Conduction and Radiation

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Lecture No. # 13
Kirchhoff Law, Absorptivity

So, we had an exhaustive discussion on emissivity, and the first and foremost of the radioactive surface properties, which characterises the efficiency with which surface emits, as oppose to a blackbody; blackbody is the benchmark, there is no blackbody, I mean, but there are bodies which come close to blackbody. But any real body will have an emission less than that. So, the ratio of the emission divided by the emission of the blackbody is the emissivity. There is a grammar or nomenclature associated with this directional spectral, directional total hemispherical, spectral hemispherical total, we did all that; we did, we how to convert directional to total, how to convert spectral to, no directional to hemispherical and spectral to total, and and starting from directional spectral to hemispherical total, we have seen.

Now, the next important property is absorptivity; because, often times, we are interested also in the absorption, it is not only the emission that we are interested in; for example, if your application is solar collector, suppose, you want intercept the solar radiation, you want to have a surface which absorbs lot of radiation in the visible part of the spectrum; once it absorbs from room temperature of 30 degree centigrade, if the temperature of the surface goes up to 80 or 90 degree centigrade which is about 363 or 373 Kelvin, from the Wien's displacement law, lambda max T is about 3000 micrometre Kelvin. So, if T is about 400 kelvin, this lambda max will be around nine micrometre.

So, the body which is heated by the incoming solar radiation which is at a temperature of 80 to 100 degree centigrade will emit in the infrared part of the spectrum. Now, if I have a surface which emits very poorly in the infrared part of the spectrum, but absorbs very well in the visible part of the spectrum, I have a good solar collector.

By the same token, if I have a surface which absorbs very poorly in the visible part of the spectrum, but emits very well, but emits very well in the, in the visible in the infrared part of the spectrum, it may be a candidate for an insulation; for example, the sun control film which is put on your on the vehicles, cars, it it cuts out the transmissivity, is very poor, the amount of solar radiation which comes in is very poor; from inside, you can see outside, from outside, you cannot see inside. So, we have been, you have seen ads of saint goblin and all that, right? Somebody pours water and this is very famous. So, we will actually see problems, how the sun control film work, how, how efficient it is, is the information which is given about this surfaces really true or whatever.

So, first we have to. So, we have to discuss about the story of radiation incident upon a surface, what can happen to that radiation? So, we have to start with that discussion and it logically leads to properties, then again, as usually, we will have integral, integrate or solid angle, integrate or this thing, and will a spectral, directional, total hemispherical, all this properties; then once you are through, now, since the brought framework is already provided, because I told you the brought framework in the context of emissivity, we use similar framework for absorptivity, reflectivity and so on; we can quickly go through this exercise. So, that we can concentrate more on some practical problems now.

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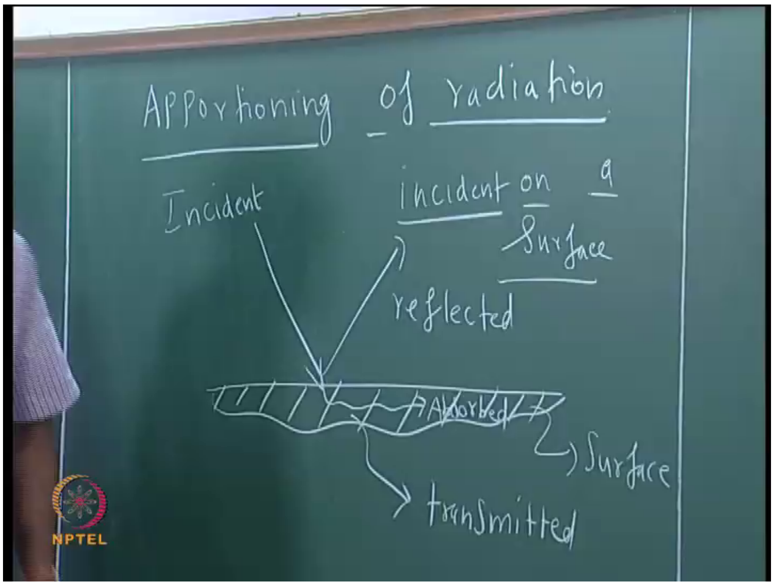

Look at apportioning of radiation incident on a surface. Let us consider a surface, radiation is incident of the surface, I will say incident; that means, this incident radiation watts per meter square; is the configuration clear? So, what all can happen to this incident radiation? What all can happen to this incident radiation?

Student: (( )).

It can, it can absorb, that mean; we will track the story later if it absorbs this, internal energy will increases, temperature will increase and how its temperature is maintained constant, then I will send the coolant and all that, that is not the story now; it can absorb, that is not the only thing it can do, and it can reflect, or if it is a glass, or a transparent, or semi-transparent medium, it will allow something to go through.

So, if we apply the first law of thermodynamics to this system, if we apply the first law of thermodynamics to this surface, do not worry about emission and all this, we are tracking what is happening to the incident; then from the first law of right? From the first law of thermodynamic, mathematically, we can state that the incident radiation must be equal to.

