Heat and Mass Transfer
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Lecture No. 11
THERMAL RADIATION 2

We were discussing the laws of back body radiation and last time when we stopped, we had stated 2 laws - Planck's law for giving us the monochromatic emissive power of a black surface and Wien's law which gives us the value of the wavelength at which the maximum value of the monochromatic emissive power occurs. Today we will take up the next law, the third law that is the Stephen Boltzmann law; the Stephen Boltzmann law is, gives us the emissive power of a black surface.

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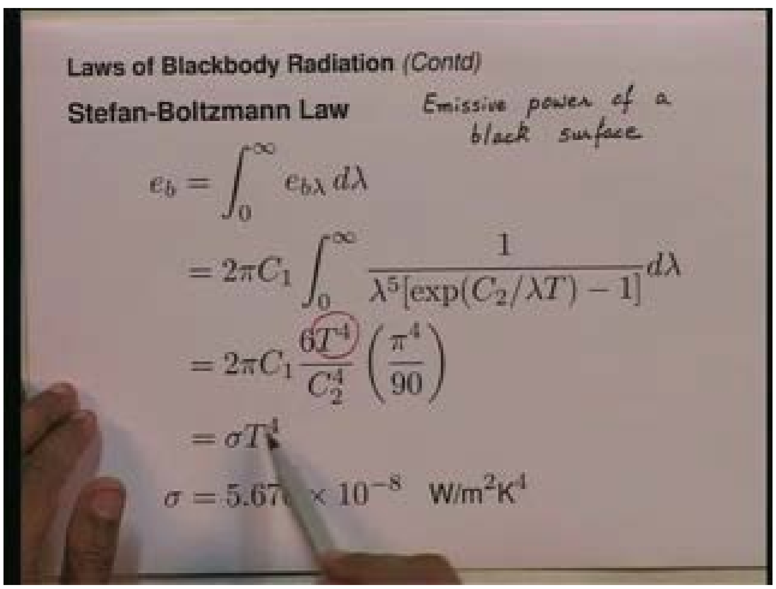

This Stephen Boltzmann law is for the emissive power of a black surface; Planck's law is given as e_b lambda so if I want to know what is the emissive power, what is the emissive power of a black surface, obviously I need to integrate e_b lambda over all the wavelengths for which the radiation is been given off and all the wavelengths for which the radiation is been given off and all the wavelengths are from 0 to infinity. So the emissive power of a black surface e_b is obviously nothing but the integral 0 to infinity e_b

lambda d lambda. So let us substitute Planck's law for e_b lambda; if I substitute Planck's law, I will get 2 pi C_1 integral 0 to infinity 1 upon lambda to the power of 5, e to the of power of C_2 by lambda T minus 1 the whole thing multiplied by d lambda. I have just substituted e_b lambda from Planck's law into this expression.

Now we have to perform this integration; I am not going to do it here in the class but what I am going to tell you is - it is possible to perform this integration by expanding the e term, e to the C_2 by lambda T term into a power series into a series expansion and then integration term by term. If you do that you will get a convergent series; you will get the result in the form of a convergent series which sums up to pi to the power of 4 into 90. So the net result of doing this integration which I am not doing here but I am saying it can be done; it is not a very difficult integration, is to give you a final expression of the form 2 pi C_1 which is any way there outside the integral and the whole integral 0 to infinity - all this expression gives you 6 T to the power of 4 upon C_2 T to the power of 4 divided by pi to the power of 4 into 90.

Now all this is a constant - 2 pi C_1 is a constant which is given by Planck's law, 6 is a constant, C_2 to the power of 4 is a constant, pi to the power of 4 upon 90 is a constant; so leave out T to the power of 4 which is the absolute temperature to the power of 4 and club all this remaining together into 1 constant, the rest of it. And what we get is therefore, this expression is equal to sigma into T to the power of 4 where sigma is all this - 2 pi C_1 into 6 upon C_2 to the power of 4 into pi to the power of 4 upon 90 and sigma if you substitute all the values comes out to be 5.670 into the 10 to the minus 8 watts per meter squared Kelvin to the power of 4. It is a constant with these values so the net result as the integration is to give us the emissive power of a black surface e_b is equal to sigma T to the power of 4 and this is called the Stefan Boltzmann law.

So, the Stefan Boltzmann law I repeat is nothing but a law which is obtained by integrating Planck's law which gives us an expression for e_b lambda, integration Planck's law over all wavelength from 0 to infinity this Stefan Boltzmann law after doing that integration says e_b is equal to sigma T to the power of 4 and sigma is given is a constant called the Stefan blotzmann constant given by this value 5.67 into 10 to the minus 8 watts per meter squared Kelvin to the power of 4.

So, we have 3 laws now for black body radiation - Planck's law which give us the monochromatic emissive power of a black surface, Wien's law which gives you the wavelength at least the maximum value of monochromatic emissive power occurs at a particular temperature and Stefan Boltzmann law which gives the emissive power of a black surface. Now let us do a problem; the problem which we are going to do is the following.

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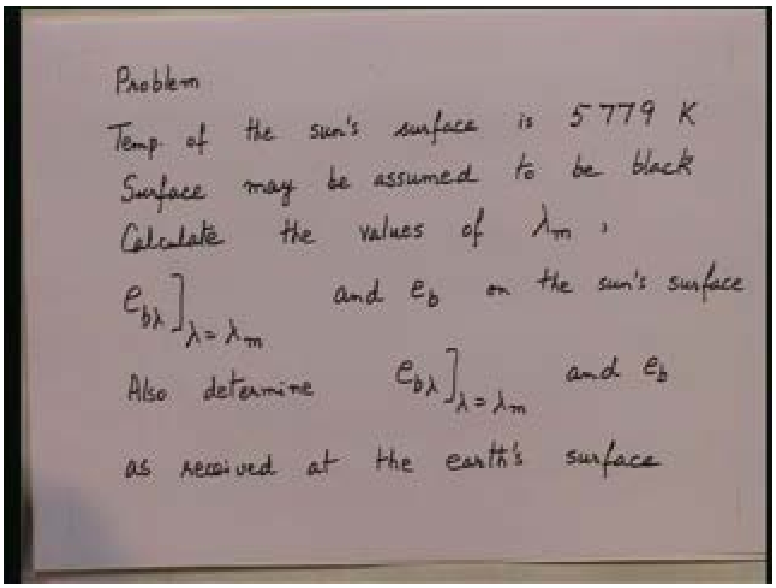

Let us do the following problem; let us say we would like to find; the problem is concerned with finding the radiation given off from the sun. The temperature of the sun's surface, temperature of the sun's surface is 5779 Kelvin - take this value as a temperature of the sun surface. And this the surface may be assumed to be black surface, sun's surface may be assumed to be black. We are required to calculate the values of, calculate the values of lambda m e_b lambda at lambda equal to lambda m and e_b. Calculate these quantities using the laws which we have just stated. Calculate the values of m e_b lambda at lambda equal to lambda m and e_b on the sun's surface; that is the problem. Also determine e_b lambda at lambda equal to lambda m and eb as received at the earth's surface. What are the values of these quantities as received at the earth's surface - this is the problem.

