Heat Transfer
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Lecture – 48
Radiation - Fundamental Concepts

We will start Radiation for in this class and follow it towards the end of this course which would complete our study on Heat Transfer. So, far we have dealt with 2 modes of heat transfer, conduction and convection both of which requires the presence of a medium. However, radiation is the one as you are all aware of does not require the presence of a medium. So, radiation plays a major role in many of the process industries and in significantly varied applications as we know of. So, we would concentrate on radiation, the radiator the radiation flux, the intensity and flux, the radiative properties.

How do we characterize the subject based on it is radiative properties? What is an ideal surface as far as radiation is concerned? We are talking about black body over here. In then is there any surface resistance to radiation that by which you can express. Since, radiation depends on temperature and on the nature of the surface. So, we will see what is what is Stefan Boltzmann law that; obviously, you know about. But, is there any surface resistance to radiation since all these surfaces and non ideal, they are not black bodies. So, can some resistance be ascribed for exchange of radiative heat transfer between the surface and its surroundings.

So, what is the surface potential? What is the surface resistance? What is the potential just outside of the surface when we consider the surface resistance? So, the body as a whole if I consider it as a black body we will have some sort of radiative potential. But, since it is surface is not acting like a black body. So, there will be some resistance. So, just outside the surface we can think of another potential with 2 potentials connected by resistance as in a circuit, electrical circuit where the resistance in here is going to be surface resistance to radiation. So, those concepts we would also discuss in this part of the course.

Also 2 bodies can exchange radiation with in between them, that they can also a exchange radiation with itself and they can they can also exchange radiative heat transfer with the surroundings. So, if the palm of my hand, if the palms of my hand are 2 surfaces are 2 different temperatures. And if I press them like this, there would be radiative heat exchange in between these 2 surfaces. Not only that they are also going to exchange heat with the walls of this room through the space in between this. So, if I bring them close to each other, the amount of heat radiative heat which they are going to exchange with the surrounding will keep on decreasing.

So, in ideally, if they are touching each other than all the heat which is released by one is going to be intercepted by the other ok. But, if I separate them out together then it is going to be then the heat that is that gets transferred from one the fraction of the heat which gets transferred from one reaching to that fraction will change will decrease. So, the how much of surface 1 is visible from surface 2 would not would definitely depend on what is the distance between the 2 or if we talk in mathematical terms what is the solid angle subtended by that would by this by surface 2 on to 1. So, we will see the concept of solid angle as well in this course.

And then let us see we have 3, 4 3 surfaces which are which form an enclosure. So, you can think of it as a triangle, where the 3 sides are exchanging heat radiative heat with one another ok. So, part of the heat released by 2 is going to go to 1, part going to 3 and maybe it may so, happen that part of the heat released by 1 is going to be observed by 1 itself. So, if it is a curved surface like this then the part of the energy which is emitted by 1 is going to incident on 1 itself right. So, that is that is possible, but if it is a flat surface then none of the radiative energy which leaves 1 is going to come back to 1.

So, the nature of the surface, the shape of the surface will also play a role; let us say we have 3 flat surfaces which are forming a triangle. And these 3 sides are at 3 different temperatures and there is going to be radiative exchange of heat in between them. What is going to be the net heat to be supplied or extracted to each of these triangles, each of these sides of the triangle so, as to maintain thermal equilibrium? These informations will be extremely useful for the effective design for the efficient designs of furnaces, because as you know furnaces operate at a very high temperature.

So, how much of heat in need to supply to the furnace to maintain the temperature of one of the surfaces at a desired level; you need this kind of calculations. So, as you can see we are always bringing in electrical analogy for radiative calculations specially when we talk about the potential, the resistance and the heat flow is something which is similar to that of current. So, there has to be a network method, see if you remember your electrical technology this star delta connections the problems on star and delta connections which we have done in electrical technology, we are going to do similar calculations for the case of radiation as well which would give, which would allow us to effectively design a furnace.

So, that is more or less what we would like to cover in the course in this part of the course. But, let us starts with let us start with radiation first and radiation is the energy emitted by an object where which does not require the presence of a medium in all surfaces above absolute 0 would emit radiation. They will also receive radiation so, it there is going to be a process of emission and absorption that are going on that will be going on.