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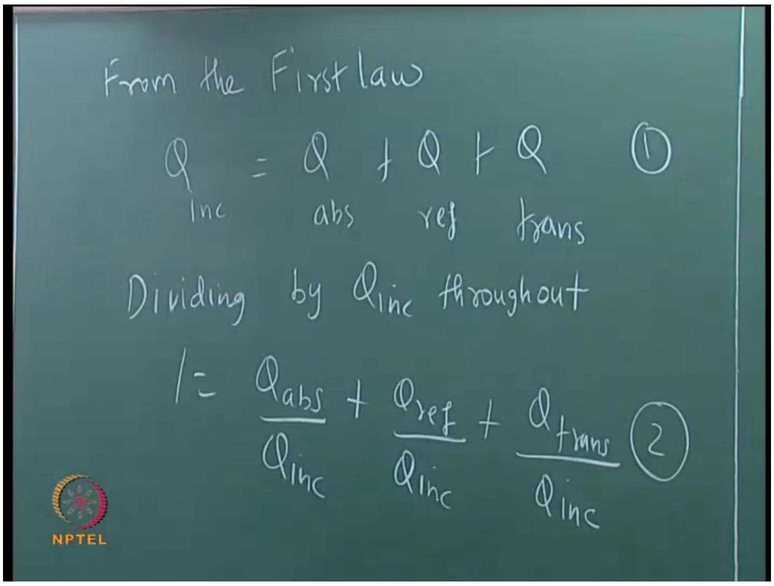

From the first law, Q incident equal to Q absorb; a b is absorbed, r e f is reflected, t r a n s is transmitted. So, dividing by sine I can divide by… So, right side, the three terms are all dimensionless ratios, none of which can be greater than the Q incident, the sum of all these can be one, individually, nothing can be more than one. So, they are they are all, they are also some measure, they are also measures of the efficiency with which the surface absorbs, the efficiency with which it reflects, the efficiency with which it transmit. So, Q absorb by Q incident is called the absorptivity, called alpha, Q reflected is called the reflectivity rho, this called the transmissivity tau.

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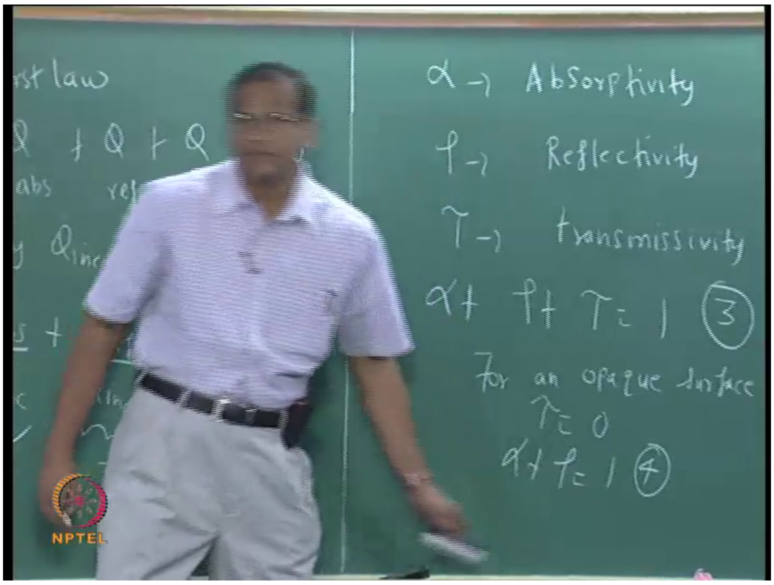

So, of course, we are talking about hemispherical total quantities, I am now, I am already the integrations have done with the respective angle and the wavelength; this is just introduced new to the concept, we will go through this individual absorptivities and reflectivities, as we proceed with this lecture, right? So, the important story is alpha plus rho plus tau equal to 1.

What is tau for an opaque surface, like the human being, or the wooden surface or whatever? Transmissivity of an opaque surface.

Student: (( )).

He is n d t. So, he will say something. I thought visibly opaque. No, no, truth (( )).

Student: (( ))

Visibly opaque is, throughout its opaque man, full part of the spectrum, fine. So, for an opaque surface, but if we pass x-rays, x-rays come out of us? How much? Now,

Student: (( ))

How much?

Student: (( )).

Ah.

Student: (( )).

I do not think so.

But we are able to take the picture of the bones everything, right? Yeah, but after that it does it comes out, but that is a, we are not talking about, that is of interest to the high energy physicist, that is a very special case; we cannot use that case to argue or general argument, correct? Then only we can say wood is opaque. So, but students are not opaque then. So, for an opaque surface tau equal to… Therefore,

