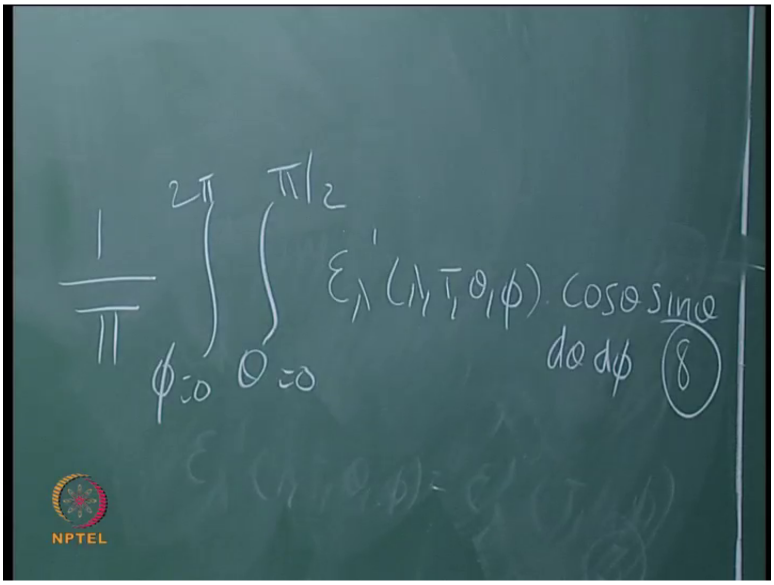

Now, let us clean this up and give a nice expression for this. So, this is equal to 1 by pi, that 1 by pi comes into 2 phi epsilon, what is the equation number 8. So, 8 is a powerful expression, which relates as spectral directional quantity to a spectral hemispherical quantity, what is that hemispherical? We did hemispherical integration, because I used theta equal to 0 to pi by 2. I did not used theta equal to minus pi by 2 to plus pi by 2.

So, it is hemispherical integration, because you are looking at radiation from the surface. This is point number 1, point number 2. Equation 8 is generic enough equation 8 is generic enough in that, it can be applied to transitivity, reflectivity, absorptivity and so all that so later on when we are going through absorptivity, reflectivity. I will quickly do this, we do not have to do this integration again, this 1 by pi into double integral is generic is generic

Now, so if you give me epsilon lambda dash either in the form of table or graph or whatever I can do the integration and get epsilon lambda from epsilon lambda, I have to do 1 more integration. I will get epsilon that is it then, epsilon sigma T to the power of 4 that is, it I can use Stefan Boltzmann's law. So, we are going through various intermediates stages. It will be curious to find out, what happens to the case of diffuse body for the case of a diffuse body.

What can happens to what can happen to epsilon lambda dash; what can we do with epsilon lambda dash; It can be pulled out from the integral sign then, this cos theta, sine theta, D theta, D 5 is basically integral D omega mo (( )) pi. So, that becomes so epsilon lambda just equal to epsilon lambda dash. So, it is consistent with or understanding it is consistent with formula, which we furiosticly or which we proposed before we formally define the epsilon lambda dash.

Furiosticly is not the word, you want another word not empirically intuitively, which you intuitively, which you intuitively what did you say (( )) which you axiomatically or intuitively proposed.

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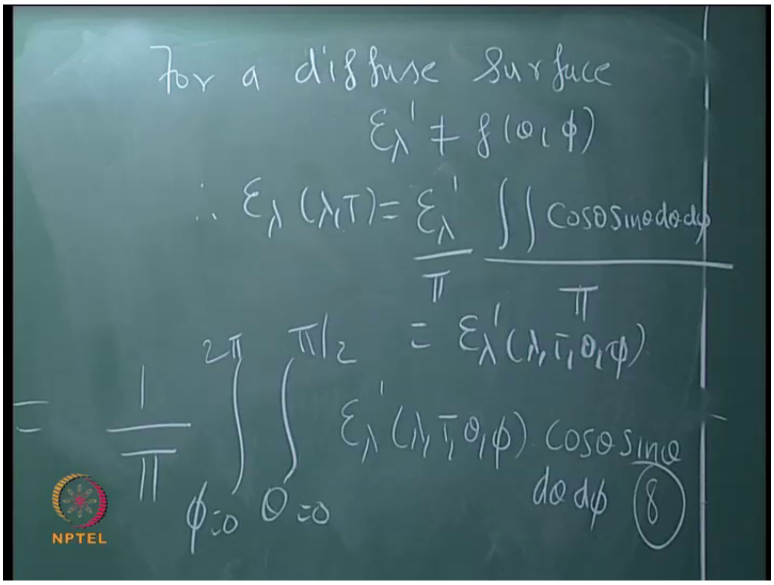

