Heat transfer
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Lecture – 48
Kirchoff's law

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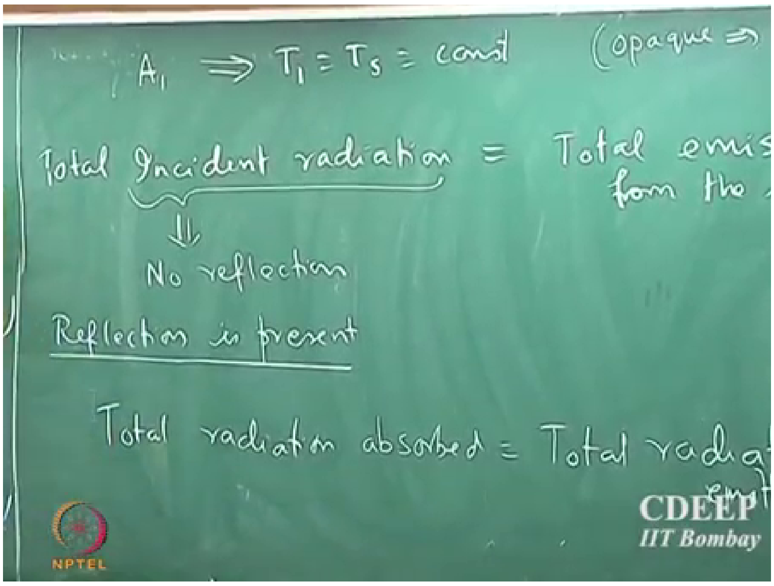

So, what will be the supposing I take object A 1 supposing I take object A 1.

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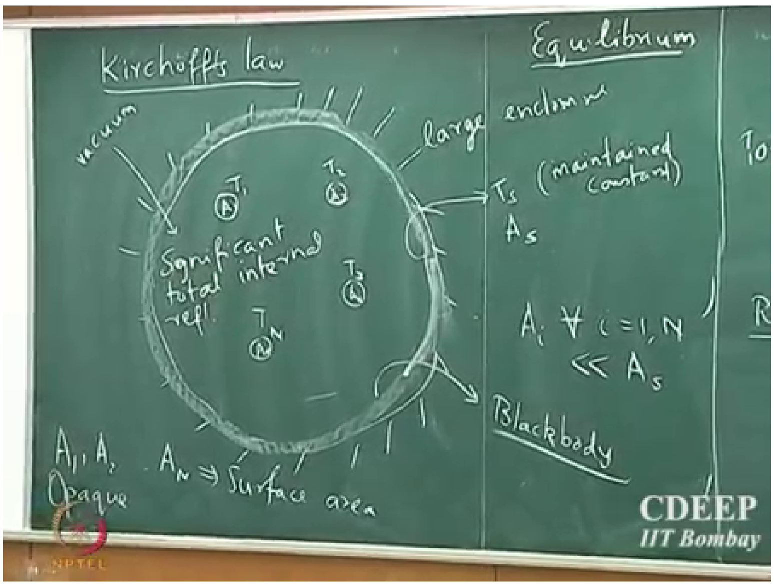

Now, I said that it maintaining I said that it is an equilibrium; I said that the system is in equilibrium which means that the temperature of that surface has to be maintained constant right. So, it has to be maintained constant. Now, if it has to be maintained constant, then whatever incident radiation right, whatever incident radiation that comes to the surface should be equal to whatever is emitted right; otherwise you cannot maintain equilibrium because there is going to be addition of energy to the capacity of the solid and the temperature is going to increase.

So, if you do not want the temperature to increase then all incident radiation should be equal to total incident radiation equal to total emission from the surface.

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Why is that?

Student: (Refer Time: 01:49)

That is a good question. So, if all of the is supposing if there is reflection right, then supposing if there is reflection is there is only absorption in the surface then whatever is the total incident that has to be emitted but supposing if there is reflection. So, this condition is if there is no reflection.