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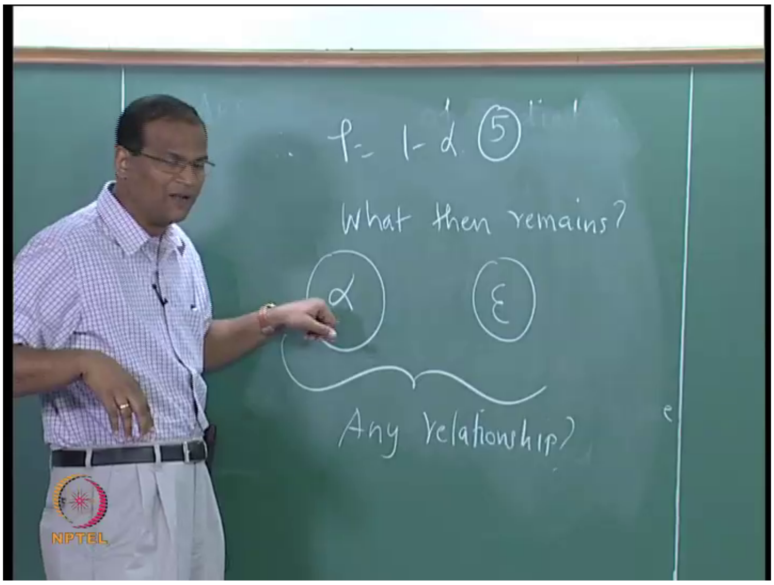

So, what then remains? What is the logic behind all this? We did some energy balance, we introduced some quantities and all that is fine, but now, I have four animals to deal with, emissivity, reflectivity, absorptivity, and transmissivity. I killed one of them and said it is opaque surface, I made him 0, tau. Now, I have three, but now I am, I am trying to see if further simplifications are possible, now, suppose emissivity is known, I am able to write alpha in terms of rho; now what then remains; alpha and emissivity, any relationship? Why you are already making the, you are telling the climax then, who said alpha is equal to emissivity? But that is also only for a special case, any relationship? So, the best minds not only worked on finding out the correct blackbody distributions, when they are looking at the properties of the surfaces, they were also preoccupied with the idea of whether the emission and the absorption or the emissivity and absorptivity are related to each other, why? It is for convenience. Suppose, I am able to establish a relationship between alpha and emissivity, then if I measure emissivity, then if I know this relationship, right now we do not say that is equal or not equal, whatever; suppose from emissivity, if I am able to get the alpha, from alpha I can get the rho and for the opaque surface, I know tau is knocked off; therefore, we just in knowledge of emissivity, I have all the properties required for carrying out my radioactive transfer analysis; of course, other things are there, that is, what the geometric orientation between the surfaces, how to put it set it up as a system of equations and solution of equation, that comes later; but fundamentally, two important hurdles have to be crossed; first is the fundamental radiation loss, which we have already seen; the Planck distribution for the spectral and Stefan-Boltzmann's law for the integrated, you have crossed that.

Now, we are going through the second most important hurdle, which is the property. Once, you characterise the surface, you also know the blackbody behaviour, then the geometric orientation, how heat surface looks at the other surface, if you are able to figure out that, then it is just the system of equations then you solve, is it okay? Now, why do you think that should be a relationship between this and this? Can such a relationship come from a theory? That is a blackbody, but now we are talking about the real surface. Thermal equilibrium is different. Since, the physical mechanism of absorption emission are different, we do not expect any logical relationship between emissivity and absorptivity to to flow from theory.

So, the relationship must come from experiment; fortunately, people have done experiments, and then, they have founded some relationship. Before we going to all this, first, we propose, we look at what is called the Kirchhoff's law; have you already studied this?

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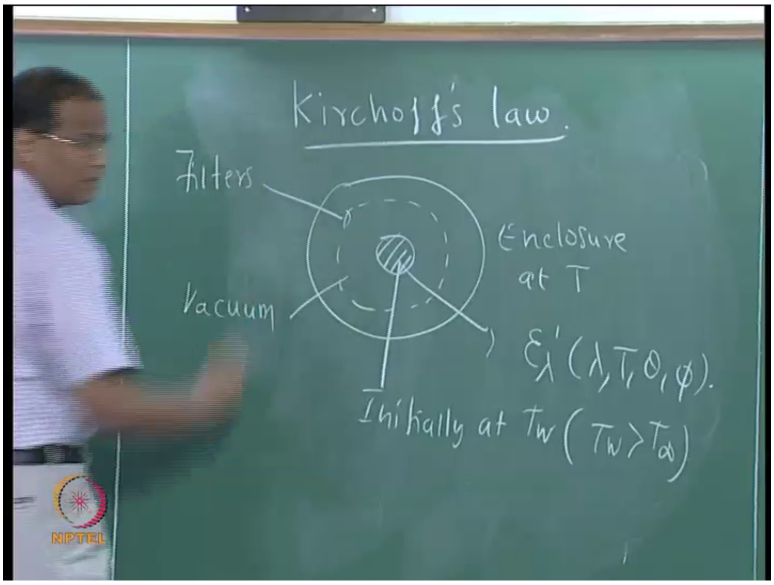

So, consider an enclosure, you consider an enclosure at a temperature T. So, inside your vacuum; now, you have a body; now, you have a body, initially at; now for a change, I do not have a blackbody, I have a black, I have a body whose spectral directional emissivity is given by alpha lambda dash, I have a real body. So, this emissivity is given by… So, what the second law of thermodynamics tell you? If T w is different from T infinity T, and T w is greater than T infinity, what will happen is, because there is vacuum, there is no conduction, and there is no convection, there is only radiation which will take place; eventually, this body will also reach the temperature, this body will also reach the temperature of T. Is it okay? Now, what is the story?