Now we take, we will take the following data for doing the problem; we will say take

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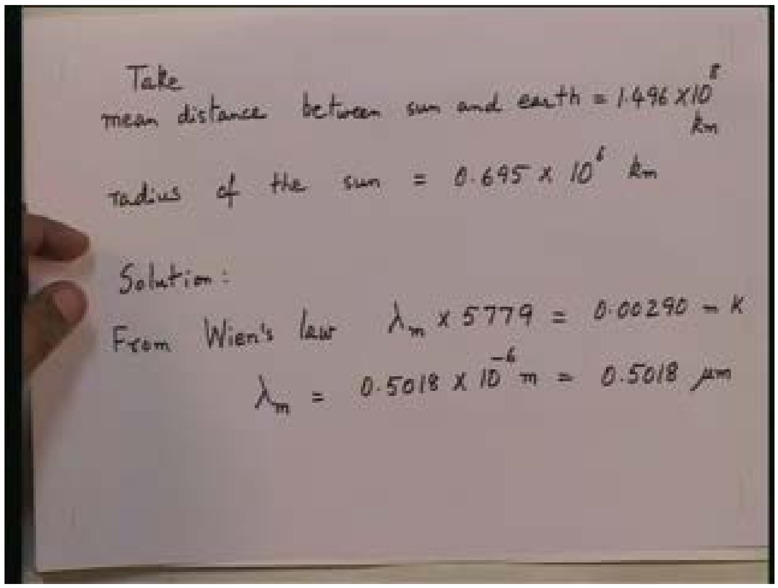

mean distance between the sun and the earth, take the mean distance between sun and the earth to be 1.496 into 10 to the power of 8 kilometers and take the radius of the sun to be equal to .695 multiplied by 10 to power of 6 kilometers. These are rough, these are values which are usually taken as the mean distance between the sun and the earth. The earth has an almost circular orbit around the sun; take the mean distance to be 1.496 into 10 to the power of 8 kilometers, take the radius of the sun to be .695 into 10 to the power of 6 kilometers, this is the problem.

So let us do it now; first of all let us apply Wien's law. From Wien's law what do we get? The value of lambda m to be lambda m multiplied by 5779 – that is the temperature of the sun surface. Wein's law says this is equal to .00290 meter Kelvin; therefore lambda m from Wein's law straight away comes out to be.5018 multiplied by 10 to the minus 6 meters or if I multiply this by 10 to the power of 6 it is .5018 microns, micrometers; so that is the value of lambda m.

Now let us apply Planck's law; from Planck's law we will get the value of e_b lambda and we want it at lambda equal to lambda m. So let us put that value, this value of lambda m which you just found out. So now let us apply Planck's law to get e_b lambda at lambda equal to lambda m, so we get from Planck's law

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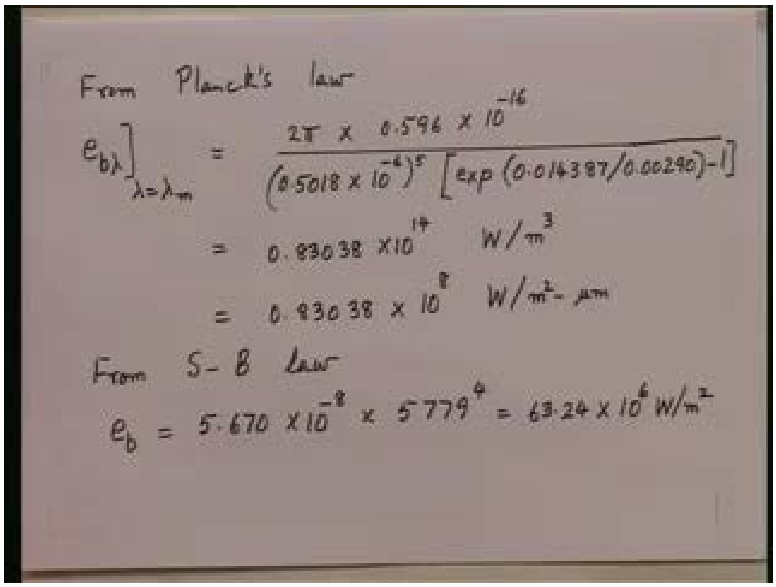

e_b lambda at lambda equal to lambda m is equal to 2 pi C_1 2 pi multiplied by C 1.596 to 10 to the minus sixteen. This is the constant C_1 divided by the lambda to the power of 5, divided by lambda to the power of 5; let us put that .5018 into 10 to the minus 6, the whole thing to the power of 5 into exponential of C_2 by lambda T. C_2 is .014387, lambda T will be .00290 minus 1 and close the bracket; that is equal to, that will come out equal to, on doing the calculation we will get this is equal to .83038 into 10 to the 14 watts per meter cube or if you want to express it in the units which we usually do 8308 into 10 to the power of 8 watts per meter squared micron. This is the unit usually used for e_b lambda so this is the next value which we are looking for - the value of e_b lambda at lambda equal to lambda max.

Now let us get the value of e, e_b rather so we will get from the Stefan Boltzmann law, from Stefan, I will write just S B law e_b is equal to sigma 5.670 into 10 to the minus 8 multiplied by 5779 to the power of 4 T to the power of 4 where T is in absolute Kelvin is equal to, that comes out equal to 63.24 multiplied by 10 to the power of 6 watts per meter squared. So that is the value of e_b - this is the first part of the problem. Now the next part is you are asked also to find the values of e_b lambda at lambda equal to lambda m and e_b at the earth's surface; so that's the next part.

Now mind you, you should note what is happening to the radiation which comes out from the sun. Suppose let us say this is the sun; let me just draw the sun here.

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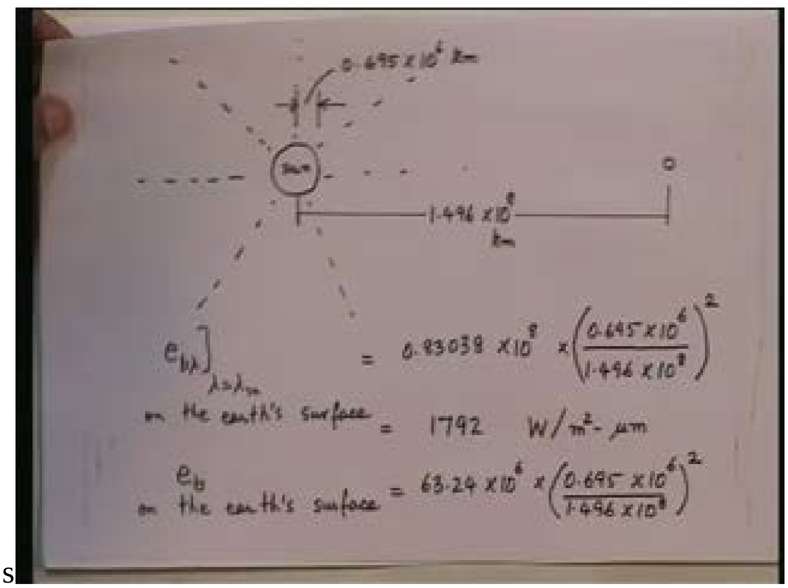

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Let us say this is the sun; radiation from the sun is going out like this in all directions spherically, that is how the radiation from the sun is going out, isn't it? And let us say this is the earth here. We are told that the average distance between the sun and the earth, the average distance – let us put that down - between the sun and the earth is 1.496, average distance 1.496 into 10 to the 8 kilometers; this is the earth, this is the sun and the radius of the sun, the radius of the sun is .695; this is the radius of the sun .695 into 10 to the 6 kilometers, .695 into 10 to the 6 kilometers - this is the geometry we are dealing with.

