Heat Transfer
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Lecture – 55
More examples; Volumetric radiation

So we have been discussing the resistance concepts.

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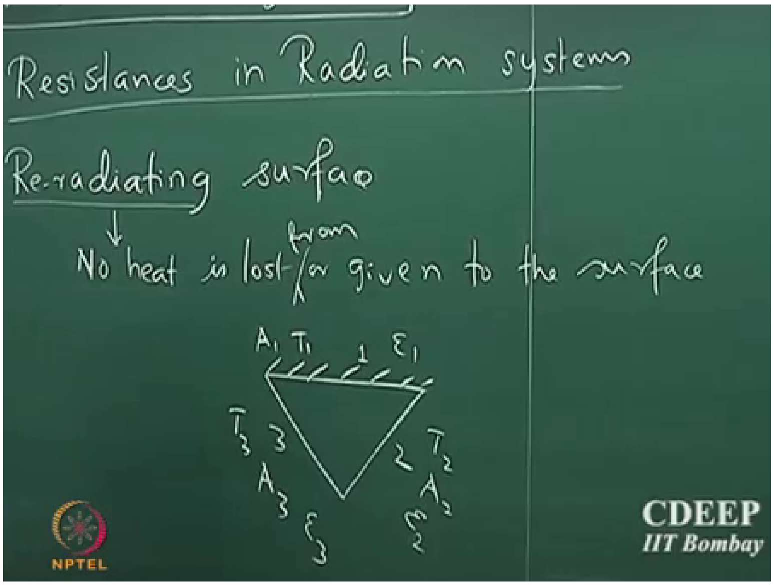

Resistances in Radiation systems

Re-radiating surface

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No heat is lost from/or given to the surface

We are going to take a specific case in today's lecture is called the re-radiating surface ok. So, re-radiating surface is essentially the one, where no heat is lost or given lost from or given to; so no heat is lost from or given to that surface and that is what is called as a re-radiating surface in say in some sense is like a an adiabatic surface ok.

So, suppose I have a; so suppose surface 1 is the re-radiating surface, which is basically adiabatic, and if I have surface 2 and surface 3 and I specify the temperatures T 1, T 2, T 3, A 1, A 2, and A 3 and the emissivity is epsilon 1, epsilon 2 and epsilon 3.

So, now I can write the resistances for this problem and find out what is the net heat exchange between 1 and 2. So, note that there is nothing that is leaving surface 1. So, there is no heat that is lost from surface 1 and nothing is added to surface 1. So, keep in mind that the resistance of every surface is not to it is atmosphere; it is actually to it is corresponding black body. So, note that the driving force is the difference in the black body radiation and the emission from that surface.

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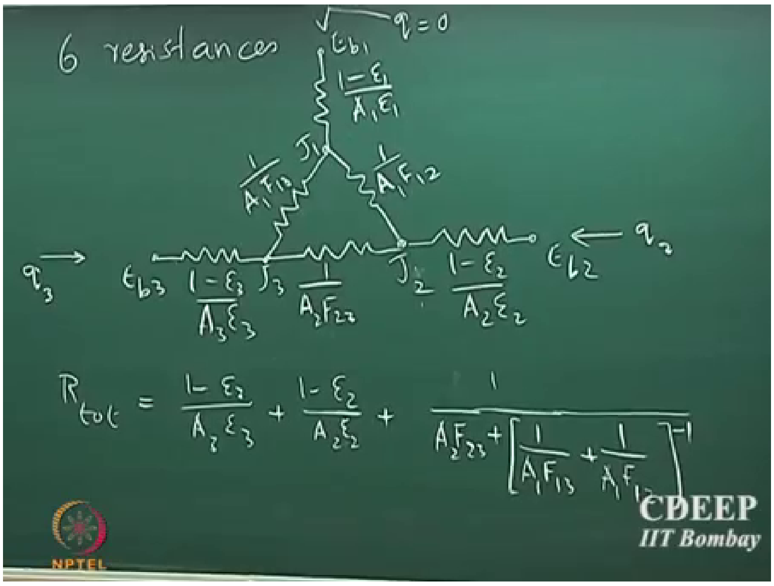

So, there are totally 6 resistances; there are totally 6 resistances. So, this is E b 1 except that the q to the amount of heat that is given or taken out from that surface is 0.