Student: (( )).

There is a body which has emissivity of epsilon lambda dash; it is in enclosure. Now the story is, I put some filters, the filters are basically band pass filters, the filters will allow radiation only in a narrow wavelength interval d lambda to path, to cross the boundary; and now, I can have as many filters as possible in as many wavelength intervals as possible. Suppose, I have one filter in a particular wavelength interval, let us say between 3.6 micrometre to 3.7 micrometre only, it allows the radiation from the body in the at the centre to reach the wall, what will happen? The radiation which goes out of the, radiation which goes out of the body in the centre which reaches the wall can only be the radiation which, which is in this wavelength; because the any other wavelength will be reflected by the filter and it will be eventually reabsorbed by the body; and since, the body is in equilibrium, since the body is in equilibrium, it must absorb exactly the same as same, it must absorb exactly the same as much as it emits, so that, it remains at a temperature of t; but since the body is allowed to emit only in the wavelength interval d lambda with the band pass filter allows, it can also absorb only in the same way wavelength interval d lambda; and this d lambda is under my control, I can change d lambda from 3.5 into 3.6 or 8.9 to 8.1, 8.9 to 8.6 or 8. to 8.9, whatever I want. Therefore, under these conditions, since the body is both emitting and absorbing only in a particular wavelength interval, I can also choose the direction, right? I can also make the filter in such a way that it will permit only in one such one, one direction; but we are taking recourse to the second law of thermodynamics, which, which forbids the body from being at a temperature, which is different from that of surroundings because eventually, equilibrium, equilibrium will be established.

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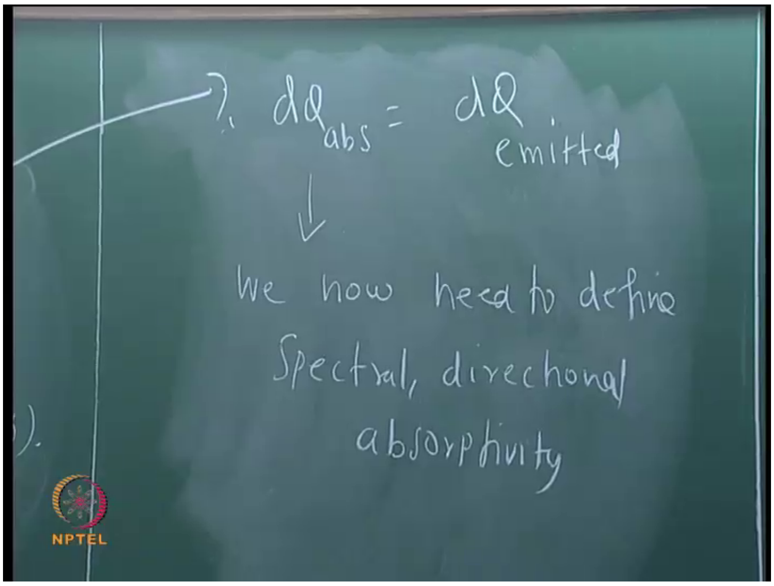

Therefore, therefore, therefore, what happens? Epsilon lambda dash, let us say therefore, d Q absorbed must be equal to d Q emitted, is it clear? d Q absorbed is equal to d Q emitted.

Now, there is a small problem in the sequence of the story; right side, you can evaluate, epsilon lambda dash I b lambda cos theta d theta sin theta d theta d five d lambda, all that you can, but d Q absorbed, in order to do d Q absorb, we now need to define spectral directional, we now need to define spectral directional absorptivity. So, so we have to hold on to this. So, let us revisit this, after we have defined this.

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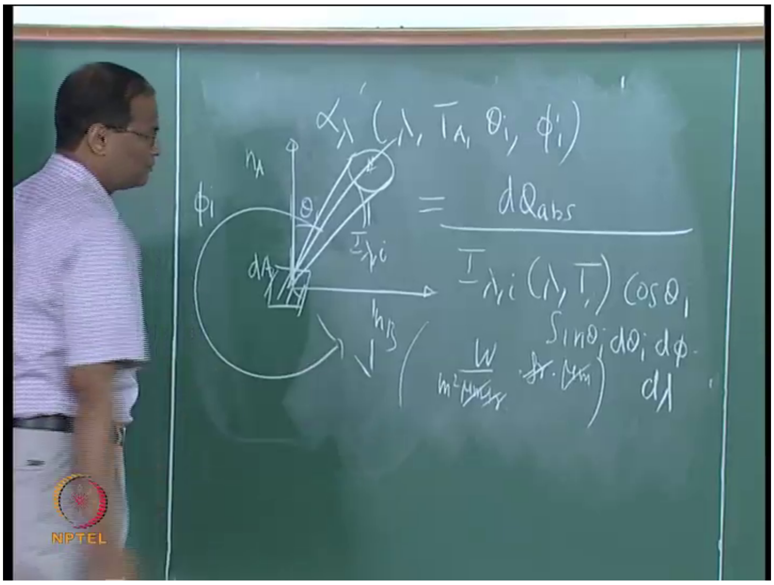