Now we will say now, we will write the story. no So, this consistent with your understanding. The two more things, which are required 1 is you integrate with respect to lambda, that is lambda equal to 0 to infinity and stay with the angle. That is called the directional total emissivity. Then, you combined these two and do all the integrations; you will get the hemispherical total emissivity. We will do those two derivations today and tomorrow's class is result for problems. I will give you epsilon lambda versus lambda and ask you to, bring your f function chart, to all the classes. Without f function chart you cannot solve problems for non-gray surfaces.

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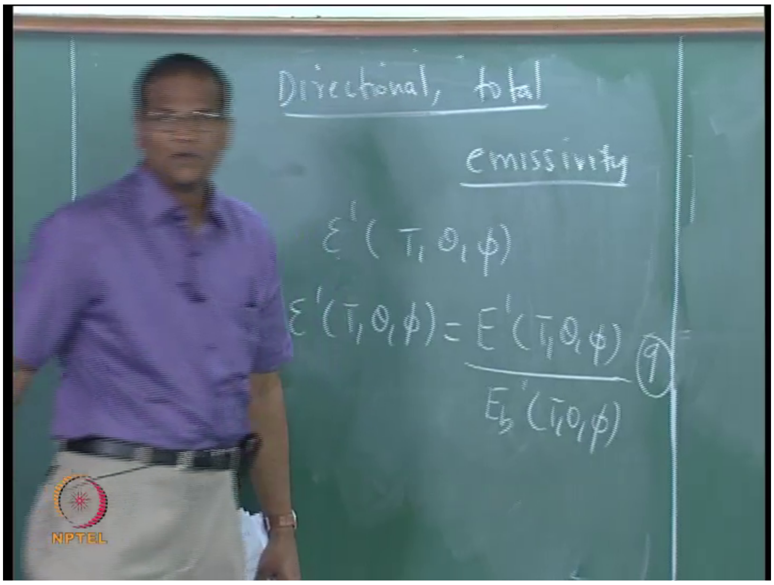

So, now directional total emissivity, what you want to call this epsilon dash? Is that so, epsilon dash the dash remains the prime denotes that it still directional quantity. This lambda, we got rid of the lambda that is, that total means integration with respect to lambda hemispherical means, integration with respect to angle. Now, e dash of E b dash it does not matter. E b dash is not a function of dash, it will be a will do that this thing there is a small the small concept involved.

What is equation number (( )) 9. So, the E b the E b dash at the particular angle is related to the I b dash at a particular angle I b multiplied by (( )) pi will come only if you integrate with respect to what is the relation between e and pi. I must be multiplied by (( )) must be multiplied by cos theta. That is only we integrate cos theta, sine theta. We will get that pi.

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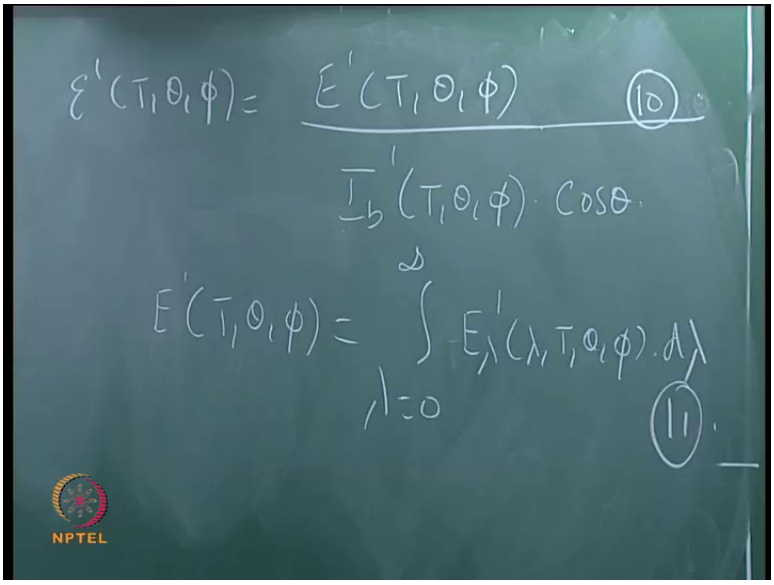

Therefore, epsilon dash will be equal to I should knock off the I can knock off the theta dependents in a short. While now, what is e dash itself 10 lambda equal to 0 to infinity e lambda dash D lambda is that correct all.