We have the value of e_b lambda and e_b at the sun's surface that is right here where I am showing it; we want the value at this point, that is at the earth's surface. Now mind you, I am not distinguished between the earth's surface and the center of the earth because the radius of the earth is so small there is no point in worrying about that here because of the distances, their other distances involved. So we have a value of e_b lambda and e_b out here, we want the value here.

Now the radiation coming out on the sun is going out spherically in all directions; so obviously it is going to be, the flux is going to be inversely proposanal to the square of the distance because the surface area of a sphere is 4 pi r square therefore e_b lambda, we can straight away say e_b lambda equal to lambda max at the earth's surface; on the earth's surface it is inversely, the value will be inversely proposanal to the square of the radius. So it is simply going to be equal to the value that we got previously .83038 multiplied by 10 to the power of 8. This is how many watts per meter squared micron multiplied by the radius of the sun .695 into 10 to the 6 divided by the distance between the sun and the earth which is 1.496 into 10 to the 8 and the square of this because it's inversely proportional to the square and that will come out to be 1792 watts per meter squared micron.

So from Planck's law if I take the average temperature of the sun's surface to be 5779, the value of, the maximum value of the monochromatic emissive power at the earth's surface is 1792 watts per meters squared micron. Similarly the value of e_b on the earth's surface will be given by 63.24 into 10 to the 6; that is the value on the sun's surface multiplied by .695 into 10 to the 6 divided by 1.496 into 10 to the 8, the whole thing squared and that will come out to be - if you calculate it, you will get the value to be, that is equal to

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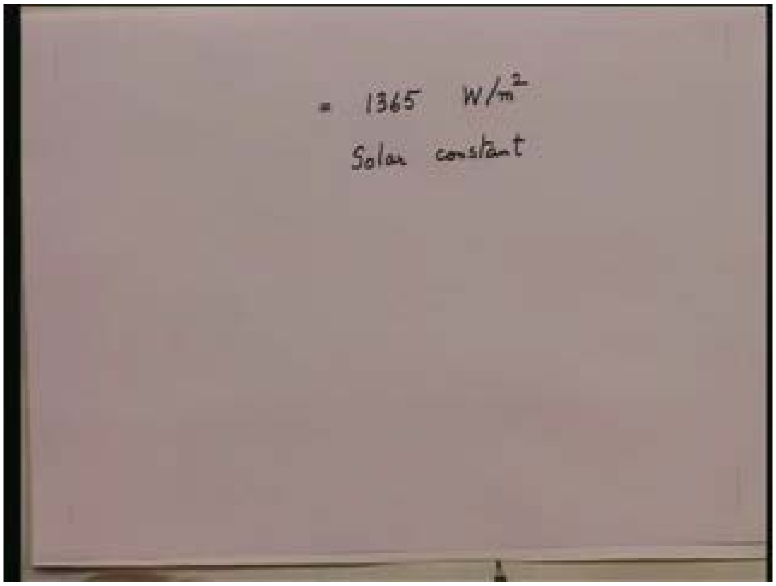

1365 watts per meter squared so that is the flux received at the earth's surface, e_b as received at the earth's surface emitted from the sun. This particular quantity is in fact called the solar constant, this is called the solar constant; so here is a simple problem which we have done to illustrate how to use all the laws of black body radiation - Planck's law, Wien's law as well as the Stefan Boltzmann law. Now if all these laws give you values for black surfaces but as an engineer we are dealing with real surfaces.

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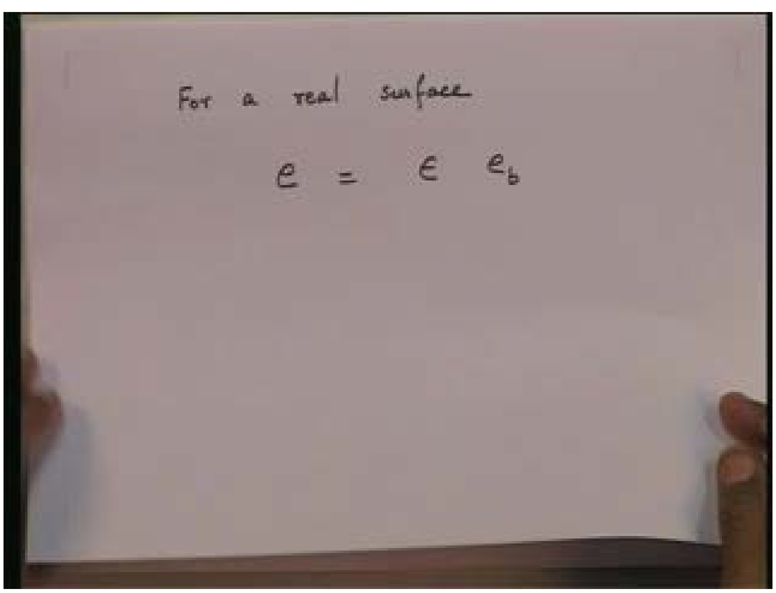

Real surfaces are not black surfaces; they have emissivities, some value of emissivity and for a real surface you know e is equal to, the value of e is equal to - for a real surface the value of the emissive power is the emissivity into the value e_b which is for a black surface; so e_b I will get from the Stefan Boltzmann law but epsilon - the emissivity of the surface - I need to know, that is a property of the surface. So just like when we did calculation in conduction, you need to know the value of thermal conductivity k everywhere.

Similarly in radiation if you know, want to know how much is going to be radiated from the surface which is at a given temperature, you need to know the emissivity of that surface. So there is a lot of data available in the literature, measurements made by various investigators over years which give us values of emissivity for all kinds of surfaces that we use in practice. Now let us look at a few such - the values I am going to show you, some values of emissivity for some common surfaces just to give you a feel for the numbers that are involved.

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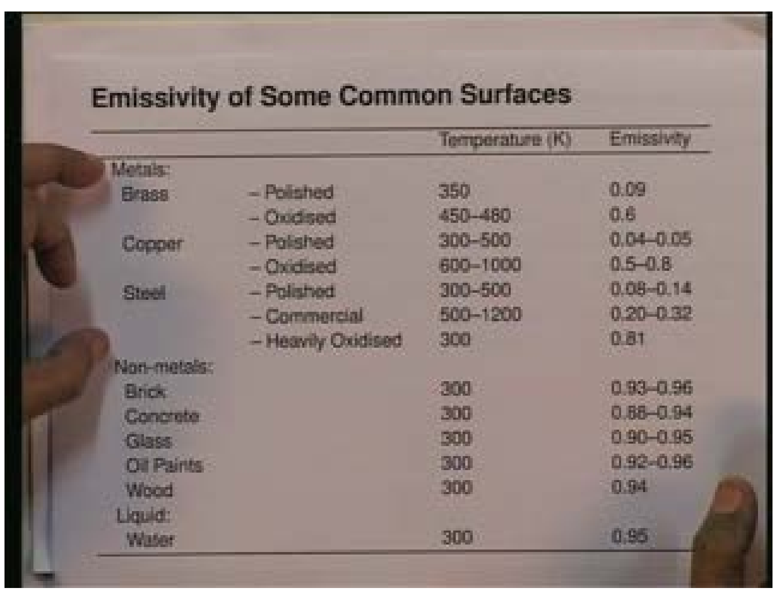