So, how do you define spectral directional absorptivity, can you tell me? From d Q absorbed; alpha lambda dash, lambda temperature of the absorbing surface, theta I phi I will be equal to d Q absorbed divided by, not blackbody divided by, how much, how much is absorbed divided by how much is incident, incident is I lambda I multiplied by all those things, can you tell me I lambda I, lambda, lambda T multiplied by cos theta I sin theta I d theta I d phi d lambda. What are the units of the numerator and the denominator? Denominator what are the units? watts per meter square per micro medium, watts per meter square per micrometre plus steradian, sin theta d theta d phi is what it is? Steradian, d lambda is what? If you want, let us consider two unit vectors. So, this, theta I, yeah, please look at the board. So, if some people have a doubt where d a will, whether d a will come; this can be made as d Q absorbed or shall we, shall we put d A here; I can declare that this is watts, right? See, this is all what we create to for us to understand; finally, we should not die because some units are not, we can adjust all this, are you getting the point? Now, something is absorbed divided by something is incident, that incident, I am relating it to the I lambda I. So, this I lambda I lambda t may also be, if you want you can also put it as I lambda d theta I phi I because, it may not be incident from a blackbody.

Let's not, see this definition itself, we can spend half an hour one hour, what are the things, I mean what what are the terms which should be contained within this brackets, correct? I lambda I lambda d, why should the incident radiation not be a function of theta I phi a, when will that happen, if it is incident from a diffused body. So, already make an assumption. So, if you do not like it, have this also, I have no objection; but as students of engineering radiation, I would like, I want you to know that we should multiply a lambda by cos theta sin theta d theta d phi d lambda d a and set it as a denominator, and numerator if you know d Q absorb, if you have meter or an instrument which measures this, you can get this spectral directional absorptivity.

Now, using these arguments for the enclosure which we use for deriving the Kirchhoff's law. So, you know that alpha lambda dash, let us ditch the d a into I lambda I, correct? I lambda I lambda theta cos theta I, I will put d omega I, d lambda is equal to, this T and this T, what is the problem now? We applied to be very careful about for this? T a. The surroundings of the enclosure and the body all are at what is the temperature.

Student: T (( )).

T. So, I should not use t a, right? **T,** if you do not like d omega I, you are welcomed to put sin theta I d theta I d five, I have no problem, right? Yeah, now, what is the equation number? For this, I keep this as one, this as two, this as three.

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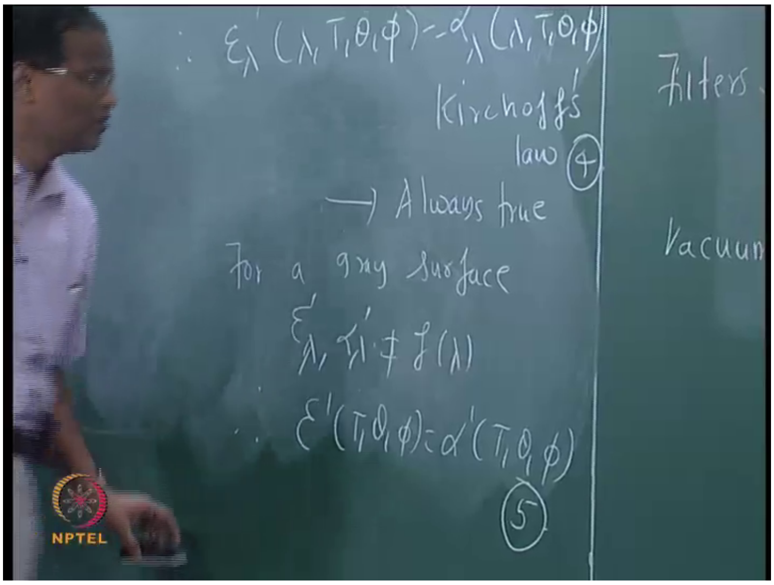

It is true, it is true regardless of, it is true regardless of direction and yeah any problem?

Student: (( )).

No no. I am writing the expression of d Q absorbed and d Q emitted. d Q absorbed, I am writing in terms of the absorptivity, and d Q emitted, I am writing in terms of emissivity. So, to cut a long story short, the spectral directional absorptivity is equal to the spectral directional emissivity; this is a Kirchhoff's law, it is with general, it is valid for any wavelength, it is valid for any angle, and do not think it is valid only for enclosure and the body has to be in equilibrium with surroundings and all that, that is basically to prove, it can be experimentally verified, this is sort of a proof from argument point of view, do not think that is a very shady proof and all that, and what will happen if the equilibrium is not there, whatever, I use these arguments to prove this. So, this was, this is called the Kirchhoff's law; Kirchhoff is again a German, kirsches means, anybody went to Germany here? (( )) what is kirsches k r crèche means church crèche means church church (( )) the church I do not know whether it is too (( )) kirsches means church. So, always true, now, we can call it four, fine. For a grey surface, what is the story for a grey surface? Epsilon lambda dash and alpha lambda dash are not functions of lambda, right? Therefore, for a diffused surface, there should be I lambda, sorry, that is what deepak was trying to tell me.