The concept of radiation can be explained by 2 theories, the first one is Maxwell's theory and the second one is Planck's theory. So, Maxwell's theory of electromagnetism can be used to express some of the radiation phenomena where Max Planck's theory is also applicable, is also applicable for the case of radiation heat exchange. So, apart from the properties of the surface we should also be aware from the very class first class itself that the radiation can be explained either in Maxwell either using Maxwell's theory of electromagnetic, Maxwell's electromagnetic theory where the radiation is treated as electromagnetic waves.

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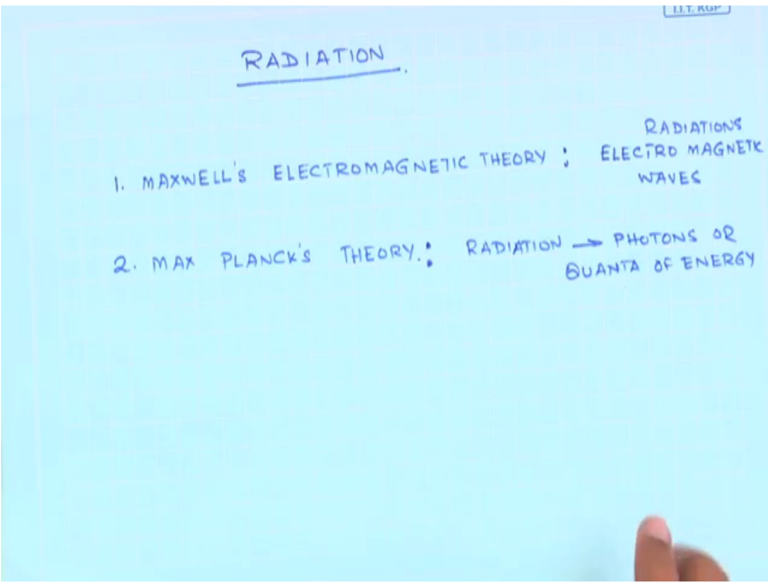

So, radiations are treated as electromagnetic waves in Maxwell's electromagnetic theory wherein max Planck's theory the radiation is treated as photons or in other words there Qantas, quanta of energy. So, both we will find its use, both concepts has been utilised. So, the results from the electromagnetic theory are used to predict the radiative properties of materials, while the results from Planck's concept has been used to predict the magnitude of radiation energy emitted by a body at a given radiation.

Now, radiations are can happen over a large wavelength range and view on one side we have the gamma rays and one on the other side we have to radio waves. So, whenever an object is emitting radiation the chances are that it is going to emit radiation over all the wavelengths. So, radiation is spectral in nature by spectral I mean that the there is going to be a wavelength dependence of radiation and not all the energy coming out of a surface is going to be equally spaced over all wavelengths. So, there will be certain wavelengths, there will be a wavelength range in which most of the energy would be concentrated and it may not be presented other wavelengths. So, the spectral nature of radiation is extremely important and we will have to take that into account.

So, when you think of this spectrum of radiation and the way it is divided into different different sections. So, there is a specific wavelength range where we can see that is the visible wavelength range. There is a specific wavelength range we in which most of the radiative heat transfer is taking place ok. And we have an infrared range and you have an you have the gamma rays range where you have energy associated with radiation. But, the thermal energy is concentrated somewhere in the middle and that is going to be our zone of interest for most of the most of the topics that we would cover over here cover over here.

So, let me draw the what kind of what kind of waves, what kind of radiation we would get and as a function of the wavelength and see whether we whether we can identify and demarked the region in which the radiation is going to be important. So, if I draw that profile over here.