Emissivity of Some Common Surfaces

		Temperature (K)	Emissivity
Metals:			
Brass	– Polished	350	0.09
	– Oxidised	450–480	0.6
Copper	– Polished	300–500	0.04–0.05
	– Oxidised	600–1000	0.5–0.8
Steel	– Polished	300–500	0.08–0.14
	– Commercial	500–1200	0.20–0.32
	– Heavily Oxidised	300	0.81
Non-metals:			
Brick		300	0.93–0.96
Concrete		300	0.88–0.94
Glass		300	0.90–0.95
Oil Paints		300	0.92–0.96
Wood		300	0.94
Liquid:			
Water		300	0.95

So here is a table showing the emissivity of some common surfaces, a table showing the emissivity of some common surfaces - the emissivity of some common surfaces. I have grouped the matter into 3 things that is – first, I am going to talk about the emissivity of metal surfaces, then the emissivity of nonmetal surfaces, then the emissivity of liquid surfaces one by one. So, let us look at the first, the emissivity of and let me just blank off the other so that your attention stays only on the first part; let us focus our attention first on the emissivity of metallic surfaces.

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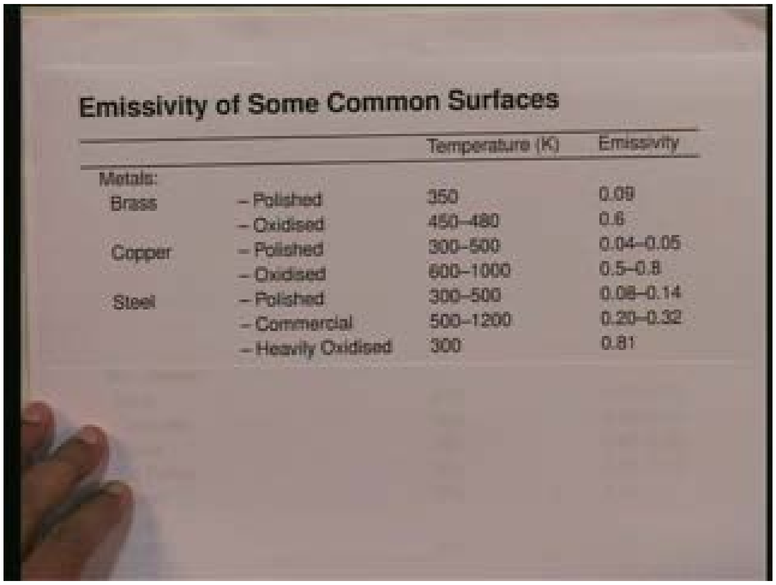

I have picked 3 here as an example, which are the 3 – brass, copper, steel and in each case I have distinguished between polished surfaces and oxidized surfaces. Polished, oxidized, polished, heavily oxidized and for steel I have also talked of commercial surfaces. Now notice the emissivity for a polished surface, polished brass surface as measured .09, polished copper surface .04 to .05, a polished steel surface .08 to .14. So, notice that once you, when you have a polished metallic surface, the value of emissivity is quite low - it has to be between 0 and 1; it is quite low, usually less than .1; .09, .04, .08 are typical values.

The moment the surface is oxidized, the value goes above .5. Look at oxidised brass - .6; look at oxidised copper - .5 to 8; look at heavily oxidised steel .81. So the movement I have an oxidised metallic surface, the value will usually be grater than .5 may be .6, .7,

.8, something like that. So this is the left thumb rule to remember - a polished metallic surface may have an emissivity of the or of .1 or less. An oxidised metallic surface would typically have values greater than .5, .6, .7 something of that order – that is one comment. If you really want of course to have precise values, you need to go to handbook. These are just some rough indicators of the type of values we get. Now let us look at the next class; that is I have put down the emissivities of some nonmetals.

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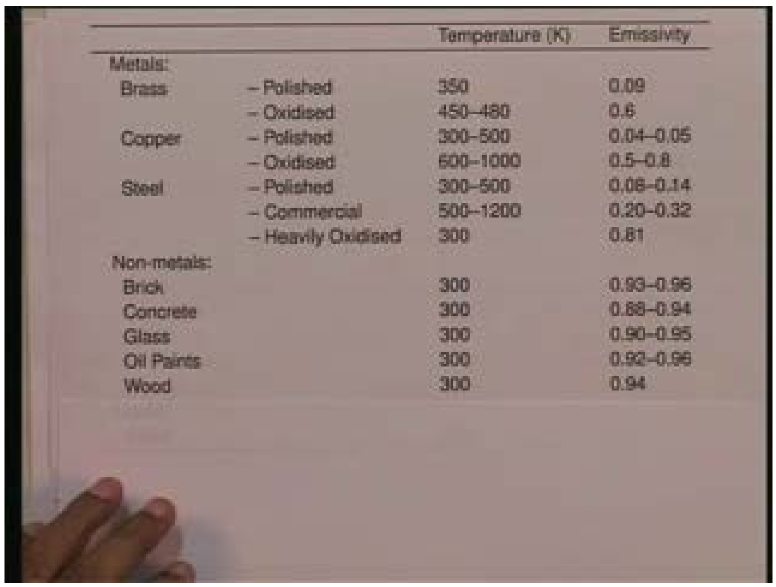

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Non-metals:			
Brick		300	0.93–0.96
Concrete		300	0.88–0.94
Glass		300	0.90–0.95
Oil Paints		300	0.92–0.96
Wood		300	0.94

Here are some emissivity of non-metals - Brick, concrete, glass, oil paints, wood - a variety of nonmetallic surfaces and look at the emissivity values. Brick - .93 to .96, concrete .88 to .94, glass .90 to .95, oil paints .92 to .96, wood - .94. So typically a nonmetallic surface would typically have a value greater than .8 more like .9 in most cases. A nonmetallic surface usually has an emissivity of the order of .9, .8, .95, something like that; so that is a second comment which, second comment about emissivity values. Again I repeat, you want precise values, you need to go to handbook because emissivity will also be a function of temperature; here I have given the value at a particular temperature. It will be a weak function of temperature not varying that strongly but nevertheless a function of temperature.

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And finally I have given the value for one liquid surface and that is water. Notice for water the emissivity value at room temperature – that is about 300 k, value is .95. Water has an emissivity of .95 at a room temperature about 300 k. This is true of most liquid surfaces; the emissivity values will be around .9, .95 for most liquid surfaces. So I want you time keep these magnitudes of emissivity in mind when you do approximate calculation in radiation. Exact values of course can always be obtained from the handbooks which are available in which measurements made by various investigators are tabulated.

Now we have talked about the emission characteristic of surfaces; we have talked about, first of all defined terms like the total hemispherical emissive power or what we call only as emissive power - the monochromatic emissive power, the emissivity of a surface, the monochromatic emissivity of surface and we have also stated the 3 laws for black body radiation. This is all concerned with radiation being emitted from a surface which is at a particular temperature; now we want to talk about radiation falling on a surface, that is radiation incident on a surface.

