Radiative Heat Transfer
Prof. Ankit Bansal
Department of Mechanical and Industrial Engineering
Indian Institute of Technology- Roorkee

Lecture – 04
Properties of Plane Surfaces

Hello friends in the last few lectures I discussed about fundamentals of radiative heat transfer and basic laws of radiation. In todays lecture I will consider the radiation from plain surfaces.

(Refer Slide Time: 00:41)

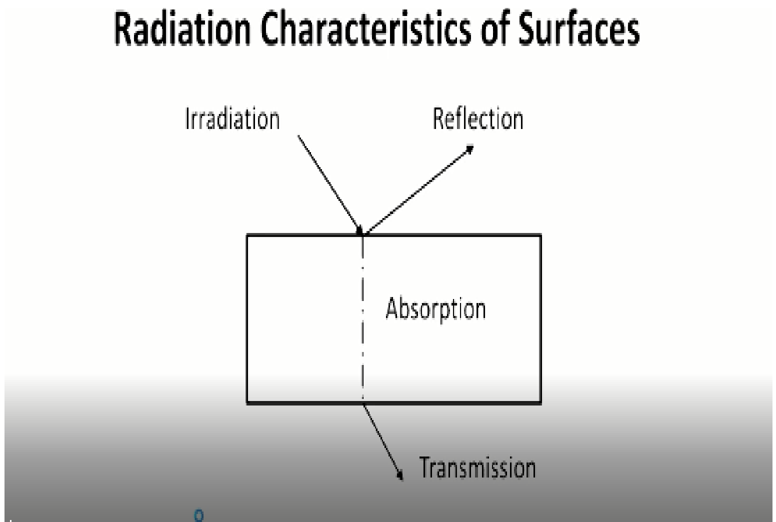
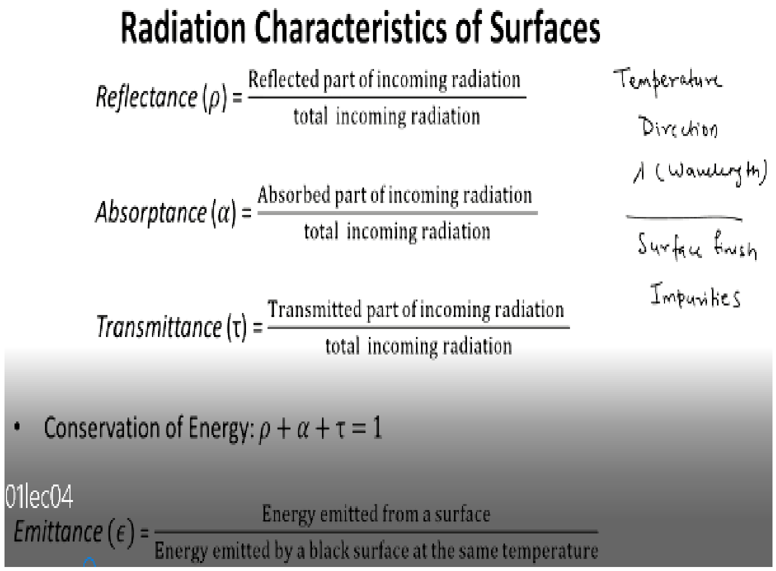


Fig. 4.1 Absorption, reflection and transmission through a plane surface.

So let us consider a plain surface of some finite thickness now radiation falls on the surface the radiation coming from some outer source the radiation that falls on the surface has 3 rules it can undergo reflection from the surface the second part can go into the surface or into the material and get absorbed and there is a third part the radiation that is not reflected neither reflected nor absorbed will be transmitted through the medium. So there are 3 components radiation deflected absorbed and transmitted.

(Refer Slide Time: 01:23)



According to the energy absorbed or reflected we define 3 parameters for the surface these parameters are Reflectance, Absorptance and transmittance and together with these 3 parameters the 4th one is also defined Emittance. Now reflectance, absorptance and Transmittance these 3 parameters not only depend on the surface property but also depend on the radiation the source of radiation from which the radiation is falling.

On the other hand, emittance is purely a surface property so we define reflectance as the reflected part of incoming radiation/total incoming radiation when we talk about total we talk about integrated over all wave lengths. As you will see in subsequent slides this reflectance absorptance and transmittance may depend on wave length and direction also but here we just give a general idea of these properties so reflectance is the reflective part of incoming radiation/ total incoming radiation.