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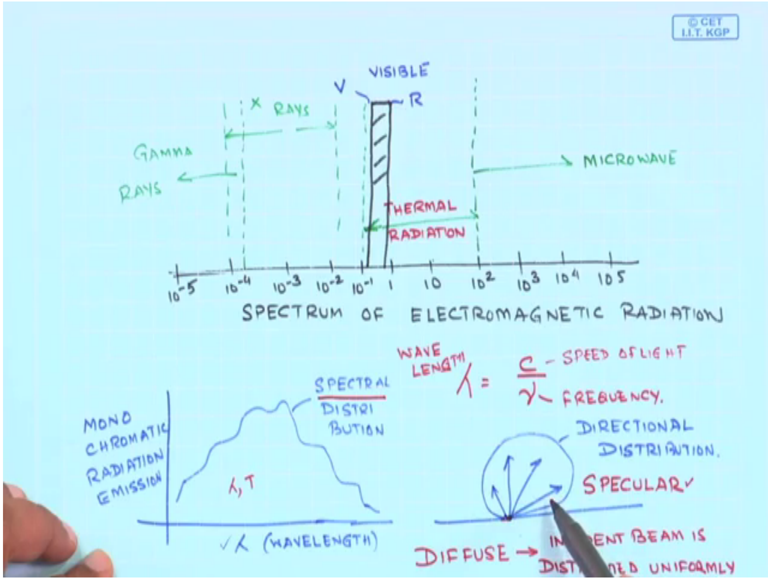

What it looks like them is. So, this is the spectrum of electromagnetic radiation. So, so, any wavelength, any radiation where the corresponding wavelength, where the associated wavelength is greater than 10 to the power 2, these are in the microwave region. Anything which is smaller than 10 to the power minus 4 these are gamma rays ok. In between 10 to the power minus 4 and in referee somewhere slightly more than 10 to the power minus 2 these are the x rays. So, between 10 to the power minus 1, 10 to the power minus 1 to about 10 to the power 2, this is the region which is of most important to this part of the course which is thermal radiation; so, between 10 to the power minus 1 to about 10 to the power 2.

And this region this one is the visible range the visible range where you have the red on one side and you have the violet on the other side. So, this is more or less the visible spectro the more or less the spectrum that you would get in radiation, but between 0.1 and 100 this is the range in which most of the thermal radiation is going to be going to be concentrated. And this should be the region which would study in this part of the course. So, as well as I was telling you the spectral nature and the so called specula nature ok. So, you this is monochromatic light, monochromatic radiation emission and if I plot it as a function of lambda which is wavelength. This is going to be a variation like this some arbitrary variation. And since, it depends on wavelength this is called spectral distribution.

What it essentially tells is that you are getting a continuous non uniform distribution of monochromatic components by monochromatic I mean single wavelength components and the magnitude of the radiation at any wavelength and the spectral distribution vary with the nature and temperature of the surface. So, this kind of distributions what you are getting out of the surface, out of the object, would depend on whatever be the whatever be the temperature of the object and whatever be the properties of the object.

So, the mono chromatic distribution of radiative emission from a surface is a continuous function of wavelength, but the value of the emission is going to be different at different wavelengths. So, that is that is what happens that is what would happen in most of the real surfaces. Where as in some cases your and there is no directional distribution on top of it. But, if you look at this surface then from a point it is this one will have a directional distribution which is which is something different from over here.

So, here the distribution depends only on wavelength, here the distribution depends on the direction as well ok. So, this is this is the difference between these 2 surfaces. So, this is a spectral distribution and the spectral is used to refer to the nature of the dependence were it depends on the on the wavelength ok. And the thick the wave nature of the thermal radiation tells you that this lambda which is the wavelength is going to be c by frequency of radiation. So, this is the speed of light that is the standard definition speed of light, speed of light.

The speed of propagation in the in the in the medium and lambda is the sorry this is lambda is the wavelength and this is the frequency. So, if the medium through which the propagation takes place is vacuum, then that c is going to be speed of light in vacuum. So, the dependence between the wavelength and frequency is simply an inverse relationship with a constant which is which is which is the speed of light in vacuum for the when we are talking about the vacuum. So, now, let us talk about the radiative properties, what are the radiative properties that we have? When a light is incident on a surface part of it is going to get reflected, part of it is going to be observed and part of it is going to get transmitted.