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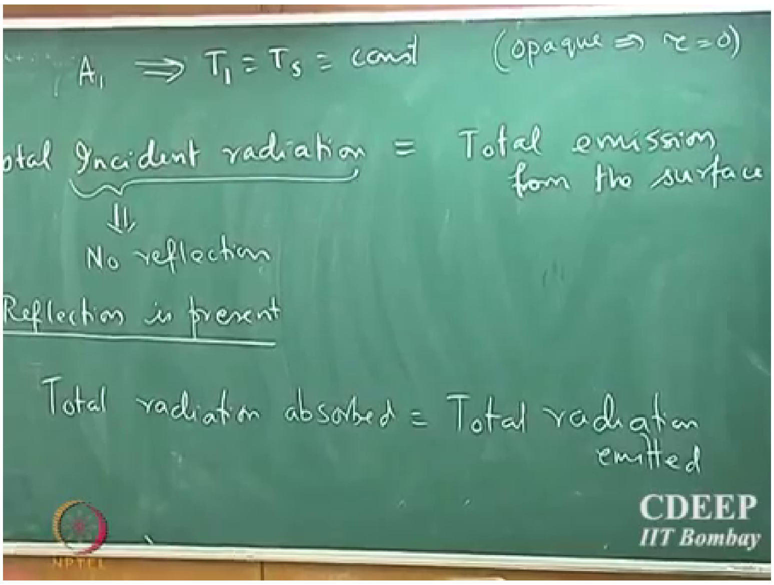

Supposing if reflection is there, supposing if reflection is present, then the total radiation absorbed equal to total radiation emitted; otherwise, there is going to be change in the temperature.

Student: (Refer Time: 02:57)

That is not a problem, because whatever is transmitted is covered in emission right whatever total emit what total amount of radiation that leaves the surface from everywhere around, it includes transmission right. You cannot differentiate between the, so when you look at the total amount of emission that comes out of the surface you will not be able to differentiate between them.

So, let us assume for now that it is a opaque object without loss of generality. So, let us assume that these objects are opaque. So, supposing we assume that these objects are opaque which means that tau is 0, which means that tau is 0. So, now we can write an energy balance I am going to erase this. So, let us assume that in general reflection is present. So, what will be the total radiation that is absorbed, if reflection is also present?

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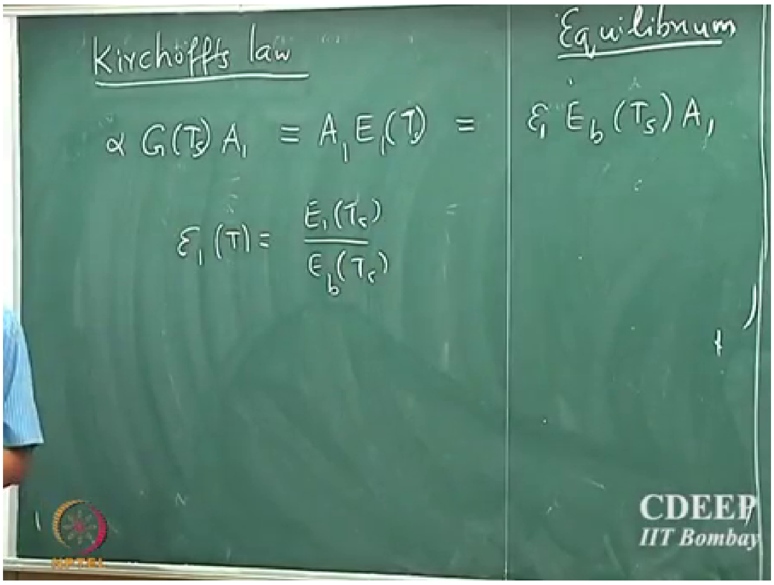

So, we defined a quantity called absorptivity. So, absorptivity multiplied by the total incident radiation. So, note that G is defined is it is an incident irradiation flux right. So, you have to multiply it by the surface area of the receiving surface that should be equal to the total amount of radiation that is emitted, so that will be E 1 of T whatever is that temperature T s. What is E 1. So, we know that emissivity is defined as E 1 divided by corresponding black body temperature right. So, we can write this as E 1, oh, I forgot to multiply by area, E 1 into area of the surface that is the total emission.

What is the total radiation that is received by the surface? Yeah, what is the total incident irradiation?

Student: (Refer Time: 05:32)

Only G of T; that we have already done; for the system that we have looked at.