So, nothing comes here and nothing goes out ok. And so this will be 1 minus epsilon 1 by A 1 epsilon 1, that is the resistance here and this is E b 3 1 minus epsilon 3 by A 3 epsilon 3, and this is E b 2 1 minus epsilon 2 by A 2 epsilon 2 and this will be 1 by A 1 F 1, F 1 2 will be 1 by A 1 F 1 3 will be 1 by A A 2 F 2 3. So, that is the resistance.

So, we have 6 resistances; 3 resistances for exchange between each of three these three surfaces and 3 resistances for the driving force for the amount of heat, that is absorbed or the net amount of heat that is absorbed or liberated by that surface, q 3 is the amount of heat that is supplied to surface three. So, what is the total resistance? What is the total resistance; maybe 1 minus epsilon 3 by A 3 epsilon 3 plus of course, you will have this 1 1 minus epsilon 2 by A 2 epsilon 2, what is the resistance for this component J 1, J 2. So, that is parallel. So, it will be 1 by A F 2 3 plus 1 by.

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So, it will be 1 by A 1 F 1 3 plus 1 by A 1 F 2 1 1 2 inverse of that. So, that will be the total resistance essentially these two resistances are in parallel with this resistance, which is present here ok. And, because there is no heat that is coming out or going out or coming in from here; this resistance does not play any role in the total radiation calculation. Although, it does not mean that there is resistance is negligible just that it does not play any role in the calculations that is all ok. So, that is the total resistance, and now you should be able to calculate the radiation exchange over all radiation exchange etcetera. Suppose you have radiation and convection and conduction simultaneously ok.

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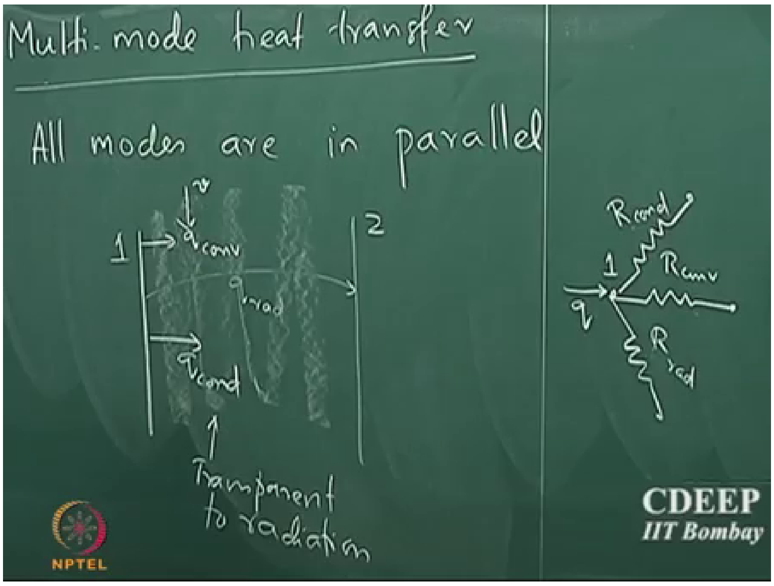

So, suppose you have all three processes occurring simultaneously; if you not dealt with conduction in detail, but let us say assume that you know how to work a workaround with convection properties. So, if all three heat transfer modes are occurring simultaneously through a surface, then it is essentially all modes are in parallel. So, that is the first thing ok, because these are independent modes of heat transfer. So, supposing you have one surface, this surface one and you have surface two ok.