So, the fraction of the energy which gets reflected as compared to the what the what is the overall energy incident on it is known as the property is the reflectivity. So, the reflectivity is defined as the fraction the numerator is going to be the fraction which is reflected fraction of energy which is reflected and the denominator is the total energy incident on it. So, the other option, other possibility is that part of the energy which does not get reflected and enters into the enters through the surface it is going to get absorbed ok. So, the absorptivity, the factor absorptivity is defined as the amount amount of energy which is absorbed in the material divided by the amount of energy which is incident on it.

Now, let us say that part is reflected; part get part gets into the system and then goes out of the system or out of the material after part of it is going to is absorbed. So, what can happen on incident energy on a surface is one it may it may get reflected, one it may get absorbed and the third is it may get transmitted through transmitted through the surface. So, the 3 properties which can be which are defined to denote these natures of the surface are reflectivity, absorptivity and transmissivity. As the name suggests the denominator in all cases would be the amount of energy incident on the on the on the on the surface.

So, in the case of reflectivity it is a fraction which gets reflected. Absorptivity is the fraction which gets absorbed and transmissivity is the fraction which gets transmitted. So, the emissivity I am sorry the reflectivity, the absorptivity and transmissivity, transmissivity all are fractions having a value from 0 to 1. And since the denominator in all cases the same, the sum of alpha plus beta plus gamma tau is going to be equal to 1. So, if I define the properties, radiative properties the radiative properties this is the reflectivity plus absorptivity plus transmissivity is equal to 1.

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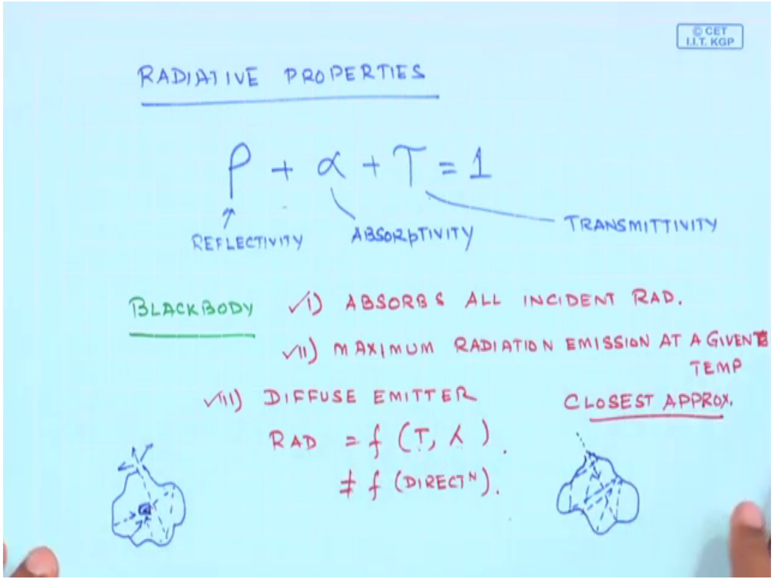

So, this is the reflectivity, this is the absorptivity and this is the transmissivity; so, fraction of fraction which gets reflected, fraction which gets absorbed and fraction which gets transmitted. So, that is why these 3 are these 3 are these 3 the sum of these 3 would be equal to 1. Now, if I go back one slide and show you this one here the this one is this this kind of surfaces where the emission depends on the direction they are known as specular. So, specular is a surface where there is a directional dependence of radiation from a surface.

So, wherever there is a directional dependence or directional distribution of energy out of a surface it is known as peculiar. And when there is no such no such dependence it is called a diffuse. A diffuse is a surface where the incident beam incident beam of energy is distributed uniformly in all directions. So, apart from these properties of radiation, this property of the surface is also important. Specular when there is a directional distribution to the energy emitted by a surface. The second type of surface is diffuse where the incident beam is distributed uniformly in all directions.

So, we will we will see what are the examples and the special features and the simplifying situations where assuming a surface specular or assuming a surface as diffuse we will provide. The other concept that I would like to introduce before I close this class is some sort of an ideal. Whenever we talk about real surfaces the properties the emissivity, the sorry the absorptivity, reflectivity and the transmissivity there must be something which can be taken as an ideal surface ok. So, we are going to compare the performance or the characteristics of a real surface against that of the ideal.