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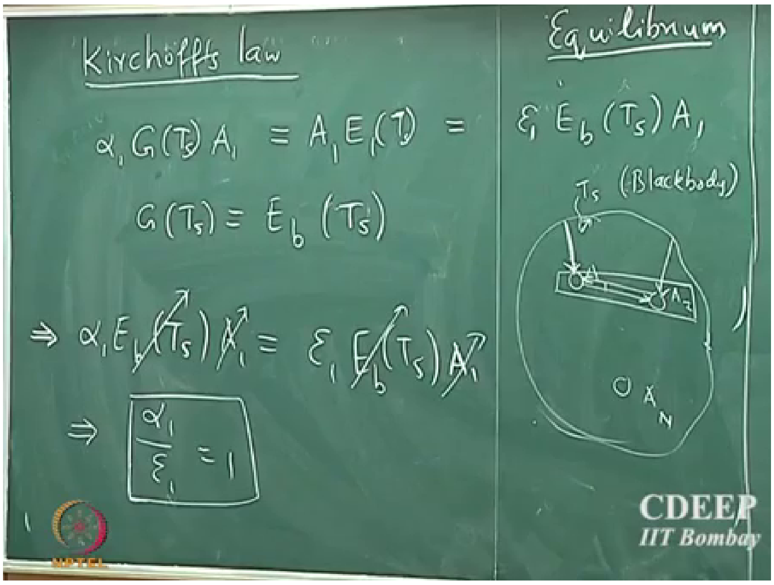

So, let me draw the system again. So, it is a large enclosure. You have small objects inside. And the surface is maintained at temperature T s, and we said that it is a blackbody. So, what will be the incident radiation to a surface, total incident irradiation. So, where is the irradiation coming, is it coming from the surface or is it coming from each of these objects, what is the primary source?

Student: (Refer Time: 06:21)

So, primary source is the this surface of the this black body surface which is emitting radiation. What about the radiation between the objects, there is radiation, but whatever radiation goes here right, the same amount of radiation also is returned back to the surface because these are very small objects. And therefore, whatever amount of radiation, so note that it will be right now we are looking at total quantity, this is true even for local quantities, we will come to that later.

So, supposing I take these two system together, supposing I take A 1 and A 2 together, and I assume that it is a vacuum condition, and both of these are maintained at same temperature right. So, they have to be maintained at equilibrium. And therefore, all of these objects together if they have to be maintained at equilibrium then the only source of irradiation that comes to each of these objects have to be from the blackbody surface which is outside, which is the inside surface of the enclosure. So, therefore, G of T s should actually be the blackbody radiation which comes from the inside of this large enclosure that we have considered.

So, if we substitute that will be alpha into A 1 that is equal to epsilon 1 E b into A 1, oops should be one here that is for the first object. So, cancel off A 1, cancel off these two. So, we find that alpha 1 by epsilon 1 equal to 1. So, this is a very, very important relationship. Note, that this is for a very specific system that we have defined here. We are going to see a general case in a short while how to enhance this property and try to look at the properties of a real system. So, this is only if these outer surface is a blackbody. So, keep in mind that this relationship is valid only when there is this outer large surface, which is a blackbody. Again this is an idealization..

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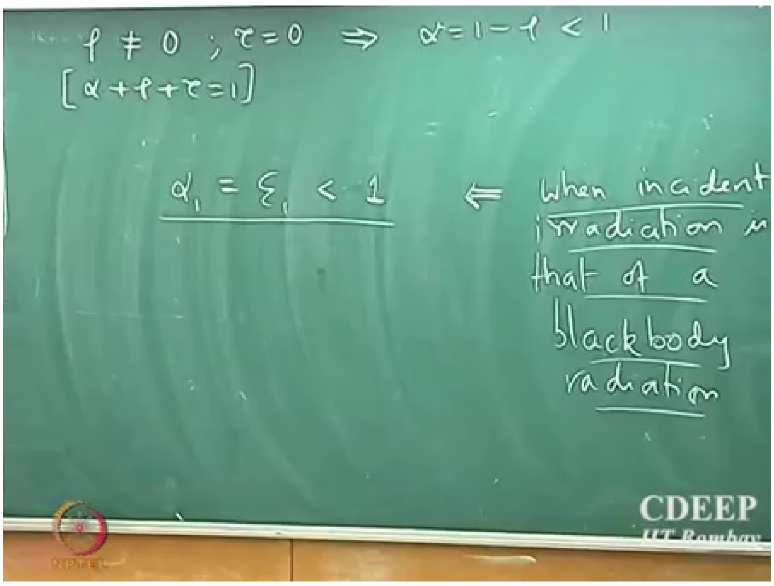