What am I trying to do the approach, I am following consistently is like this I formally introduce, I formally introduce a definitions of a particular emissivity denominator is black body. I do not work with denominator is fixed, I keep on manipulating the numerator, how do I do? There is two ways, which I can do now this E b dash, I am writing it as I b dash into cos theta. So, equation 10 is just slightly different version of 9, where the e changes to I now in order to get that epsilon dash. I have to link this epsilon dash to epsilon lambda dash, because I know epsilon lambda dash from epsilon lambda dash, I have to get epsilon dash.

So, side I have to bring epsilon lambda dash. So, I have to approach it in such a way that I will make use of a epsilon lambda dash that is, the directional spectral emissivity denominator is I b. I do not; I cannot do much with the denominator numerator. I can work with this, what is this numerator? There was a lambda after integration the lambda vanished. Therefore, I am just writing out this expression for this e dash. In terms of e lambda dash, this e lambda dash can be written in terms of epsilon lambda dash that is all so.

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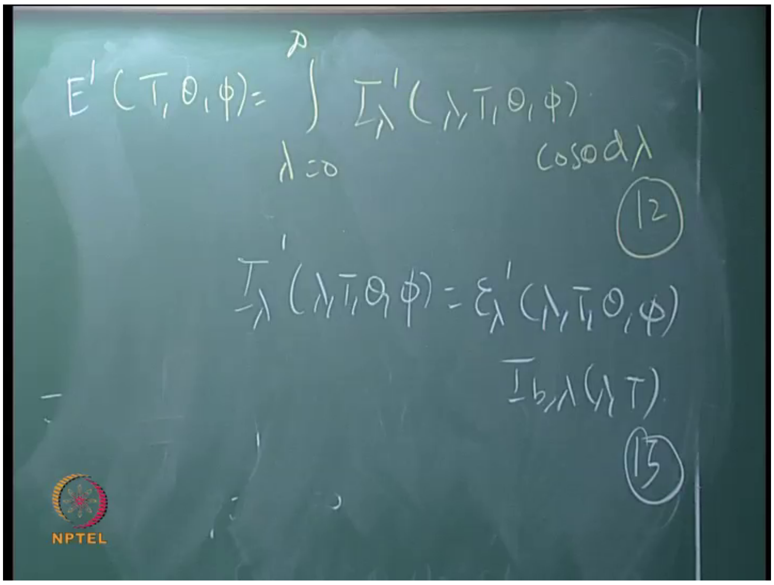

Now, you substitute everything you will get the expression. Now, we do this carefully, what is a relationship between e lambda dash and I lambda dash (( )) cos theta. So, 12 but what is I lambda dash itself, is that correct is that correct 13.

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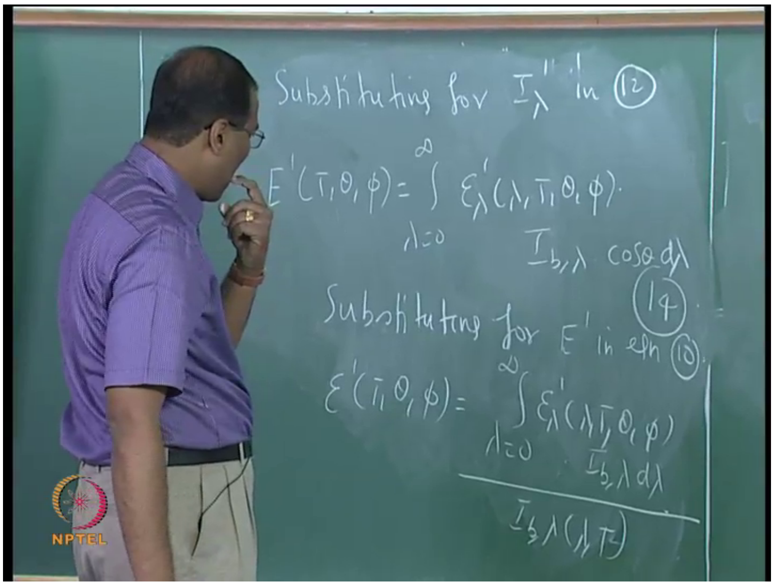

Now, substituting for I lambda dash in 12 is equal to lambda equal to 0 to infinity epsilon lambda dash, I b lambda do not forget the cos theta. Now, I can substitute for capital e dash in my original definition, for epsilon dash that is not equation 9, but equation (( )) say confidently. I can substitute in equation 10.