Now, let us say that there is radiation mode of heat exchange between one and two ok. Now, in principle if there is a there is a medium in between we are going to see in a short while, how to characterize radiation in this medium, but let us assume that there is no radiation, which means that if the medium is transparent; the media is transparent to radiation, which means there is no absorption or emission whatever is coming in this side is transmitted to the other side of the medium. And there are media which actually has this property and we will see that in a short while.

But, there could be conduction through this media right; that could be conduction mode of heat transport from surface 1 to 2, and if the media is flowing with a certain velocity there could always be a convective mode of heat transport from surface 1 to 2. So, the way to characterize this is supposing, if this is surface 1 and the amount of heat that is provided to surface 1 is q, then it is just that all three are happening in parallel. So, if you are able to find out the driving force and resistances for each of these mode of transport, then we could represent it as resistance for conduction resistance for convection and resistance for radiation ok.

So, if we know how to find the driving force and most of the cases we know for conduction, we know that temperature difference is the driving force for radiation we know that the exchange between the two surfaces is the driving force for radiation exchange and for convection also it is the temperature difference, which is the driving force.

So, if we know that when we can find the resistances, and we should be able to incorporate the multiple mode of heat transport in a very very easy fashion, if you know how to construct the resistance network. So, note that this is true only when there is constant rate of heat transport in the media; if there is heat generation; obviously, you cannot write resistance networks for conduction mode of heat transport. In that case you will have to write the full model and solve the full problem ok.

So, we will actually deal with coupling of convection and conduction, when we actually look at heat exchangers. Let us assume that; we know how to characterize convection and this is the way to include all three modes of heat transport and I want to include this for sake of completeness of radiation processes ok.

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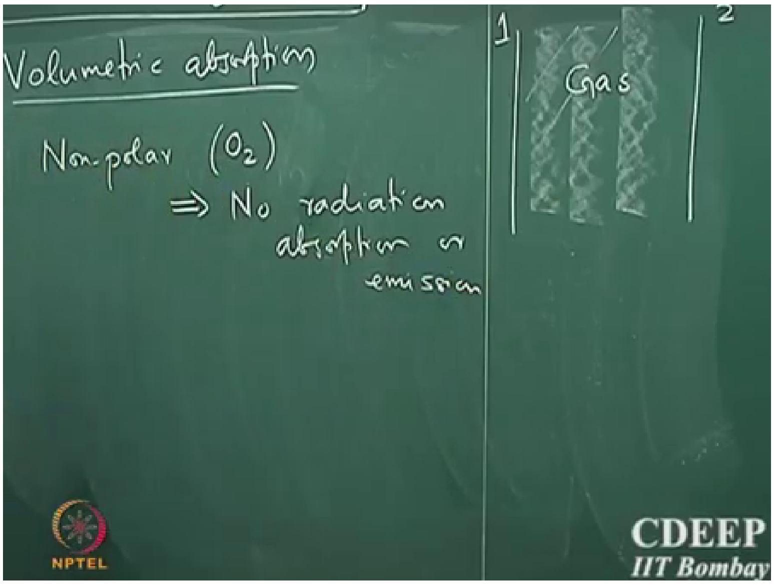

Volumetric absorption

Non-polar (O_2)

$\Rightarrow$ No radiation absorption or emission

So, we are going to see volumetric absorption. So, when we start initiated discussion on radiation, so we observed that the radiation is a surface area process for solids and liquids, which is present in a certain container, but for gases it is a volumetric process. So, if we suppose we assume that we have two surfaces ok, surface 1 and surface 2 and let us say it is filled with some gas ok.

So, the aspect of volumetric absorption depends upon the nature of the gas. So, supposing, if it is a polar non-polar gas ok; it is a non polar gas for example, like oxygen ok, so non-polar gas, they have almost no radiation absorption. The absorptivity is almost 0 they do not absorb or emit radiation, and that is because of the nature of the gas it is a non polar gases. And so they do not absorb or emit radiation, but supposing, if I have polar gases; what is a good example of a polar gas ammonia ok.