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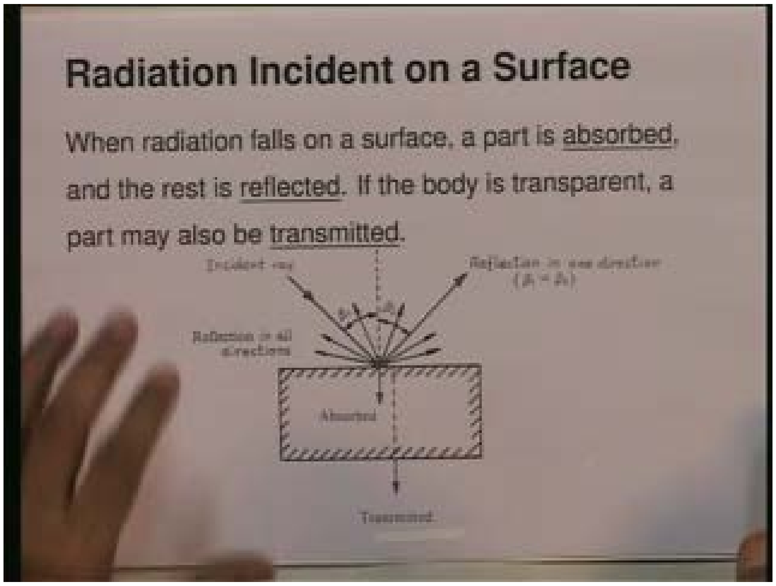

Let us now talk about radiation incident on a surface - this radiation which we are talking about may have come from some surrounding surface; it may been emitted by some surface and then it is falling on the surface with which we are concerned. So the radiation falling on a surface has originated from probably from some other surface from which it is being emitted. Now when radiation falls on a surface, a part of that radiation is absorbed and the rest is reflected if the body is transparent, a part may also be transmitted.

So, 3 things happen to radiation when it falls on the surface, when it is incident on the surface - a part of that radiation is absorbed, a part of it may be reflected and a part may be transmitted through that body if that body is transparent to radiation. Say for instance light is falling on the glass, then some of the light may go through the glass. This is shown pictorially in this figure here where I have drawn a rectangular block and said some ray of radiation is falling. I have shown just one ray not radiation coming from all directions just as an example; I have shown one incident ray coming here and I have said what will happen to it - it will be reflected, it will be as part of it will be absorbed and a part will be transmitted.

3 things will happen – reflection, absorption and transmission; a part will be reflected, part will be absorbed and the remaining may be transmitted or if it is opaque to radiation, then it will only be reflected and absorbed. Now the reflection itself can be of 2 types; one is - the reflection may be like we have when light falls on a mirror for instance. Typically, optical light falls on the mirror, the angle of incidence T equal to angle of reflection; so reflection may be of that type in one direction with the angle of incident equal to angle of reflection or reflection may be in directions as it is shown by all these arrows here going outward, that means reflection is in all directions.

So, generally for surfaces that we deal with in real life when thermal radiation falls on a surface, any ray maybe come from one direction, from all direction but any particular ray which comes and falls on a surface will normally be reflected in all directions not following this rule of the angle of incidence being equal to the angle of reflection. So keep in mind reflection in all directions is the thing that generally occurs; so we are not talking about that; defining, we are going to define some terms concerned with radiation incident on a surface. The first term which we are going to define is the following - we say we define a term called the total hemispherical irradiation H.

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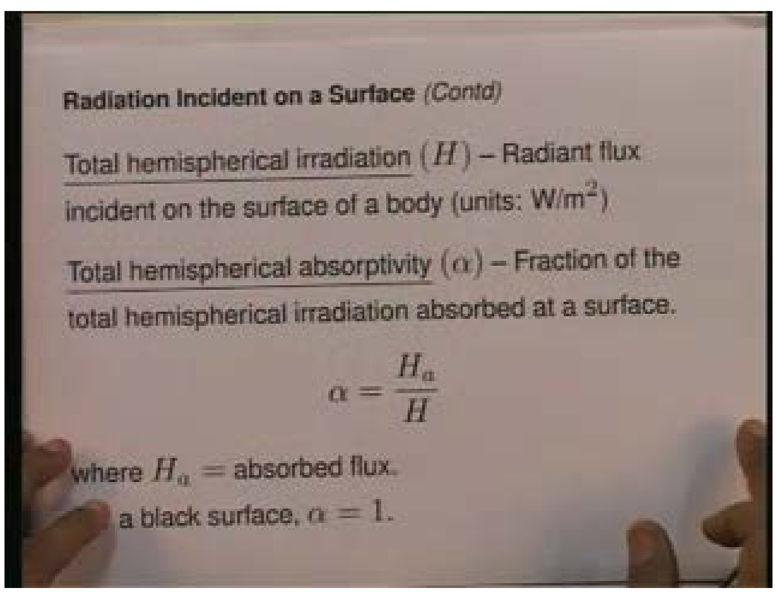

We define it as the radiant flux incident on the surface of a body. The units of it would be in watts per meter squared; the total hemispherical irradiation is the radiant flux incident on the surface of a body. Now let me illustrate this with a sketch again.

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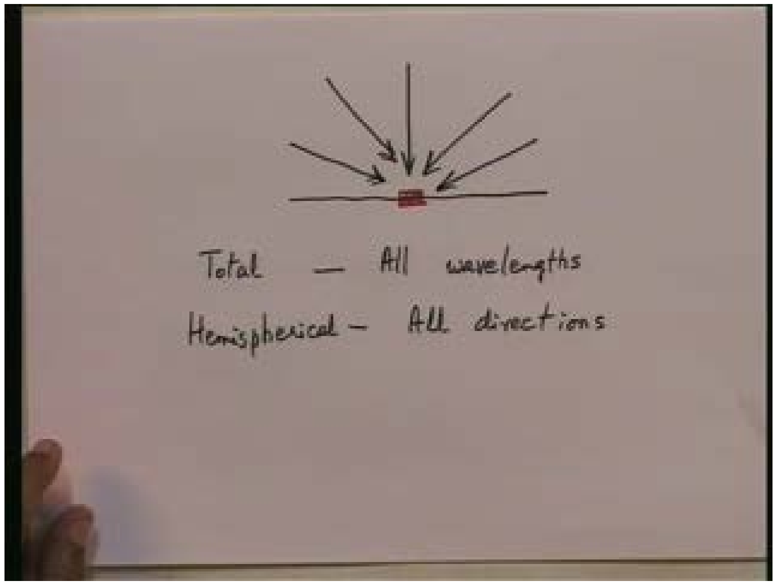

Let us say let us say this is some surface like this and let us say radiation is incident on it from some surrounding surfaces. Radiation emitted by surrounding surfaces is incident on this surface coming from all directions like this; this is radiation incident on a surface. And let us look at an area here on this surface; some area here on which the radiation is incident. Now the total hemispherical irradiation I have said to you is the radiant flux incident on the surface of the body in watts per meter squared. The word total which I use stands for all wavelengths; that is what you mean by total - something summed over all wavelengths 0 to infinity. And the word hemispherical is includes all direction, all directions within a hemisphere – that is what we mean by the words total and hemispherical.