So, substituting for e dash in equation 10, so can I pull out the cos theta from the integral (( )) is that a cos theta in both the numerator and denominator (( )) can we get rid of that cos theta. So, everybody agrees we pull out cos theta. Now, this will be nothing, but into divided by (( )) dash.

That is fine (( )) for which 1 (( )) why it already done is it (( )) where is a denominator (( )) done. So, what is I b of T what is Ib of T (( )) what is Eb of T (( )) sigma into (( )) T power 4 what is the relationship between e and i.

Student: (( ))

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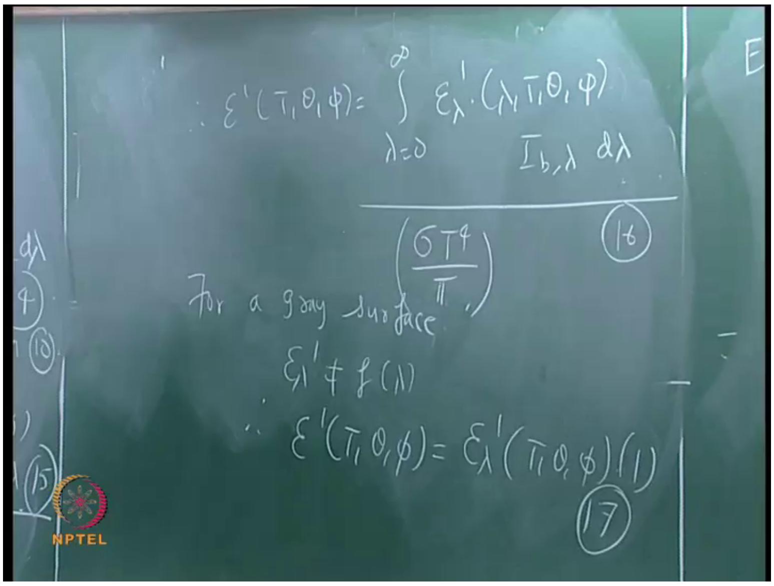

Therefore, I b equal to (( )) sigma T to the power of 4 by pi divided by that is it, I hope it is and whether it is or we made any mistakes.

Now, the acid test is what happens if it is a gray surface (( )) if for a gray surface, so what is integral lambda is equal to 0 to infinity Ib lambda sigma T to the power of 4 by pi. So, it will be into 1.

Therefore, the formulae we derived for the hemispherical directional emissivity and as well as for the directional total emissivity, when reduced to the special case of a gray and diffuse body respectively or a diffuse and gray body respectively, reduce to the cases for which we are able to intuitively, guess the values of epsilon lambda dash. Therefore, the expressions must be correct.

Therefore, these two expressions which we derived in today's class can be used to relate the fundamental emissivity of epsilon lambda dash to that quantity, which is the emissivity integrated, once either with respect to angle or with respect to wave length in tomorrow's class. First ten minutes we will do the both the integration. Therefore, it will just be a triple integral; therefore, you will if you do the triple integral, the dash also will go and the lambda also will go; the dash involves double integral because theta and phi the lambda involves, one integral lambda is equal to 0 to infinity. So, if once all the three integrations are done, the triple integral is done, you get simply the emissivity.

The emissivity which we use in all the courses before have come from this route epsilon lambda dash is the origin of all these, that can be obtained from theory or that can also be obtained from basic experimental e transfer. is that clear This is the way to learn radiation, there is a formalism involved, it is on data book. If somebody gives you emissivity and you just put epsilon sigma T to the power of 4 and find out so many watts per meter square. So, we will stop with this. So, it is imperative, that if go through the notes and tell me if there any Google's, I mean bungling anything and I missed out some cos theta or sine theta something check and then tomorrow's class, we will complete the other integration and we will work out problems.

Once you work out problems, it will re-enforce all the concepts which we have studied. So, as we can see lambda is equal to 0 to infinity and all that is coming. So, I can have epsilon lambda different values for different lambda bands. for different lambda bands If you want to calculate the fraction, how we will do that? You would use the f functions chart; So, please bring f function chart and calculator tomorrow's class tomorrow 8 to 9 we will work out two good problems.

Thank you.