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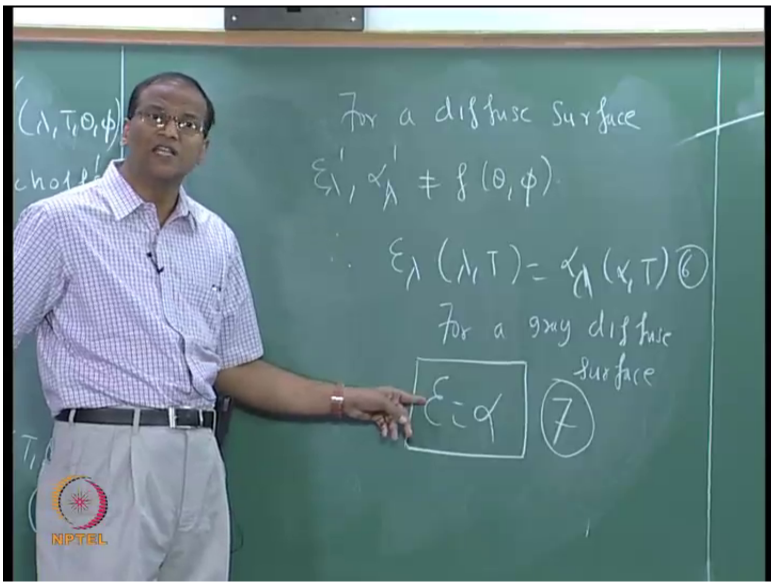

There should be I lambda, sure. Now, for a diffused surface, see the theta I phi I is very important, because normally, you can keep it as theta and phi or theta and phi, but when you are considering a reflection, here you are considering only absorption; when you are considering reflection, there is a theta I phi I and theta r phi r, correct? It can receive the radiation from incident can be on one direction and the reflection can be in all directions, it can be diffused; or it can be specular; that means, it is entering in one direction, it is going in one, one direction only; that is why absorptivity, we use I with the respect theta I phi I, but reflectivity left theta or phi r it is complicate reflectivity; reflectivity is one of the most complicated thing, and it is the most fundamental property. So, I will tell you what are the complications associated with reflectivity in tomorrow's class or next week's class.

Now, for a diffused surface the epsilon lambda dash is not a function of theta phi. Therefore, is that correct? The dash goes off, right? It is the same in all the directions, for a grey diffused surface, for a grey diffused surface So, for a grey diffused surface, very important result for a grey diffused surface, the emissivity is equal to the absorptivity; this is also equal to the hemispherical total emissivity and the hemispherical total absorptivity, because it really does not matter. The other important thing is equation seventh is not the Kirchhoff's law; it is the post processed version for Kirchhoff's law for a grey diffused surface; Kirchhoff's law is more general, it is the spectral directional emissivity equal to spectral directional absorptivity; many people will say that Kirchhoff's law means epsilon equal to alpha, it is very special case of that. Now, for a great diffused opaque surface, finally, what is a overall picture? What is, what is the grand picture?

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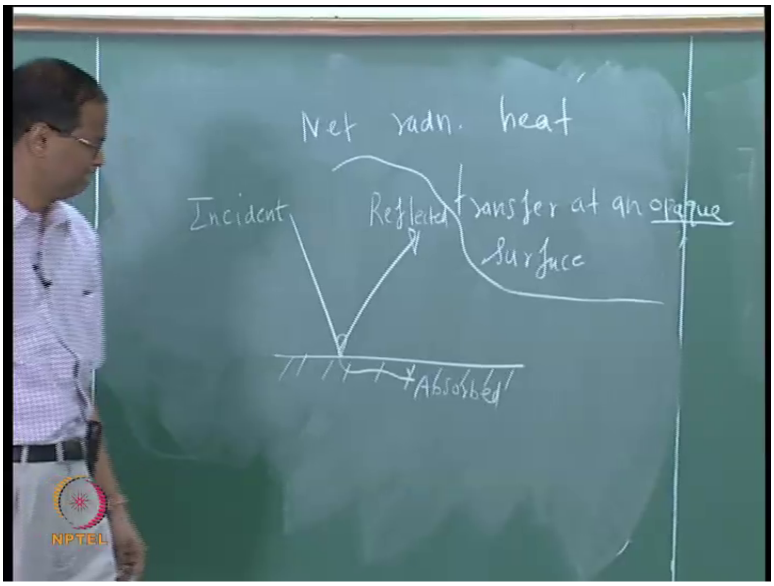

Now, it is very common engineering assumption, suppose, I want to find out the radioactive heat transfer between the walls of this classroom; the walls of the classroom are opaque, fine? Sure, they are opaque and if we make the assumptions that these walls are made up of grey diffused surfaces, then the walls of the enclosures of this classroom can be treated as a grey opaque diffused enclosure, which considerably simplifies the analysis, why? tau equal to 0. So, from handbooks, or data books, or from experiments, or somebody tells you what the emissivity of the surfaces are, you can calculate the absorptivity, you can calculate the reflectivity, you can proceed with the detailed radioactive heat transfer calculations.