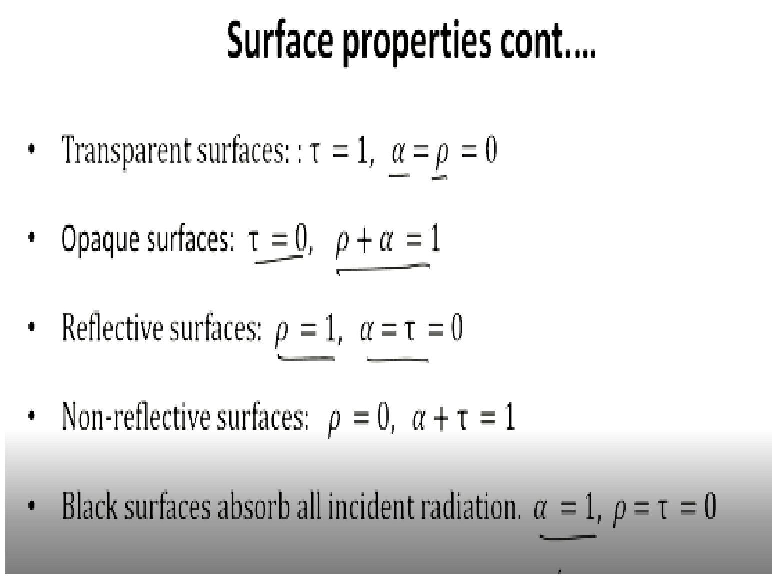
And similarly absorptance is defined as the part of incoming radiation that is absorbed within the medium or the surface/total incoming radiation and the transmitted transmittance is defined as transmitted part of the incoming radiation/total incoming radiation and these 3 components have to satisfy conservation of energy and that is why the sum of reflectance Absorptance and transmittance it should be =1.

So these 3 parameters reflectance Absorptance and transmittance are dependent on incoming radiation and we will see how to calculate these properties the 4th one is the Emittance that is defined as energy emitted from a surface/energy emitted by a black body at the same temperature so this emittance is a function of surface property a surface parameters like temperature it may also depend on some other conditions of the surface like surface roughness.

Or some impurities some quoting okay. So the parameters that basically define or govern these parameters are temperature, direction, wave length. So these are the major parameters basically that decide the amount of energy that is reflected absorbed or transmitted okay. But there are some other minor factors like surface finish okay roughness of the surface and impurities. Okay like for example aluminium surface may oxidized it over a period of time.

And its properties like reflectance and absorptance may change okay due to oxidation. So we will see how these things basically are governed.

(Refer Slide Time: 04:45)



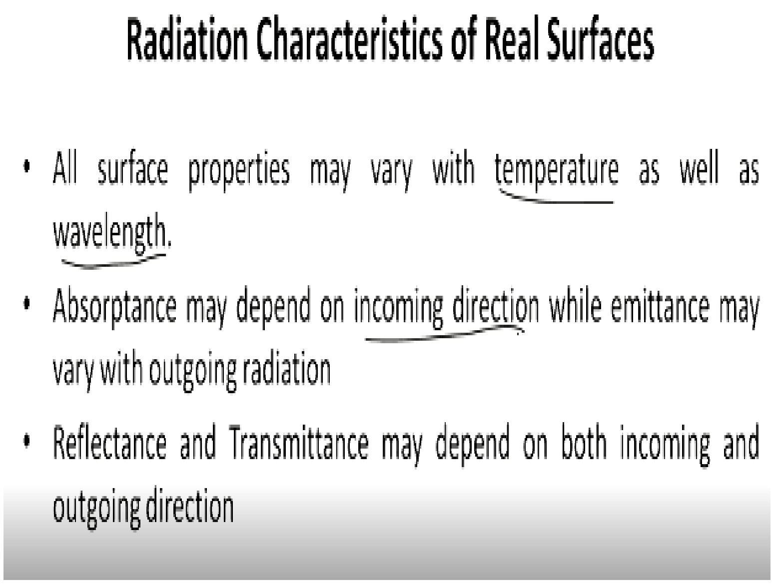
Now there are some special classes of surfaces like transparent surface, opaque surface and so on. The transparent surface is the one which does not absorb or reflect any radiation so whatever radiation falls on this surface will be basically transmitted okay so many dielectric and non-conducting materials basically come under this category. So they have very poor reflectance and absorptance the dialectic and nonconductive materials

Then we have opaque surfaces which have 0 transmittance but they have strong reflectance and absorptions. So many metals come under this category they have free electrons and these free electronics basically are responsible for strong reflectance and absorptance. Then we have reflective surfaces which are purely reflecting surfaces they have zero value of absorptance and transmittance so many polished surfaces like mirror they come under this kind of surfaces.