So, such ideal surface is in radiative heat transfer is assumed is termed as the black body. So, what is a black body? A black body is something it is an idealized concept; a black body is something which absorbs everything that is in that is incident on it. So, therefore, the absorptivity of a black body is equal to 1. On the other hand the second characteristics of a black body is that no at a given temperature no other object emits more energy than that of a blackbody. So, blackbody emits the emissive power of the black body is maximum compared to all other surfaces. So, black body absorbs anything and it emits the maximum amount of energy.

The concept of black body is extremely important in radiative heat transfer. Because, it let us you set a standard surface against which the performance of all other surfaces are to be evaluated can be evaluated. So, let us note down the special nature characteristics of a black body. It is an idealized surface, idealized concept and the first one is absorbs everything as I said ok. The second one is maximum radiation at a given temperature that is the second one and. The third one that black body is a diffuse emitter. As I said from a black body the radiation from a black body is a function radiation is a function of temperature and wavelength. So, but it is not a function of direction.

If you can compare this, what we have done in this case the radiation takes place at all wavelengths and the amount of radiation is going to be a function of temperature. So, if the if I increase the temperature I am going to get a second curve which would which would show that it is going to provide higher amount of energy so, emission. So, the radiation emission is definitely a function of lambda it is also a function of temperature. So, common sense tells us that more the temperature higher is going to be the emission. Apart from that there could be directional dependence of radiation what we call as specular, where there is the from the from the point the there is going to be different in different directions it would emmit different amounts of energy.

So, ideally the radiation is a function of temperature, it is a function of wavelength and it is function of direction. But, in for case of a black body if the radiation is not a function of direction, it is a function only of temperature and that of lambda. So, when a surface is not a function of. When the emission from a surface is not a function of the direction it is called diffuse emitter. So, in order to be a blackbody these 3 conditions are to be satisfied that it should observe all incident radiation coming at all possible coming from surfaces at all possible temperatures in all possible wavelengths.

And at a given temperature it is going to emit the maximum amount of radiation that you can think of and it is going to be at the diffuse emitter. So, examples of there are some surfaces which closely mimic the behaviour of a black body for example, the closest approximation of a blackbody. The closest approximation of a black body can be obtained when you think of a small cavity. So, this is a small cavity which you can think of with a very small opening over here. So, anything any ray which comes inside is going to be reflected multiple times and the chances of multiple time it is going to reflected and the chances of it is going back outside through the narrow pore is extremely small.

So, what it tells us is it gives us the situation in which any energy which comes inside is going to be absorbed which it is going to be absorbed multiple times inside the system and the fraction of energy which may go out is going to be extremely small. So, it obeys or it confirms to the first approximation of a black body; that means, anything which is incident on it is going to be absorbed over here. Now, let us think of the surface once again the chances of the emission that you are going to get out of this is same in all direction. So, if something leaves through this pore, it can be in any possible direction. So, therefore, this is one of the closest approximations that you can get of a black body and let us assume that you have placed an object over here.

In the one which enters is going to reflect multiple times and come to it from all possible directions right. So, energy is going to be incident on any object placed inside the cavity. So, therefore, it is going to be a diffuse a radiation of interior surfaces. Since, it is coming from all surfaces all points all surfaces all points on the surface. So, the body placed inside the cavity will experience evaporation from all possible directions. So, therefore, the black body is going to be a diffused emitter, since it is going to radiate at the object inside the inside the cavity equally with equal probability from all directions.

So, normally a cavity is the closest approximation of a black body that one can get in the. So, the properties of blackbody, the radiative properties of any real material, how they differ from that of a black body and what is the closest approximation of a black body we have discussed that. But, what is left to be left beside is: what is the black body radiation intensity. Is there a formula, is there some way by which we can find out what is the spectral and once again spectral means wavelength dependence. What is the spectral radiation intensity of a black body? As we understand it is going to be a function of temperature, it is going to be a function of wavelength. There it is going to be some other constants which are going to be involved in that expression.

So, in the next class will see: what is the spectral radiative intensity of a black body and how this can be connected with the radiation flux from a point source. If I put a point source of radiation on a given surface, how much of radiation total radiation I am going to get out of the surface.

So, that is what we will cover in the next class.