So, total hemispherical irradiation H is the radiant flux incident on the surface of a body so many watts per meter squared. Now I have already told you a fraction of this may be absorbed; let us say the fraction of this irradiation absorbed at the surface is alpha. We call alpha as the total hemispherical absorptivity of the surface; alpha the total hemispherical absorptivity is the fraction of the total hemispherical irradiation absorbed at the surface. Let us say the absorbed flux is Ha; the incident flux is H and the absorbed flux is Ha so alpha is nothing but Ha upon H; Ha is the absorbed flux both that in watts per meter squared. And obviously for a black surface, by definition a black surface is one for which alpha is equal to 1. A black surface has the absorptivity, the total hemispherical absorptivity equal to unity.

So, we have defined 2 terms - H the total hemispherical irradiation which is incident on a surface and alpha which is the total hemispherical absorptivity of the surface. We defined 2 terms; now let us define 2 analogous terms for monochromatic irradiation. Next 2 terms we are going to define - a concentrated monochromatic irradiation; we say monochromatic hemispherical irradiation will use the symbol H lambda for it, monochromatic hemispherical irradiation use a symbol H lambda for it is the radiant flux incident on the surface of a body per unit wavelength and it will have the units of watts per meter squared micrometer micron.

So, H lambda is nothing but dH lambda d lambda the watts per square meter per unit wavelength dH d lambda or we can say dH is nothing but H lambda d lambda. If I integrate H lambda over all wavelengths, then I have got to get the quantity H. So another way of defining H lambda is to say it is that quantity H lambda is that quantity which when integrated over all wavelengths 0 to infinity will give me the total hemispherical irradiation on the surface. So we can say and now let me repeat - the monochromatic hemispherical irradiation on a surface H lambda is that quantity which when integrated over all wavelengths ranging from infinity gives us the total hemispherical irradiation H incident on the surface; so that is another way of looking at the quantity H lambda.

And we define the last term now; the last term will be the monochromatic hemispherical absorptivity of a surface for which we will use the symbol alpha lambda, monochromatic hemispherical absorptivity of a surface alpha lambda and we say it is the fraction of the monochromatic hemispherical irradiation absorbed at a surface.

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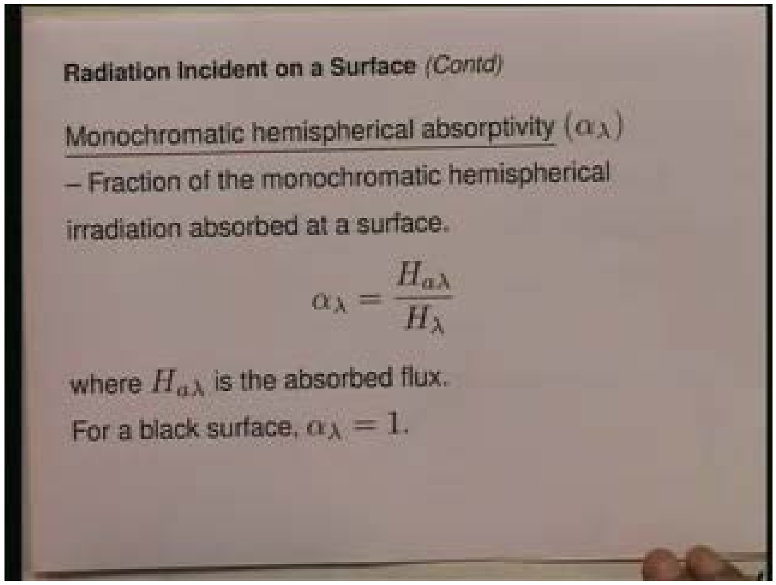

Out of the quantity had lambda, a certain amount is absorbed; let that be Ha lambda, the ratio Ha lambda by H lambda is the fraction that is absorbed of the monochromatic hemispherical irradiation and we will denote by the symbol by the alpha lambda. So alpha lambda is Ha lambda upon H lambda; Ha lambda is the absorbed monochromatic hemispherical irradiation. Obviously again for a black surface alpha lambda is equal to 1; so this irradiation falling on a surface H affects all the radiation H lambda if it is monochromatic values that you are looking for, a certain fraction out of it is absorbed.

In the first case, the fraction absorbed we call as the total hemispherical absorptivity denoted by symbol alpha. In the second case, when it is monochromatic, we call it the monochromatic hemispherical absorptivity and denoted by the symbol alpha lambda. In the same manner exactly in the analogous manner, I can define terms like total; I can define terms like total hemispherical reflectivity and monochromatic hemispherical reflectivity - these would be rho and rho lambda.

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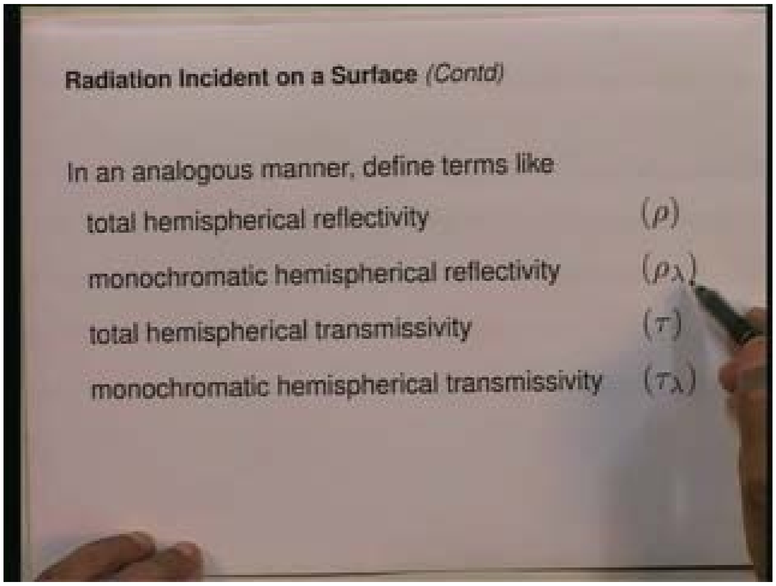

And I can define terms like total hemispherical transmissivity and monochromatic hemispherical transmissivity which would be tou and tou lambda. What would be rho? rho would be the fraction of the total hemispherical irradiation incident on the surface which is reflected from the surface. And what should be tou? tou would be the fraction of the total hemispherical irradiation incident on a surface which is transmitted through that surface.

So, rho and tou are similar to alpha; alpha stands for the absorbed fraction, rho for the reflected fraction, tou for the transmitted fraction and the corresponding quantities with monochromatic level are alpha lambda, rho lambda, tou lambda.

