Conduction and Radiation
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Lecture No. # 12
Emissivity Contd.

So, we will continue with the discussion on emissivity. So, we worked out a problem in the last class, where I gave you the spectral emissivity; what it is? It is the hemispherical spectral emissivity. From the hemispherical emissivity, we got the hemispherical total emissivity; we worked out for tungsten bulb; of course, that bulb is nowadays is dying, from that second generation, third generation from that we went on to C F L, and now, from C F L we are going to L E D and so on.

Now, same 3000 Kelvin, we will work out the problem for a material which is competing with tungsten; there are other possible alternatives, right? If something is heated to 3000 Kelvin, it will also glow and all that.

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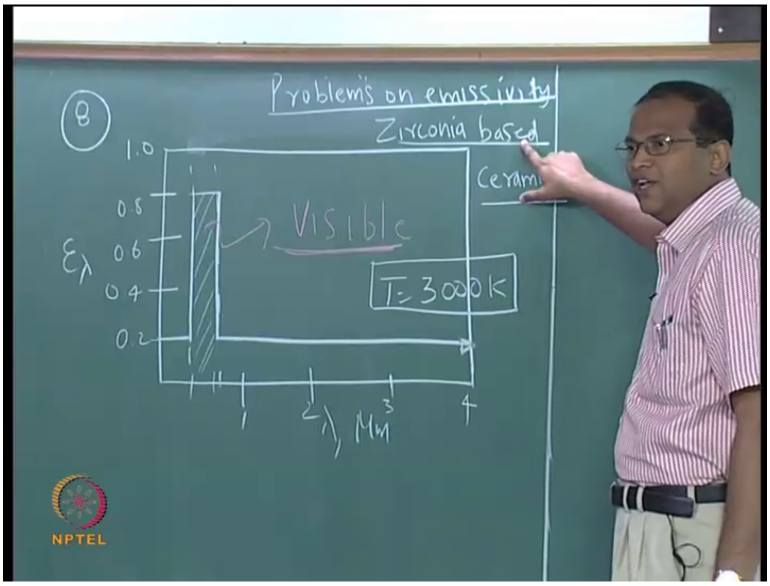

Let us look at material like a ceramic material, zirconium based ceramic; assuming that experimentally, somebody conducted experiment. So, epsilon lambda versus lambda, how do you do these experiments and some basic ideas will be clear from problem number nine, which we will solve after solving this problem eight. You just need a detector and calibrate it, and then you can get emissivity.

Now, epsilon lambda versus lambda, you select this or the zirconium based ceramic. Now, for the visible part of the spectrum, it has got a high epsilon lambda which is 0.8. So, the reminder of this spectrum, that is less than 0.4 and greater than 0.7, it continues to be 0.2; it is showing a spike in the visible part of the spectrum.

Now, assume that the, in your tungsten bulb, everything is remaining the same; you pull out the tungsten filament, you are replacing by zirconia filament. Now, we want to compare, what will be the power consumption of this zirconia bulb? What is the ratio of the power consumed by the zirconia bulb to the power consume by the tungsten in the visible part of the spectrum, which will give more light. So then, you get an idea of the engineering aspects of what will happen if epsilon lambda versus lambda is given for various surfaces, and you are trying to calculate epsilon, and you are trying calculate other quantities, which are of engineering interest; that is the goal of this problem or solving this problem.

A zirconia based ceramic, problem number eight, a zirconia based ceramic, a zirconia based ceramic, has hemispherical spectral emissivity, a zirconia based ceramic has hemispherical spectral emissivity distribution as shown in the figure, a zirconia based ceramic has hemispherical spectral emissivity distribution as shown in the figure full stop. This is being considered, hemispherical spectral emissivity distribution as shown in the figure full stop, this is being considered for use, this is being considered for use as the filament of a light bulb, this is being considered for use as the filament of light bulb.

The questions are a) what is the total hemispherical emissivity of, what is the total hemispherical emissivity of a zirconia filament operating at 3000 Kelvin, what is the total hemispherical emissivity of a zirconium filament operating at 3000 Kelvin? B) for zirconia and tungsten operating at 3000 Kelvin, for zirconium and tungsten operating at 3000 Kelvin, for zirconium and tungsten operating at 3000 kelvin in an evacuated bulb, in an evacuated bulb, for zirconium and tungsten operating at 3000 kelvin in an evacuated bulb, which filament requires, which filament requires larger power consumption; again, there will be a question mark, which filament requires larger power consumption?