They reflect all the radiation that falls on them and similarly we can define non-deflecting surfaces the which do not reflect surfaces. So many non-metallic surfaces rough surfaces will come under this category and then there is a theoretically defined theoretical concept of black surface that basically absorbs all the radiation so for a black surface the reflected part and transmitted part of radiation will be 0.

All the radiation that falls on the black surface will be = absorbed part of the radiation okay and for black surface the emittance is = Absorptance as Kirchhoff law. Now this absorptance is = emittance also has some limitations we will see as we go further.

(Refer Slide Time: 06:42)



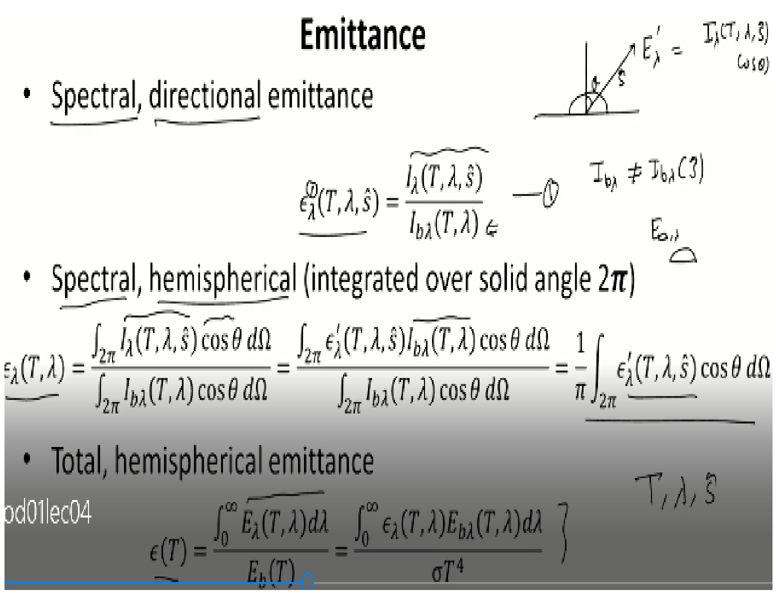
So radiation characteristics of real surface they depend on temperature as well as wave length okay as I have already told there are these are the major factors the temperature and wave length okay Absorptance may depend on incoming direction while emittance may depend on outgoing direction. So when we have heated metallic plate and we look at this heated metallic plate what we find is that it appears very bright when it is viewed at an angle okay.

It is because the metals have very high emittance when seen from an angle so emittance basically depends on outgoing direction if you look at an angle it will appear very bright if you look at the metallic plate heated metallic plate normal to it. It may not appear that bright okay similarly incoming direction also plays an important role if the sun is overhead the amount of energy absorbed by a solar collector is going to be more.

If the sun is at an angle, then the Absorptance will change and that same amount of energy will not be absorbed. When we are standing in front of fire our body is exposed to different type of radiation as compared to when we are standing in front of the fire okay and similarly the reflectance and transmittance will depend on the direction of incoming radiation as well as the direction of outgoing radiation.

So direction plays an important role in radiative heat transfer and we will see as we discuss each of these quantities.

(Refer Slide Time: 08:23)



So the first quantity that we discuss is emittance okay. So emittance is purely a surface property okay and it is defined as amount of energy emitted from a surface/amount of energy emitted by a black surface at same temperature okay. So we define spectral means at a particular wavelength and directional that means at a particular in a given direction. So for example we have a surface so we are talking about amount of energy emitted in a given direction.

So this is basically e lambda prime directional emittance okay and this will basically nothing I lambda cos theta where theta is the normal angle. Okay so amount of energy emitted in a given direction at a given wave length/same amount of energy emitted by a black surface Ib lambda not please note that in expression of ib lambda I have not used the direction S cap okay because the intensity of black body is isotropic.