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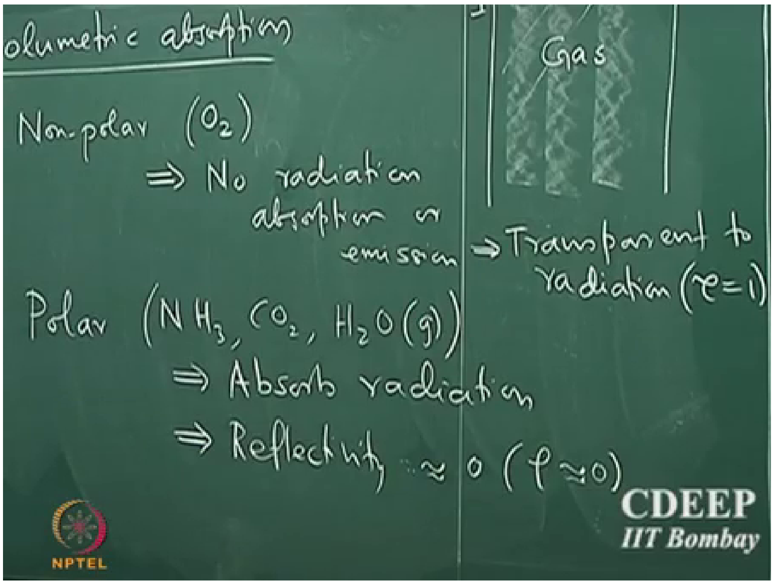

olumetric absorption

Non-polar (O_2)

⇒ No radiation absorption or emission ⇒ Transparent to radiation ($\tau=1$)

Polar (NH_3, CO_2, $H_2O(g)$)

⇒ Absorb radiation

⇒ Reflectivity ≈ 0 ($\rho \approx 0$)

So, ammonia is polar carbon dioxide is polar, and you have water vapor is polar, it is a gaseous state they are all polar gases. So, they have a definite, they have the ability to absorb and emit radiation at different locations in the media. So, when I say these non polar gases do not absorb or emit, they are essentially transparent to radiation, which means that the transitivity is equal to 1 ok. But for polar gases, that is not necessarily the case; the other property of polar gases is, that the reflectivity is almost negligible. So, these are properties. So, they have negligible reflection. So, they just emit absorb and transmit ok.

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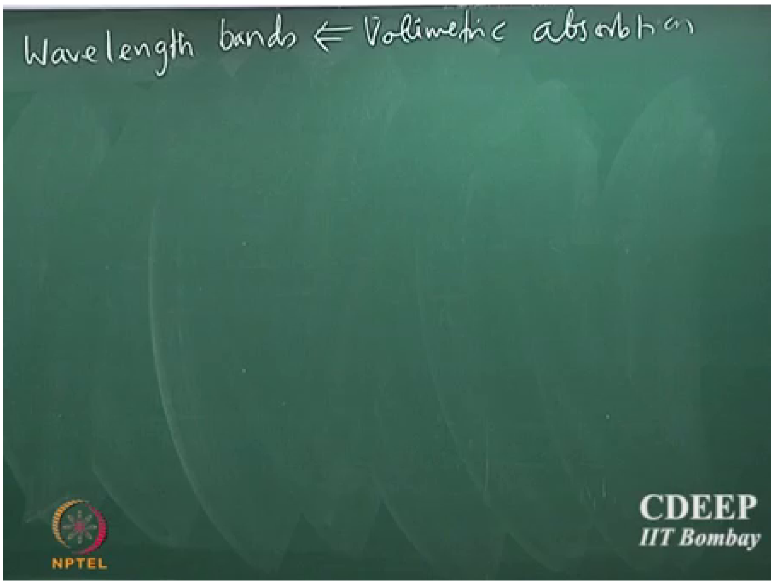

Wavelength bands ⇐ Volimetric absorbtion

So, the volumetric absorption process, they occur typically in what is called the wavelength band. So, the observant wavelength band; so it is not like a specific wavelength at which, the emission and absorption is going to occur it is going to be a band in which, they are going to absorb and emit radiation ok.