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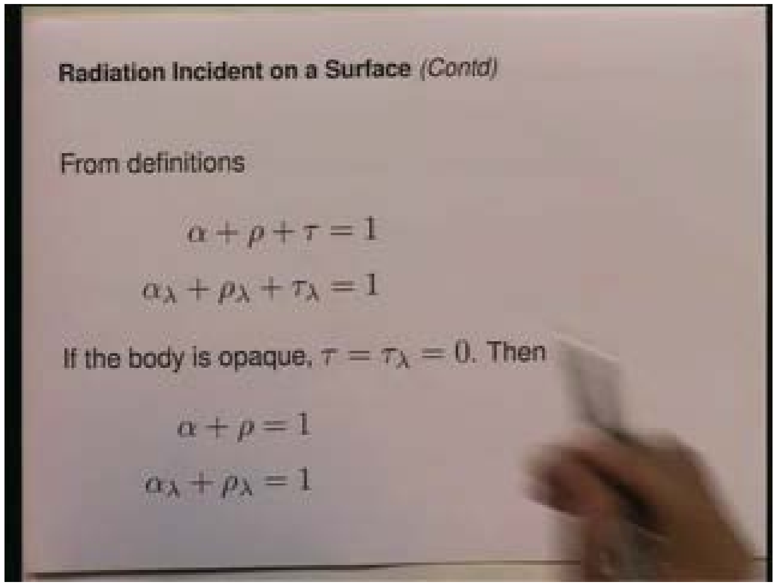

Therefore it follows from the definitions; it follows that alpha plus rho plus tou must be equal to 1; alpha lambda plus rho lambda plus tou lambda must also be equal to 1. That follows from the definitions because only 3 things can be happened to the radiation; it can be absorbed, it can be reflected or it can be transmitted and the sum of the 3 fraction has to add up to 1 for all the incident radiation, these 3 things can happen.

So, alpha plus rho plus tou is 1, alpha lambda plus rho lambda plus tou lambda must be equal to 1 and if the body is opaque, like for instance it is a metallic surface say for instance so that no radiation can go through the surface. Then if the body is opaque, tou and tou lambda would be 0 and then alpha plus roh is equal to 1 and alpha lambda plus rho lambda is also equal to 1. So instead of the first 2 expression here, I get these 2 expressions if the surface of the body, if the body is opaque and no radiation is transmitted through it. And this is very true very often because we deal very often with metallic surfaces so no radiation goes through and alpha plus rho is equal to 1; alpha lambda plus rho lambda is then equal to 1.

Now, let me just sort of put things together just to recapitulate again once more what we have said; we have now defined the following quantities. I am just sort of repeating things a little.

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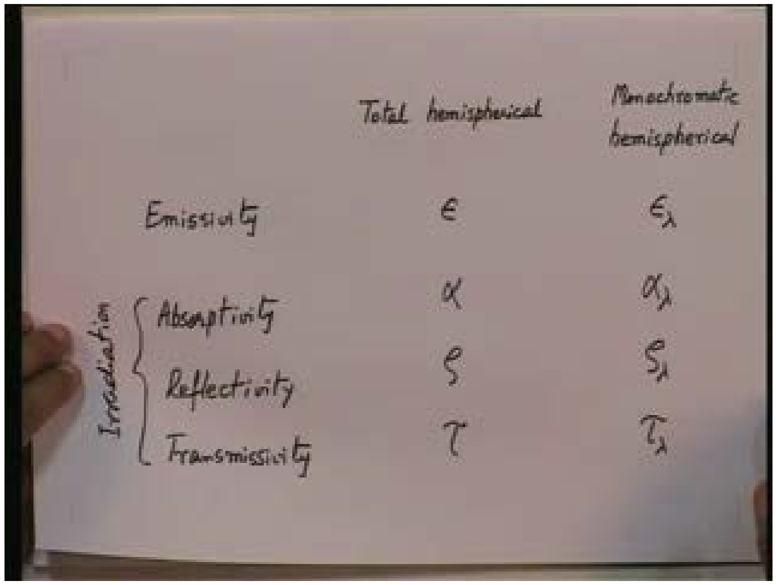

I am saying, let me make a table so I will say first total hemispherical, total hemispherical and monochromatic hemispheric. We have defined 2 types of quantity - monochromatic hemispherical, total hemispherical emissivity we have define for radiation which is emitted from a surface and total hemispherical emissivity we have epsilon; if it is the monochromatic value we have epsilon lambda. Then this is with the respect to emitted radiation, then with respect to irradiation.

We have defined 3 quantities – absorptivity, then reflectivity and transmissivity; transmissivity which we call as alpha, rho, tou, alpha lambda, rho lambda, tou lambda so these are all properties that we have for the surface. The last 3 are for irradiation that is radiation incident on a surface; these are for irradiation. The first one is for emission so these are all, this is kind of a snapshot of the terms we have defined and also I repeat that we have also got the same abbreviated versions that we had earlier.

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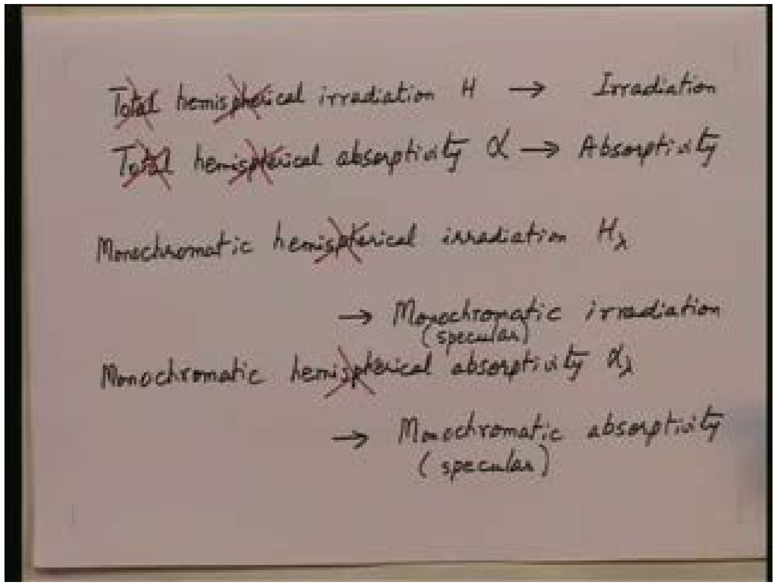

That means we will use the same abbreviations earlier; we will not keep on saying things like, instead of saying total hemispherical irradiation, instead of going on saying this every time we will which is the quantity H. We will normally delete the words total and hemispheres and refer time it only as irradiation in the same way that we did that earlier for emissive power.

Similarly the quantity total hemispherical absorptivity which is alpha we will simply call it as absorptivity. By deleting the words total and hemispherical, they are implied or when we we will not keep on saying monochromatic hemispherical irradiation which is H lambda, we will simply call it monochromatic irradiation; we will simply call it monochromatic irradiation deleting the word hemispherical. And finally in the same way, we will not use the phrase monochromatic hemispherical absorptivity that is alpha lambda. We will delete the word hemispherical and simply call it monochromatic absorptivity, simply call it monochromatic absorptivity. And also like earlier, we will, instead of monochromatic, sometimes following other authors we will use the word specular instead of monochromatic and call it specular irradiation or specular absorptivity instead of monochromatic absorptivity.

You should know these different terms that are used by various people. Many people instead of calling it monochromatic absorptivity call it as specular absorptivity so I want you to know these terms. Now let us do one more problem again so that these ideas get illustrated about these terms – absorptivity, monochromatic absorptivity, etcetera.