That means intensity Ib lambda is not a function of the direction so it is independent of direction d that is fine the denominator there is no S cap so this is the spectral directional emittance okay amount of fraction of the amount of energy emitted in a given direction at a given wave length. Okay now we other 2 more quantities spectral hemispherical and emittance now hemispherical means integrated over the entire solid angle okay.

So the symbols sometimes use is this okay so we write E lambda okay that when we write this sometimes this is used or we simply call it spectral hemispherical emittance we mean basically amount of energy emitted at a given wavelength in all the directions that is 2 pi solid angle. So how do we find it so epsilon lambda t lambda that is hemispherical emittance I have not used the prime here which is basically denoting the direction.

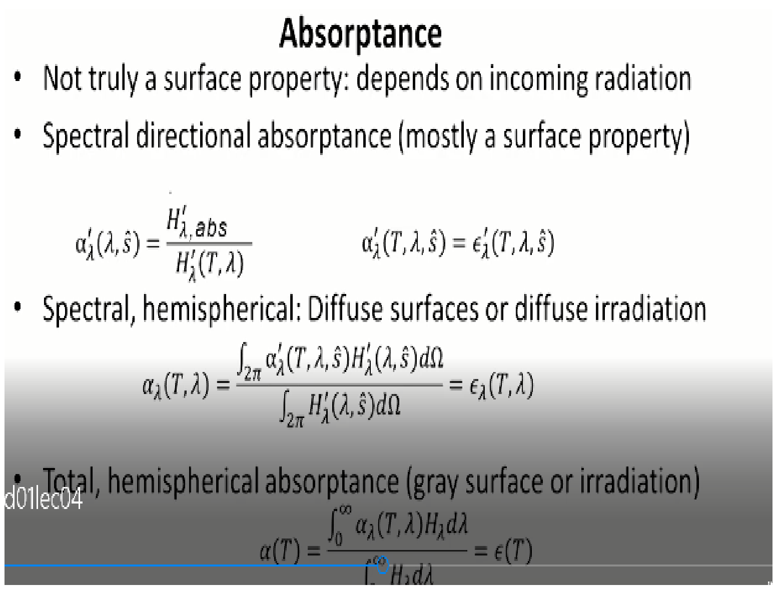
So this is hemispherical so we integrate over the solid angle 2 pi both in the numerator and the denominator so we write spectral directional intensity multiplied by cost theta power angle and integrated over the solid angles. Okay now this intensity from this can be substituted from this expression. So we can write I lambda as = epsilon lambda prime times Ib lambda so from this let us call this equation 1 and from equation 1.

We substitute the expression for I lambda and what we get is this expression. Now under certain assumptions we can take either Ib lambda out of this integral or this epsilon lambda out of the integral okay. So we will see this in a while but for this case Ib lambda is independent of direction so this can be pulled out okay. We can take out Ib lambda from numerator as well as a denominator.

And this expression simplifies to 1/pi integral/2 pi directional spectral emittance integrated/solid angle okay so this is the expression for spectral hemispherical emittance. Now we also define total hemispherical emittance that means integrated over all the solid angles and also integrated over all the wave length. So this is defined as the amount of energy emitted integrated over all the wave lengths from 0 to infinity/the total black body emissive power okay Eb.

So this basically gives you the expression for total hemispherical emittance. So these 3 quantities are of interest and all these 3 quantities are basically dependent on temperature, wave length and direction. Okay so they are purely surface properties okay as compared to absorptance and reflectance. That depend on incoming radiation these are purely surface properties here is an example that basically shows you the emittance.

(Refer Slide Time: 12:54)



On the left figure is basically the emittance of some non-conductors like wood, aluminium oxide copper oxide glass okay and what we observed so the XX is or basically this is a polar chart the radius here that direction of radius basically represents the magnitude of emittance while the theta direction represents the angle of emitted energy. So 0 means normal to the plane of the surface and we see that starting from 0 degree.

That is normal to the plane and up to the value of around 70 degrees non-metals have very good emittance. They emit good amount of energy in the angle 0 to 70 degree while they emit very small amount of energy at the grazing angles of 70 to 90 degrees in this range. So if the angle is very large very less amount of energy is emitted okay so you should not be able to receive much of variation from a non-conductor non-metallic surface.