So, what we are going to see for the next 15 minutes or so is to find out how to characterize this process. So, in order to characterize we need to define, so note that we want to characterize this process of absorption of radiation. So, it has to there has to be some intrinsic property, which quantifies the absorption process right. So, that is what is called the absorption coefficient.

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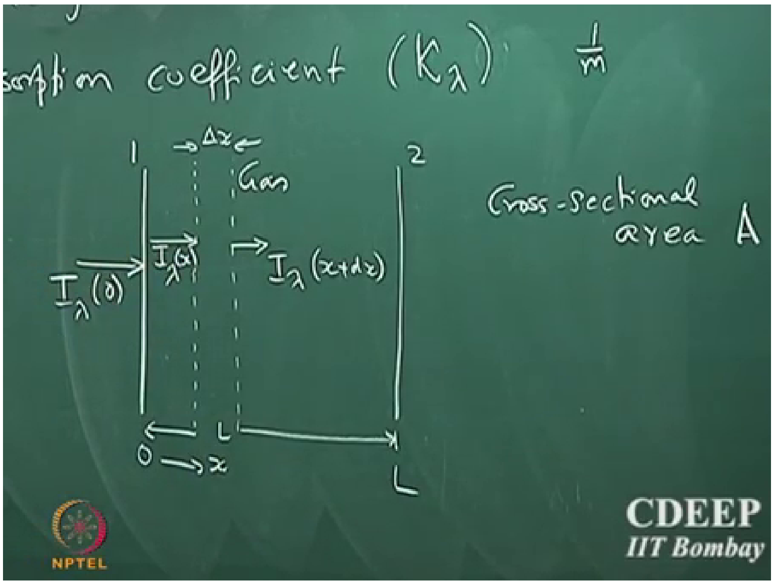

So, it is like when you had conductivity which quantifies the amount of heat that it conducts or rho c p which is the intrinsic property to store heat in a system.

So, similarly absorption coefficient is the quantity, which quantifies the amount of radiation; that is absorbed by a given some given medium. So, it is represented as kappa and of course, it is the function of the wavelength and the units are per meter. So, it basically tells you, what is the quantity of radiation that is absorbed as you go into the media per unit length ok? So, as you go how much is absorbed, that is what is quantified by absorption coefficient ok. So, suppose I take; so I have a gas, which is filled inside these two plates: surface 1, surface 2 and let us say the intensity of radiation, that enters the gas at surface 1 is I lambda naught ok. And, if the width of this width of separation is 0 to L ok, the width of separation is 0 to L and if I call this as my x coordinate system.

So, now we said that it is occurring in wavelength band; and therefore, we can write a differential balance. So, if this thickness is delta x ok, and if the intensity of radiation that occurs at some x location is I lambda x and what leaves is I lambda x plus d x ok. So, that is the flux of intensity that leaves. And, if the cross sectional area of radiation outside the board. So, this is perpendicular to the board the cross sectional area is A the cross sectional area is A; so now, I can write a energy balance for this.

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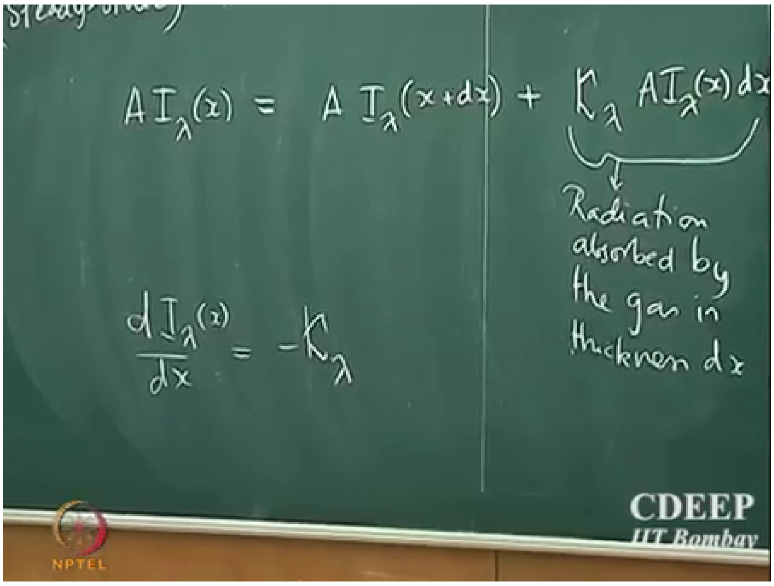