Now, there are some interesting things that we can actually read from this expression. So, we said that reflectivity is not 0 right. So, we said that the reflectivity is not 0. And we said that transmittivity is 0, because the object is opaque, so which means that alpha is 1 minus rho which has to be less than 1 right because of the conservation property alpha plus rho should be equal to 1. So, note that the conservation property is alpha plus rho plus tau equal to 1. So, from the conservation rule, alpha has to be less than 1. So, what does it mean? So, alpha 1 that has to be smaller than 1.

What does that mean? So, note that we have not specified any property of those small objects. So, those small objects they are any real surface. So, what this relationship says is that the emissivity of any real surface, it has to always be smaller than 1 and that is what we observed right. We said that the emissivity is the ratio of the emission from a real surface is the black body. So, we assume that blackbody radiation always emits the highest amount of radiation and in fact that comes out of the energy balance.

Without looking at what is this, what is the actual property of the real surface, we are able to show that the emissivity of the surface is always less than 1 simply by the relationship that absorptivity and emissivity should be equal for this system. Keep in mind that this is only if the this is valid only when incident irradiation. This is very important. This is valid only when the incident radiation is that of a black body radiation. This is very important. This relationship is valid only when the incident radiation is that of a black body. We are going to extend this relationship and see what is the validity of such a relationship for other surfaces, but right now what we have shown is only for that of a blackbody radiation all right.

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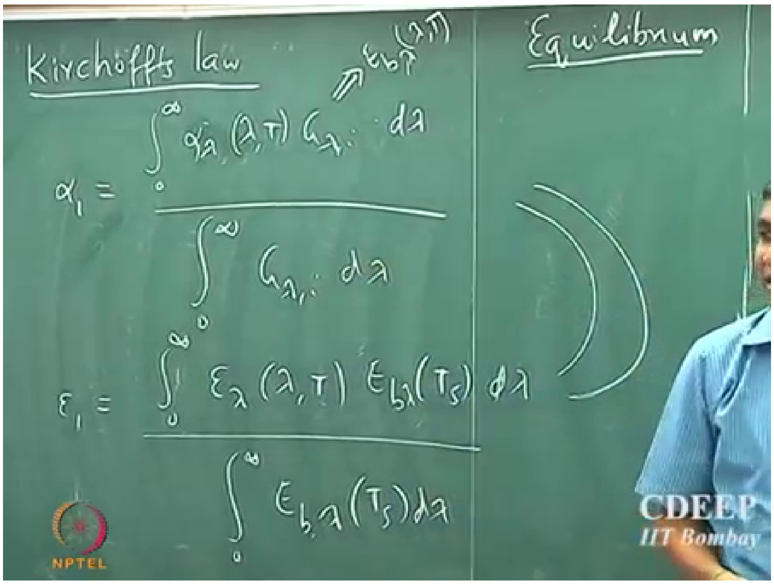

So, by definition total absorptivity is integral 0 to infinity G lambda alpha lambda incident, but for this case the intensity of radiation is basically that of a black body radiation right. And similarly, epsilon 1 is integral 0 to infinity epsilon lambda d lambda divided by integral 0 to infinity d lambda. So, if these two have to be equal, so if these two quantities have to be equal, so note that we are trying to equate these two quantities we say alpha 1 equal to epsilon 1, when G lambda equal to E b. So, the incident radiation irradiation is also that of a black body radiation. So, when is that possible?

Student: (Refer Time: 13:06)

That is right.