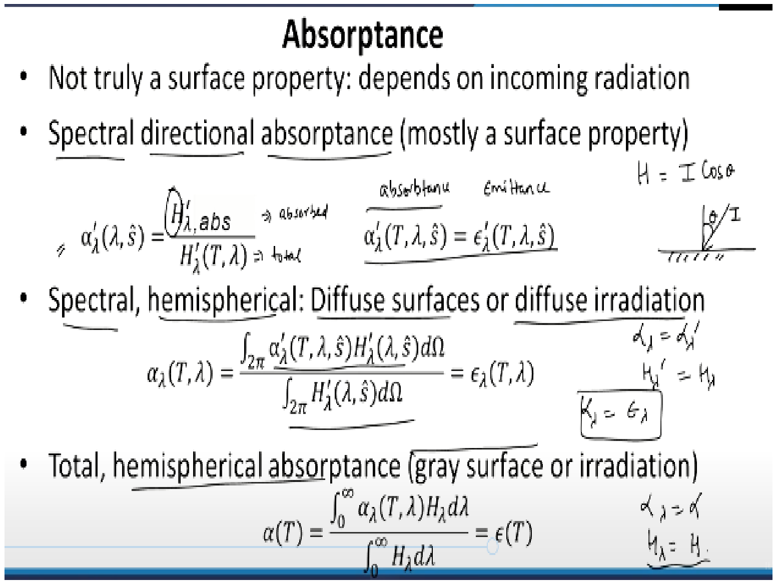
If you are looking at the surface from an angle > 70 degree in contrast to non-metals the right picture shows you the emittance of metals. Now metals have almost very small compared to non-metals they have very low emittance in the entire direction starting from 0 degrees to 90 degree the values varies from 0.06 at 0 to 20 degree here to a value of 0.14 so the values compared to non-metals are very less.

But they are even less at the angles 0 to near normal so metals have low value of a maintenance at a normal direction non-metals have high value at normal direction. Non-metals have poor value of emittance at grazing angles 70 to 90 degree while metals have relatively high emittance in those range okay. So a metal surface will appear very bright when looked at an angle close to 70 80 degree it will appear very bright because of the emittance which is higher in this range.

Okay then we define a diffuse emitter or a Lambert surface in which case emittance is same in all direction that means epsilon lambda=epsilon lambda prime that means it is independent of direction whatever direction it is coming from is equal okay all the direction the emittance is same such a emitting surface is called diffused emitter or Lamberts surface okay. So okay so metals have that I have explained and then we define gray surfaces.

In which emittance does not depend on wave length okay so in this case epsilon is=epsilon lambda all the wavelengths have the same value epsilon. So when we have such a surface in which emittance does not depend on wave length such a surface is called gray surface.

(Refer Slide Time: 15:57)



The second quantity is absorptance now as I have already told absorptance, reflectance and transmittance they are not purely a surface property. They depend on incoming radiation no we define just like emissive power is the outgoing energy from the surface we define irradiation H is basically a magnitude of incoming radiation so we have incoming intensity let us say I and then we multiply by cos theta this is basically =H.

The incoming intensity so let us say we have a surface and radiation is falling on the surface with intensity I okay. And the angle made by this is theta so H is the amount of energy falling on the surface that is called irradiation okay. So we define absorptance, spectral directional is represented with the superscript prime absorptance at a given direction. In a given direction at a given wavelength.

The spectral directional Absorptance is defined as the ratio of energy absorbed by the surface in a given direction in a given wave length/total energy falling on the surface. So this is the total energy total irradiation and this is basically absorbed part okay so redefine spectrum direction Absorptance in this way. Now in thermodynamic equilibrium and that is basically a most surfaces qualify this can be taken as.

Or assumed as a surface property spectral directional absorptance can be taken as a surface property however total and hemispherical absorptance cannot be taken as a surface property. As you will see but directional spectral Absorptance can be taken as surface property and it qualifies the Kirchhoff law. So emittance the spectral directional emittance =spectral directional Absorptance this is a surface property.

Now we define spectral hemispherical absorptance just like redefine spectrum hemispherical emittance we integrate over all the solid angles. So amount of energy absorbed by the surface/total energy falling on the surface integrated over the entire solid angle of 2 pi. Now if by chance we can take out this actually lambda out of the integral or we can take out alpha lambda prime out of the integral the simplified this analysis.

Now this can be taken out of the integral in two conditions one is diffused surface now we already know what is the diffused surface epsilon alpha lambda =alpha lambda prime okay. If alpha lambda prime= alpha lambda we can take it out okay or diffuse irradiation that means H lambda prime=H lambda that means irradiation is independent of direction. So under these two conditions either of the quantity can be taken out of the integral.