Now, before we proceed to the spectral total emissivity; no, spectral hemispherical absorptivity, I will just give you a sneak peek into what all this will eventually lead to; because, we should be able to relate to the final goal; the final goal of all this is that you should be in a position to calculate the net radiation heat transfer from any surface. This surface may be a surface which is isolated or this may a part of several surfaces in enclosure or in a furnaces or a combustion chamber, whatever. Now, what is the net radiation heat transfer at a surface? The net radiation heat transfer at a surface is incident, reflected, absorbed. I am talking about at an opaque surface. Now, there is also an emission consequent upon the surface of the temperature being at a temperature greater than 0 Kelvin. So, the net radiation heat transfer at the surface is what is going out minus what is coming in; what is going out has two components, the reflected component and the emission component, what is coming in is the incident. Therefore, the net radiation heat transfer is a reflection plus emission minus incident; if everything is written consistently in watts per meter square, all the three are in watts per meter square, you will get this. So, the eventual goal is some fellow will may emit, it may also receive radiation from the sun, he may also become hot (( )) in between some, some other things will also take place, may be Q is equal to h a delta, some convective cooling is also there, some wind is also blowing, if all these things are taken into account.

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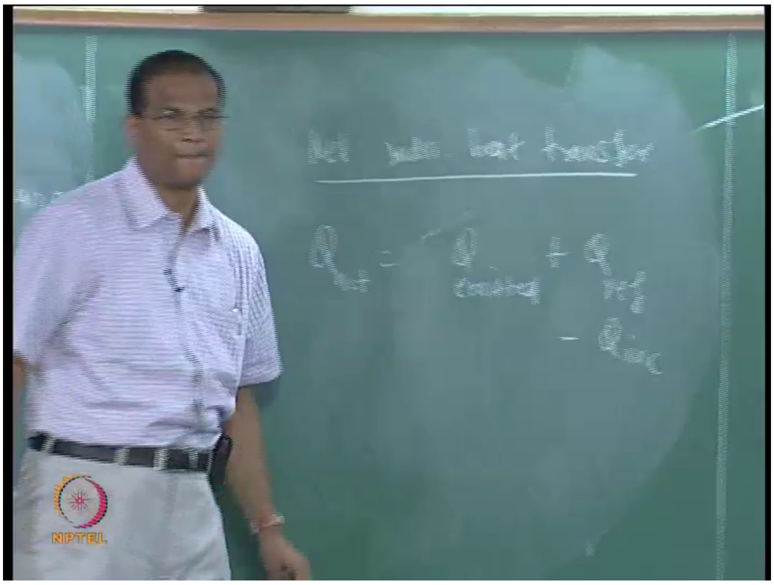

So, now, you look at the energy equation and then you will write all these, if convection and conduction are ruled out then the net radiation heat transfer at the surface is given by, Q net or Q equal to, Q, that is taken care, what is going out minus what is coming in.

Q net is equal to what is absorbed. That is a net radiation heat transfer the surface. This much has to be removed, otherwise the temperature of the surface will increase, if you do not want to, so, what will happen is, if it reach, if you for a solar collector, you have an energy balance like this, then you send, you send your cold fluid and heat it up, and that is how you get a solar water heater. So, you may have, why? That I do not know, Q net is positive or that depends on situation; if the incidence is too much and emitted is less, that is what you want, right? Then Q net will be minus, if Q net is minus or plus depending on your sign convention, accordingly the body will get heated or it will get cool.

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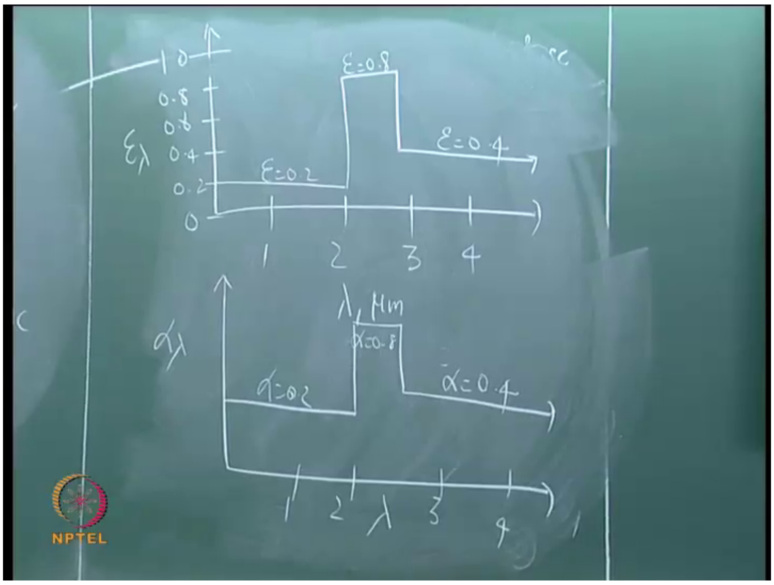
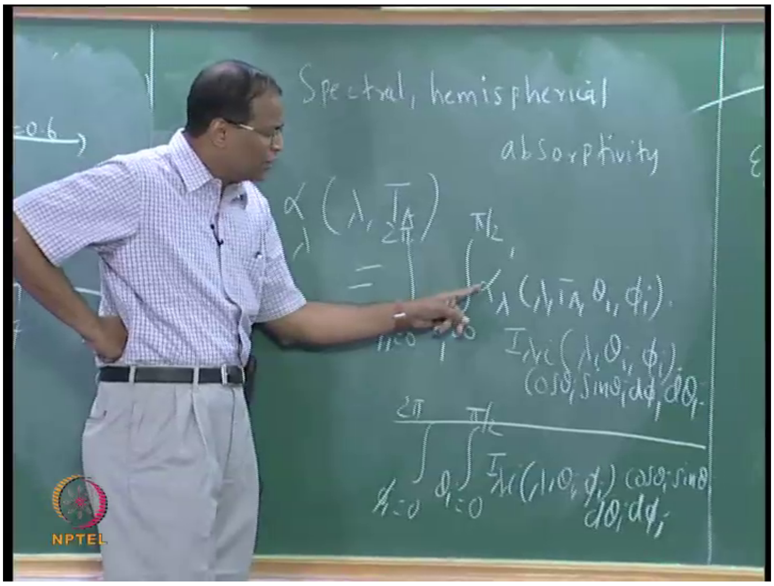