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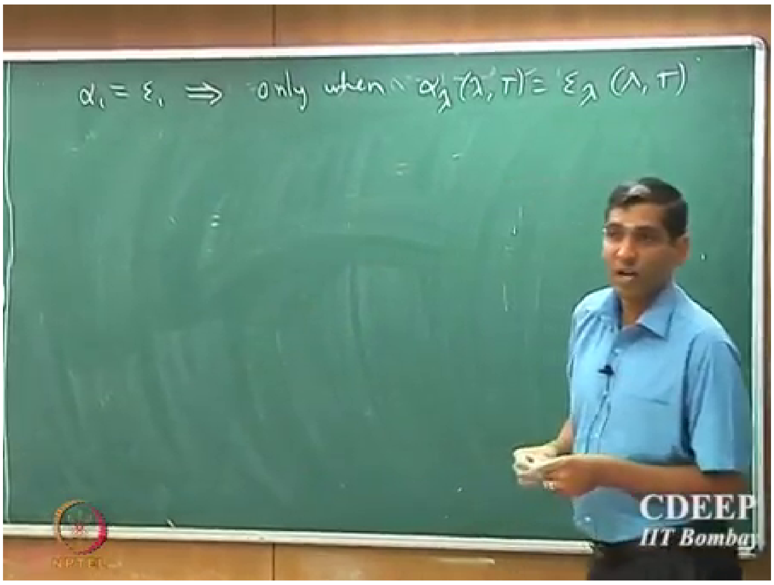

So, this is possible, so this is possible only when so alpha 1 equal to epsilon 1 only when alpha lambda lambda comma t equal to epsilon lambda of lambda comma t. So, this means that the spectral hemispherical absorptivity and the spectral hemispherical emissivity also have to be equal to each other. So, it is a very, very important relationship; simply by looking at the definitions and a simple energy balance very simple energy balance, we are able to show that the absorptivity hemispherical absorptivity of a real surface should be equal to its emissivity if the incident irradiation is that of a black body radiation.

Student: (Refer Time: 14:04)

Is there any other way, if the incident irradiation is black body?

Student: (Refer Time: 14:13)

Right.

Student: (Refer Time: 14:19)

Right I have always assumed that E b lambda, and we are going to look at that particular case what happens when alpha and epsilon are not going to be a special functions of lambda that we have not seen yet, we are going to see that then it is possible. But at least for a right now when we assume that its only the incident irradiation is blackbody, we do not have to worry about that. Any other questions?

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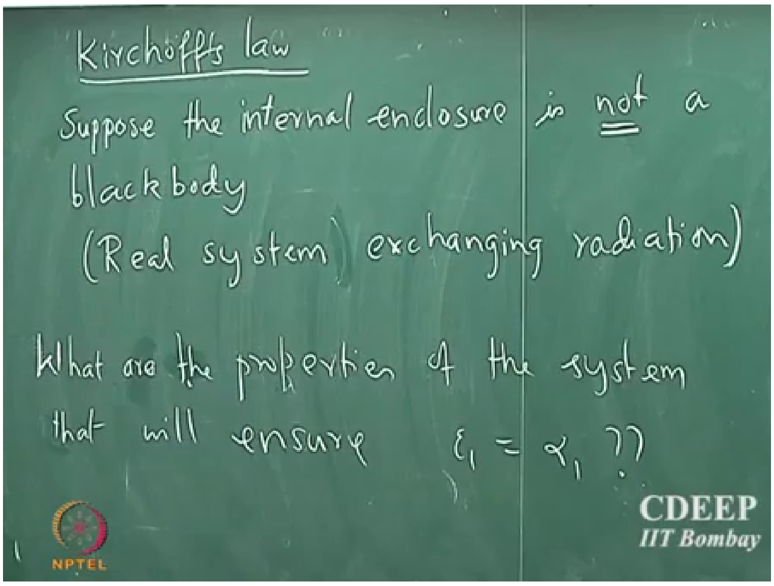

Suppose we assume that suppose the enclosure if not a black body suppose we say that the internal enclosure is not a blackbody right. So, this is very important. So, now, we are going to relax the assumption of Kirchoff's law saying that the internal enclosure is a black body. So, now we are really looking at a real system, looking at real system exchanging radiation, looking at a real system exchanging radiation where the incident irradiation is not that of a black body radiation.

Now, can we ask a question as to when what is the property or rather what are the properties of the system ensure epsilon 1 equal to alpha 1. So, now supposing we want to look at a real system, so this is the first time you are actually trying to characterize a real system for radiation. So, what should be the property, what are the properties of the system in order for epsilon 1 should be equal to alpha 1. So, note that here I have assumed that the incident radiation is not a blackbody radiation.