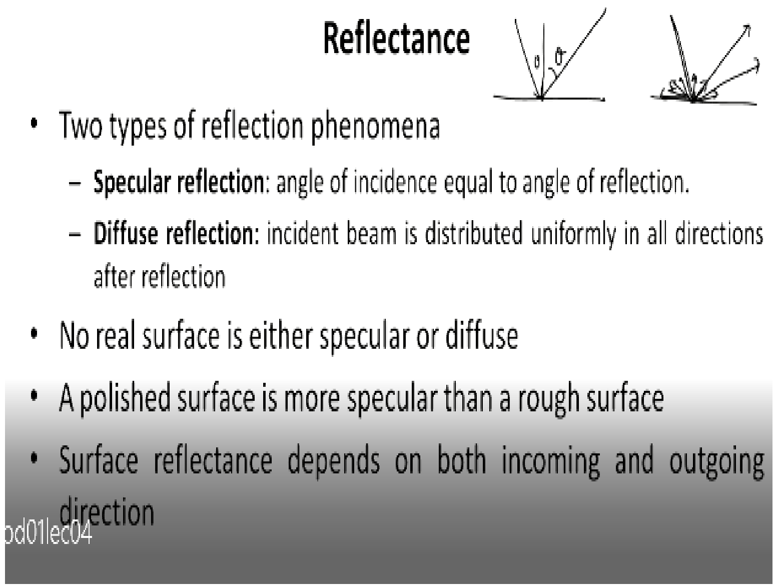
And the analysis becomes very simple and alpha lambda=epsilon lambda. So this is not a surface property it is a surface property only if the surface is diffused or the irradiation is diffused. So under these two conditions only we can write alpha lambda=epsilon lambda otherwise we cannot write it okay similarly we define total hemispherical Absorptance okay by integrating over all the wavelengths.

So alpha lambda T lambda irradiation H lambda/total irradiation falling on the surface. Now again with the same argument we have to take out this alpha lambda and H lambda out of the integral. Now this can be done in two situations when the surface is gray that means alpha lambda is = alpha then we can take it out of the integral or H lambda is = H okay now this is very restrictive.

Okay to have irradiation independent of wave length is very difficult to have in practice. So mostly this expression will be valid only for a gray surface that means it absorbs radiation in dependent of wave length the same magnitude. The surface is gray we can take alpha lambda out of the integral and then in that case alpha will be = epsilon that means total hemispherical absorptance= total hemispherical remittance.

Okay so the third quantity is a reflectance there are two types of reflectance as I have already told.

(Refer Slide Time: 20:55)

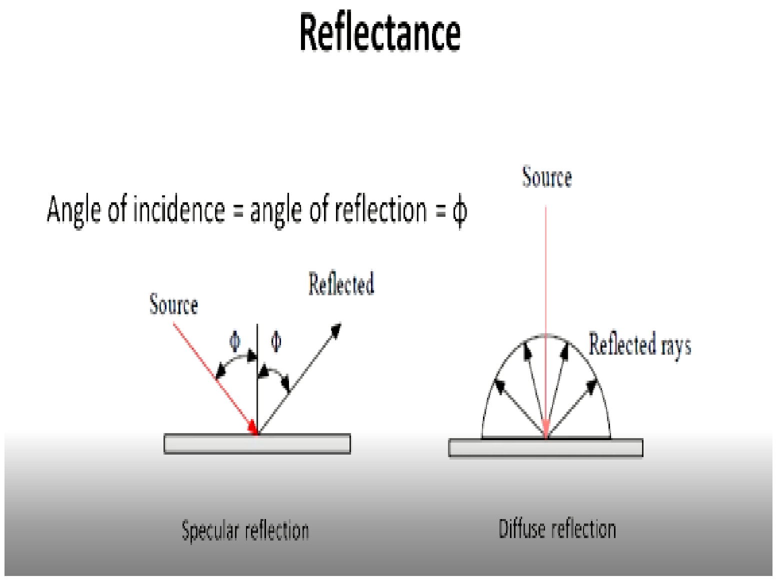


One is a specular the radiation coming from one side at an angle theta it goes into another direction making the same angle it follows geometric laws of optics and this is this type of reflectance or reflection is called specular reflectance okay. Where we have a ray coming at an angle and it reflects back at the same angle this type of reflectance is specular reflection. Then we have another type of reflection we call diffuse reflection.