So, if it is a steady state process assumes steady state, then whatever enters this element here should be equal to, what leaves the element plus whatever is absorbed ok. So, that will be A times I lambda x, that is the net rate at which the radiation is entering that element that should be equal to area into I lambda x plus d x plus whatever is absorbed. Now, note that this is the; I should have mentioned this absorption coefficient is actually the fraction of radiation, that is absorbed at that location right. So, that will be k lambda into A I lambda x multiplied by d x ok.

So, that will be the net radiation, the total amount of radiation that is absorbed. So, this is the radiation absorbed by the gas in d x that is the amount of radiation that is absorbed. So, after simple algebra, so you will see that we can rewrite this is d I lambda x by d x equal to minus kappa lambda ok.

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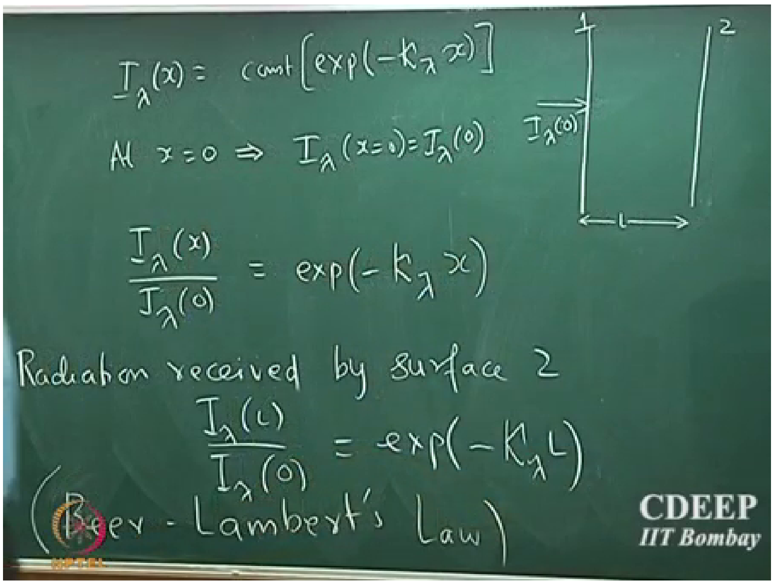

$$I_\lambda(x) = \text{const}\left[\exp(-k_\lambda x)\right]$$

At $x = 0 \Rightarrow I_\lambda(x=0) = I_\lambda(0)$

$$\frac{I_\lambda(x)}{I_\lambda(0)} = \exp(-k_\lambda x)$$

Radiation received by surface 2

$$\frac{I_\lambda(L)}{I_\lambda(0)} = \exp(-K_\lambda L)$$

(Beer - Lambert's Law)

I can solve this equation I lambda x equal to some constant into exponential of minus kappa lambda into x; how do we find this constant? So, remember the picture, what is entering is; surface 1, surface 2, what is entering at x equal to 0 is; I lambda naught ok. So, if I know how to measure that I am done right.

So, at x equal to 0 that is the boundary condition ok. So, I can substitute that and I can find out that I lambda divided by equal to exponential of minus k lambda x. So, what will be the intensity with, which the radiation leaves the surface at L, what will be the intensity with which the radiation will hit surface 2 is I lambda L right. So, I substitute this to radiation received by surface 2 is I lambda L by minus does this expression look familiar Beer Lambert law right. So, this is what is called as Beer Lambert's law.