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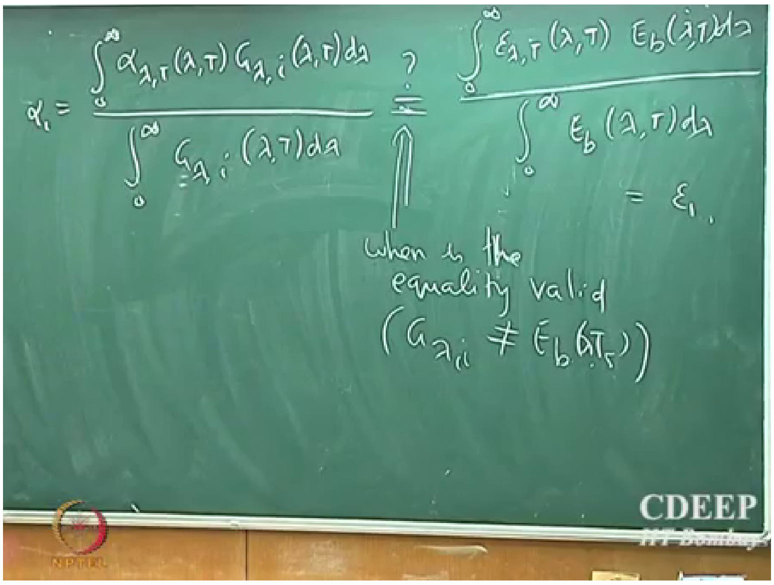

Let us write the expressions again. Alpha 1 is integral 0 to infinity, so the question is when is that equal to integral 0 to infinity epsilon lambda divided by when is that equal to where are these two quantities equal to, so this is the total emissivity right by definition. So, if G lambda i i is not a blackbody radiation when are these two equal.

Student: (Refer Time: 18:06)

When?

Student: (Refer Time: 18:10)

Diffuses only for local quantity, this is already note that this is already spectral hemispherical that is the spectral hemispherical quantity, always keep in mind the integrals, you should always remember what those integrals are. It is alpha lambda t is already integrated over the two angles in the hemisphere right. So, it is already spectral hemispherical quantity. So, when can it be equal, when can the equality be valid? So, note that G lambda i is not blackbody radiation, it is not a blackbody radiation. So, when can it be equal? So, only when these two quantities are simultaneously independent of the wavelength right.

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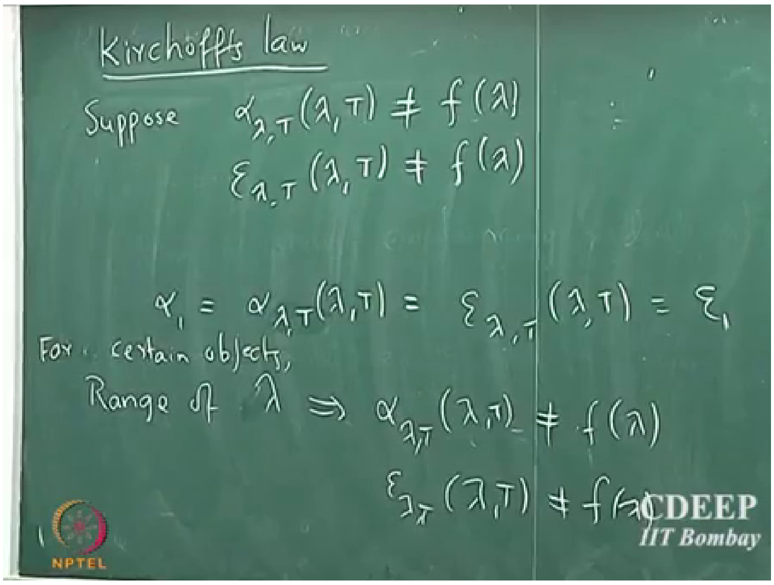

So, let us take a hypothetical case. So, suppose alpha lambda is not a function of lambda, and similarly if epsilon lambda T is not a function of lambda. If both these are not function of lambda, just accept for a moment that it can it is possible, and I will describe you in a minute, how it is possible. So, supposing you say that absorptivity and emissivity are not a function of lambda then this integrals will essentially boil down to. So, note that this is for a real surface, we are talking about real surface exchange of radiation with real surfaces. We have not assumed that any of the surfaces is blackbody.