Where we have radiation coming from one side but it is equally reflected in all the directions okay this is diffuse type of reflectance. So mostly so there is no real surface that basically satisfies specular or diffuse polished surfaces like mirror they behave very much like a specular reflector okay a polished surface is more like a specular then a rough surface if you have a rough surface and then it will behave like a diffuse surface.

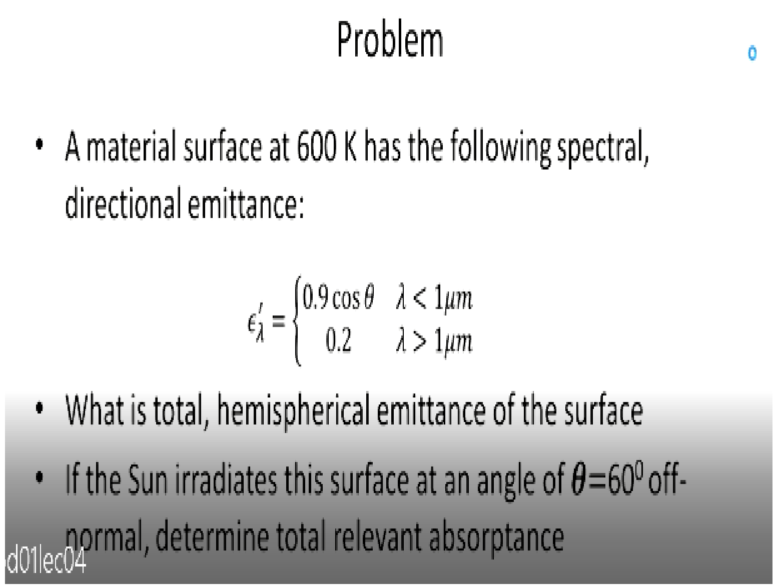
It will reflect relation in all the directions that reflectance the property reflectance will depend on incoming radiation in coming direction as well as outgoing direction. So amount of energy reflected coming from this direction and going in this direction okay is different from coming in this direction and going in this direction. So incoming direction as well as outgoing direction both are important to calculate the value of row both the directions are important. The incoming direction as well as the outgoing direction.

(Refer Slide Time: 22:26)



So this is just a pictorial representation of specular and diffused reflection okay specular incidents angle is = angle of reflection while in reflected whether the direction of incoming radiation is normal or off normal all the energy will be reflected equally in all the directions. So that is basically the diffuse reflectance.

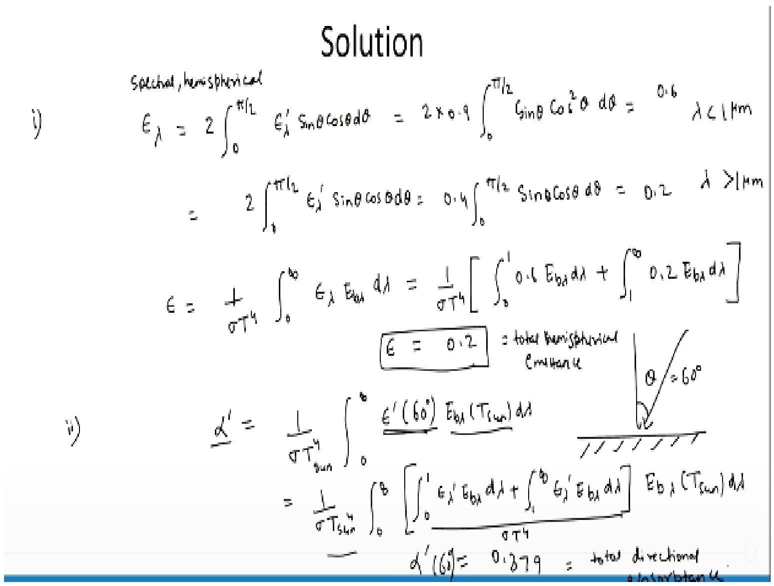
(Refer Slide Time: 22:48)



So let us do one problem on the concepts learned in this class okay we have a material surface maintained at 600 kelvin with directional spectrum and emittance =0.09 cos theta where theta is the polar angle wave length range <1 micron and the value is 0.2 for wavelength range >1 micrometre we have to find out total hemispherical emittance of the surface okay this is not a property that depends on irradiation.