Now, because you have already done the Kirchhoff's law; suppose, I give you a surface which is like this, epsilon lambda, is this clear to you? A very small problem, now what is the question now, number?

10, problem number ten, the hemispherical spectral emissivity of a surface is, the hemispherical spectral emissivity of a surface, the hemispherical spectral emissivity of a surface is given on the blackboard. Draw the, draw the corresponding distributions, draw the corresponding distributions for hemispherical spectral absorptivity and hemispherical spectral reflectivity, draw the corresponding distributions for hemispherical spectral absorptivity and hemispherical spectral diffusivity. No math, because I have not defined all this values for you, all this quantity; alpha lambda and rho lambda, that is what I want, I want the distribution for, can you tell me? Take two minutes, yeah, now, you have to go back to the definition of, you have to go the Kirchhoff's law. I have removed the diffused and all that, because I have told you its hemispherical, already; are you able to follow the question? So, what is the distribution for alpha lambda?

Student: (( )).

Ha, very good. Same as this, what about for reflectivity? Very good, very good. One minus this, that's all, you understood this. Now, I do not even have to define alpha lambda all that for you, but for the sake for the completeness, we will do this. See, if I give you emissivity distribution, you are able to do you are able to manipulate and get all the other distribution; however, calculating alpha from alpha lambda is not so straightforward. I need to know the variations of I lambda with respect to lambda, or I should tell you that this I lambda is coming from sun, are you getting the point? That means, I am interested in calculating the solar absorptivity; if I tell you, what is the source temperature from where the radiation is incident, then you can consider the sun to be a blackbody at 5100 Kelvin, treated as a blackbody, use f function chart and calculate as if you are calculating emissivity; otherwise, it is my responsibility or it is my responsibility to give you I lambda versus a function of lambda, is it clear?



Now, let us draw the distribution for, yeah, if I know the source temperature, I do not need additional information; if I know the sources from a blackbody, I do not have to tell how I lambda varies with lambda, because I know blackbody variation; if you do not give me the information about whether that is a blackbody, or grey body, or whatever, then you give me I lambda versus function of lambda, you draw the graph and give me, then we can calculate, are you getting my point? Now, so, it is starts with 0.8 up to, up to two, then 0.2 up to three, then.

Student: 0.6.

So, if you have to calculate the rho from rho lambda and also alpha from alpha lambda, I need to know the I lambda I, are you getting the point? Or it is very easy, I calculate alpha first, and then use alpha equal to one minus rho, that is also possible, are you getting the point? So, there are various options available for us.

Now, spectral hemispherical absorptivity. What is the definition? Yeah, alpha lambda is there, what that t a? I keep writing this t a, t a is temperature of the absorbing surface. So, what will be the, what will be the mathematical definition for this, I lambda I. Let us not worry about the temperature, if I tell you the lambda theta I phi that is enough, into, sin theta I d phi d theta I, that is it, right? Not divided by, yeah. So, if I give you the, if I give you the distribution or the functional relationship between alpha lambda dash as a function of this theta, and I also give you information on I lambda I, it is possible for, for me to multiply alpha lambda dash by I lambda I and integrate over the complete hemisphere, and get the numerator; integrate just the I lambda I over the hemisphere and get the denominator; and this the ratio then, ratio of these two will give you the, will give me the alpha lambda. Now, already there is overdose. So, tomorrow's class, we will do the directional total absorptivity and hemispherical total absorptivity, and starts solving problems. Fortunately, I do not give you problems where all these are given, you have to integrate and all this; may be, we do problems like this, where the directional effects are already taken into account, I say, already it is hemispherical; but the basic idea behind giving you fundamental definitions is, if you encounter a directional nature of distribution, it should be possible for you to handle, correct?