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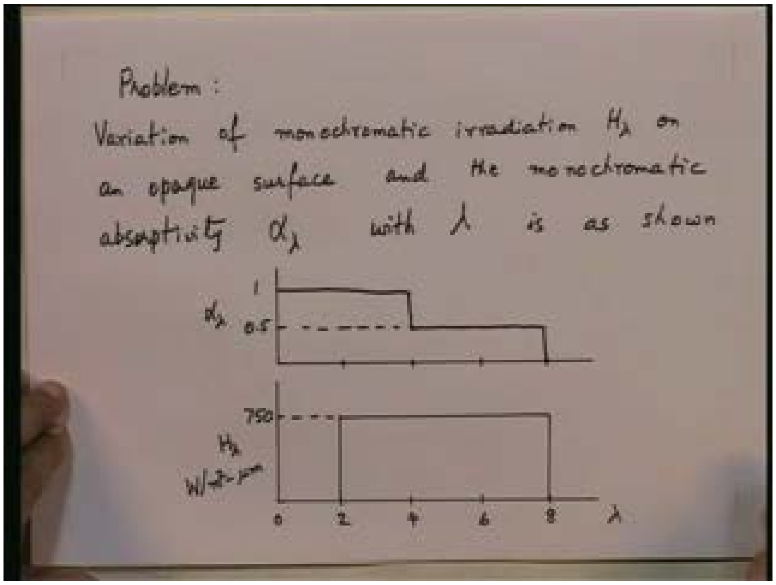

So let us do the following problem; problem we want to do is like this, we say, let us say I have a surface; for a surface, the variation of monochromatic irradiation, variation of monochromatic irradiation that is H lambda on an opaque surface and the variation of the monochromatic, the variation of the monochromatic irradiation on an opaque surface and monochromatic absorptivity and the monochromatic absorptivity that is alpha lambda with lambda with wavelength is as shown. For a given surface, this is the variation; some variation which I am going to show now - it is like this.

Let us say for first, for, I mean one for alpha lambda, the other for H lambda; this is lambda on the X axis. Let us say this is, this is lambda and this is 0 microns, 2, 4, 6 and 8 microns. Now the variation of the H lambda is given to be the following; you are told that H lambda for this surface is like this. It is a simple rectangle like this for the surface; this is H lambda in watts per meter squared micron and the value is 750. So it is 750, the value is 750 from 2 to 8 microns otherwise it is 0 and epsilon, I mean alpha lambda varies from like this - 1 comes down to .5, then is .5, then is 0.

So, the variation of alpha lambda is - this is 1 this .5; so alpha lambda is 1 from 0 to the 4 microns and .5 from 4 to 8 microns thereafter it is 0. So this is the variation which is given; find, calculate

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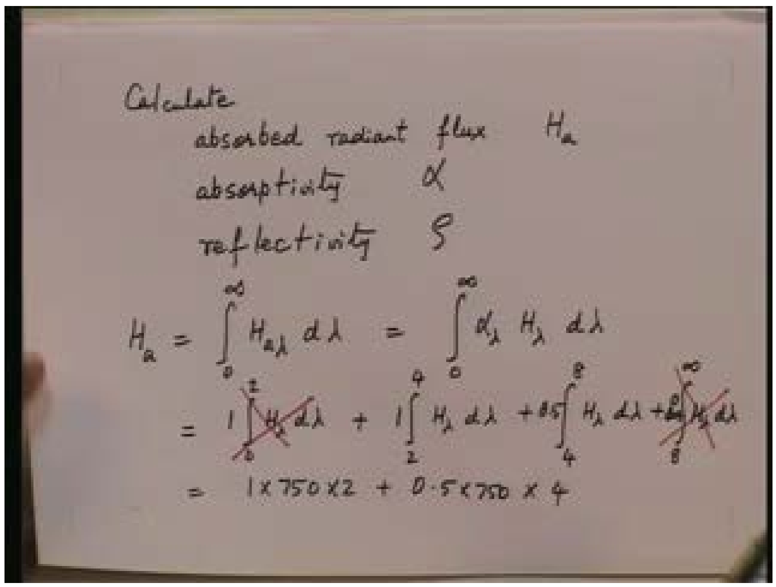

absorbed radiant flux that is Ha. Calculate the absorptivity that is alpha and calculate the reflectivity that is rho. Now what are they? Very easy to find out; Ha the absorbed radiant flux is the integral 0 to infinity; Ha lambda d lambda that will be the absorbed radiant flux. So that is nothing but the integral 0 to infinity, alpha lambda, H lambda, d lambda where H lambda is the incident flux that is nothing but now let us do it in steps.

Let us take it first from integral 0 to 2 microns and put a value of H lambda from 0 to 2 and put the values of alpha lambda from 0 to 2 which is 1 plus integral 2 to 4. Value of alpha lambda is again 1 and can, since it is constant I can take it outside the integral multiplied again by H lambda d lambda plus the integral from 4 to 8 alpha lambda is .5 H lambda d lambda. And finally the last one - 8 to infinity 0 and that is to be multiplied by H lambda d lambda.

So, we will get 1 multiplied by 750 into 2; the first integral plus the first is 0 of course, the second one gives you 1 into 7 into 2, the third one gives me .5 into 750 into 4 and the last one also is 0. So these 2 go away - the first and the last are both obviously zeros because here H lambda is 0 and here alpha lambda is 0. The second and the third give me these values and if I calculate them I get nothing but 1500 plus 1000 which is

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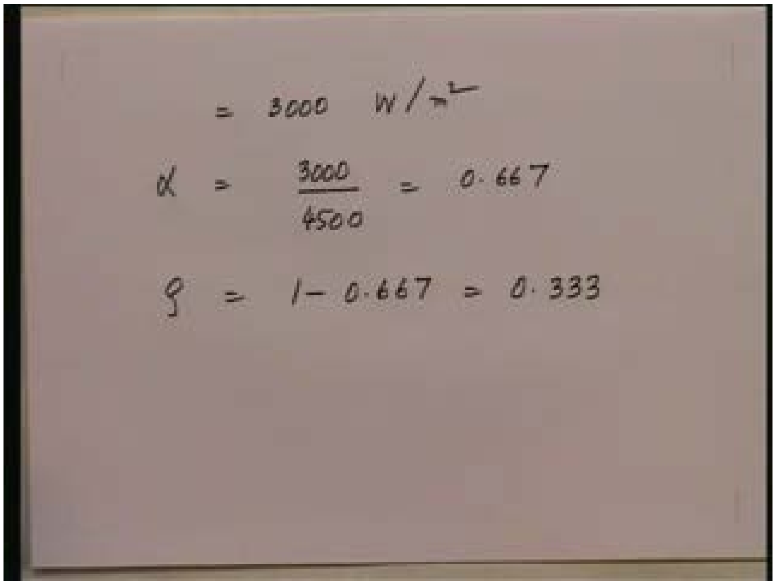

3000 watts per meter squared – that is the value of Ha. So therefore, what is alpha? alpha is nothing but 3000 divided by the incident radiation; the incident radiation you know is nothing but 4500 - 750 into 6 - and therefore alpha is .667 and it follows that, because the surface is opaque it follows therefore that rho must be equal to 1 minus .667; that is it must be .333.

So you see: here is a very simple problem in which we have illustrated the ideas of all these quantities which we have defined today namely the absorptivity, the reflectivity of a surface. Now today we have completed how to deal with radiation which is coming from all direction that is hemispherical radiation. Next time we will look at the direct nature of radiation.