This is a purely a surface property we also have to find the relevant absorptance for the radiation coming from the sun okay this is going to be a property depending on the sun radiation. Okay the angle of theta is given as 60 degree.

(Refer Slide Time: 23:35)



So let us solve this problem okay we will use this expression for so we have to find out let us look at the expression that we have derived. So we will be using this expression for spectral hemispherical emittance and total hemispherical emittance okay so we first find out the total sorry spectral hemispherical evidence spectral hemispherical okay epsilon lambda is = 2 0 to pi/2 so there is no dependence on azimuthal angle.

So we have already taken out the azimuthal path the only dependence is on polar angle epsilon lambda prime sin theta cos theta d theta okay. We are basically integrating over all the solid angles okay and this will be equal to so we have been given this value 0.9 cos theta okay so

2*0.9 okay 0 to pi/2 sin theta cos square theta okay d theta. We have substituted the value 0.9 cos theta for epsilon lambda prime okay.

And this value will basically come out to be I am just leaving the integration part to you. So this will be given by 0.6 the value will come out to be 0.6 for lambda value <1 micrometre. Okay so for wave length range in lesson one micrometre the emissive with emittance spectral hemispherical emittance is 0.6. Now the same value we can find out for wavelength range <1 micrometre this will be = 2 0 to pi/2 epsilon lambda prime sin theta cos theta d theta equal to.

Now this value is 0.2 constant so this will be 0.4 0 to pi/2 sin theta cos theta d theta okay and this value will be coming to 0.2 okay for lambda value >1 micrometre. So this is the spectral hemispherical emittance now we have to find out total a total hemispherical emittance. So total hemispherical emittance will be = 1/sigma T to the power 4 where T is the temperature of the surface 600 kelvin integrated over the wave lengths 0 to infinity.

Epsilon lambda Eb lambda d lambda okay amount of energy emitted by the surface/amount of energy/by a black surface so this will be = 1/sigma T to the power 4 we have to divide in the wave length range 0 to 1 and 1 to infinity 0 to 1 epsilon lambda is 0.6. Eb lambda d lambda + 1 to infinity 0.2 Eb lambda d lambda okay and this value we can easily solve this value will come out to be 0.2 okay by using this black body emissive power tables.

We can calculate this expression okay and this value will come out to be 0.2. So total hemispherical emittance is =0.2 okay now we have to find out so this is the first part we have to find out the relevant absorptance. Now solar angle the solar energy is coming at an angle theta which is =60 degree so we have to find out total directional absorptance we have to find out epsilon prime okay.

So this epsilon prime will be =1/sigma t to the power 4 where T is the sun temperature okay integrate it over all the wave lengths 0 to infinity directional emittance epsilon prime okay at an angle of 60 degrees and then Eb lambda at the sun temperature d lambda okay. So this will be =

1/sigma t to the power 4 0 to infinity now epsilon prime integrated over all the wave level and 60 degree okay.

So we have to first evaluate this so this will be = 0 to 1 okay we have this dependence 0.9 cos theta so we will write this like this 0 to 1 epsilon lambda prime Eb lambda d lambda + 1 to infinity epsilon lambda prime Eb lambda d lambda so this is going to be epsilon prime at 60 degree angle. Okay and then we just multiply by this will be divided by sigma T to the power 4 okay and then you multiply by Eb lambda T sun d lambda.

Okay so let us see what we have what I have done so 1/sigma so we had we have to find out directional total absorptance alpha prime integrated for all the wave length. So what I have done is I have taken directional emittance at 60 degree angle integrated over all wave lengths multiplied by solar spectrum Eb lambda. And then integrated over all the wave lengths so 1/sigma T sun power 4 remains the same 0 to infinity.

Now this epsilon prime is basically done on this type of calculation that we have done in the first part. So epsilon prime is epsilon lambda prime for lambda <1 micron it will be = 0.9 cos theta okay so 0.9 cos theta Eb lambda at the surface temperature d lambda and divided by sigma to the power 4 similarly +1 infinity epsilon lambda prime Eb lambda d lambda okay. And then Eb lambda T sun D lambda okay.

So when we solve this basically what we get is = alpha prime is = in 60 degree angle this will be = 0.379 okay so this is our total hemispherical emittance and this is = total directional absorptance okay. I thank you for giving your kind attention so I wind up this lecture with this numerical problem thank you.