Now, so these kinds of surfaces, so there are surfaces where for a range of lambda, so the absorptivity is not a function of lambda. This is for certain objects, I will give you a few examples of these in a short while. For certain object, it is being found that for some range of lambda, the absorptivity and emissivity simultaneously are not a function of the wavelength. An excellent example of this is actually snow you know. So, you see these snow and these mountains. So, they also emit and absorb radiation. So, a certain wavelength, they actually absorb and emit irrespective of the wavelength at which the emission and absorption actually takes place. How many of you take photography, how many of you have photography as a hobby?

Student: (Refer Time: 21:56)

Ok, all right. So, what happens is have you taken pictures of snow?

Student: (Refer Time: 21:08)

No, not try. So, what happens is when you actually take pictures of snow you know with a normal lens and normal camera what you get is a blurred image. The reason why you get blurred image is because whatever radiation that comes out of this surface are actually independent of the wavelength, because note that when you are taking a picture what you are actually capturing is at a certain frequency right.

So, the light that is emitted or the radiation that is emitted by the surface if that is not sharp in that particular frequency then the image that you are going to capture is going to be completely blurred and in fact that is exactly what happens when you captures snow. So, what people do usually is you put something called an uv filter. So, there is a filter which is available to capture snow. So, you have to use a uv filter if you want to capture a photography of a snow object or a mountain which has snow, so that is because of this property of snow.

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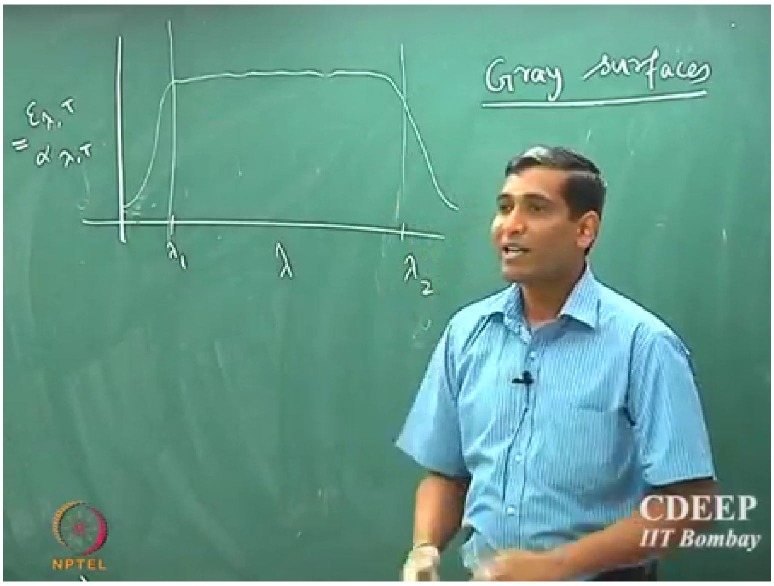

So, the snow has some interesting property; in fact, there are several other objects which has such property. So, there is a range of lambda, lambda 1, lambda 2 let us say, where approximately the absorptivity and emissivity they remain constant. So, they remain constant and they are equal to each other. So, this is at a certain range not an all ranges. So, at certain range, the absorptivity and the emissivity is a spectral hemispherical absorptivity and emissivity they happen to be equal to each other and constant and independent of the wavelength. And in fact, such surfaces are called as gray surfaces such surfaces are called as gray surfaces. And in fact, the name probably stems from the idea of blackbody, black body emits at all wavelengths, it absorbs at all wavelengths and gray surfaces they have a special property where there is a specific wavelength at which they absorb all irradiation and emit all irradiation, so that is what and the name gray actually stems from that idea.

So, what we are going to do in the next lecture is we are going to take this forward and see how to quantify other radiation properties, and really the actual quantification of radiation of real surface starts from Kirchoff's law. So, I would encourage all of you to you know read Kirchoff's law and understand what it really means to say that the absorptivity of a surface and the emissivity of a surface for a wavelength is independent of the wavelength.