Part C) with respect to production of visible radiation, with respect to the production of visible radiation, with respect to the production of visible radiation, which of the two filaments is more effective or more efficient, which of the two filaments is more efficient; with respect to the production of visible radiation which of the two filaments is more efficient, justify? That means, you will have to justify with some numbers, justify.

Shall we start solving? So, epsilon, the story is, from epsilon lambda, you have to convert in to epsilon; and then you have to use the Stefan-Boltzmann's law; and then look at the power consumption, some critical data is not given, the area of the bulb; but needless to say, area of tungsten bulb is the same as the area of zirconia bulb and all that you can cancel, all the T infinity, other things will not, T is also the same, T infinity is the same. So, the power consumption will be direct ratio of the emissivity only, then the part three is you have to look at what is the radiation which is produced in the visible part of specterum.

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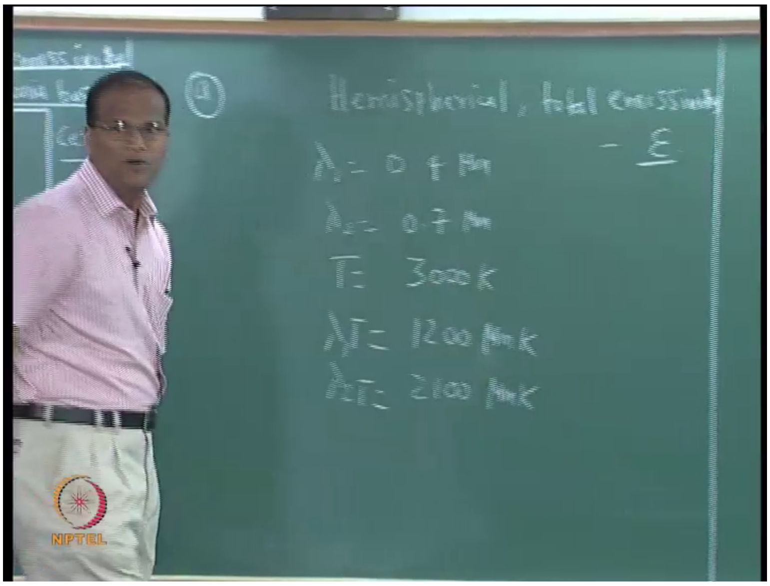

Now, a) I want to get this fellow, hemispherical total emissivity. So, I called this as lambda one, this lambda two, right? lambda one and lambda two, visible part; T 3000 kelvin. So, lambda one T is 1200 micrometer Kelvin; starting is good, no problem. Now, we write an expression, what happened? Vinay, any problem? You are stuck without paper, pencil, calculator or what? Everything is there

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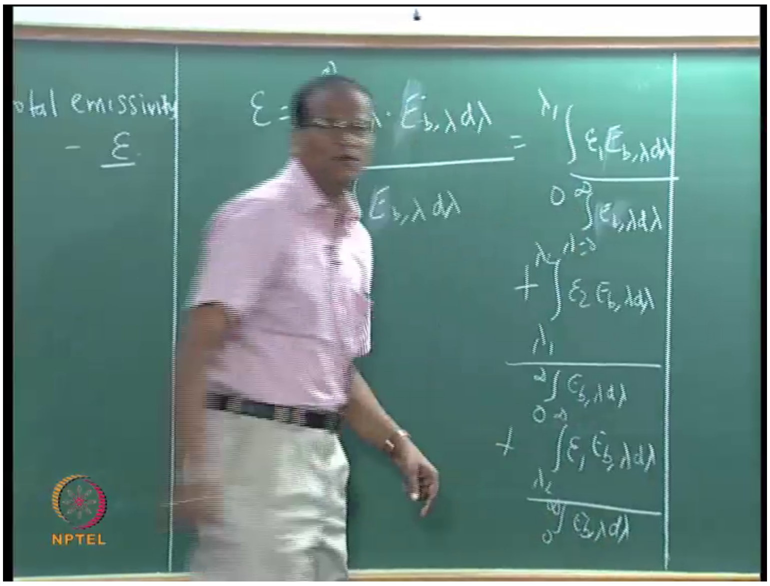

You have to write the formula for epsilon is, what is the formula we have? All that cos theta, sin theta is all those things are not really important for us; already, I gave epsilon lambda. So, that theta is taking care of the, theta will trouble if I have the epsilon lambda dash. Now, the dash is not there, right? This can be broken down to… This is not, better to use I b or E b? Better. There is no problem in using either I b lambda or E b lambda, but do not use E b lambda numerator and I b at lambda denominator; and all the answers will be cupping by factor of pi, or one by pi, or whatever, you may get incredible emissivity. So, plus lambda one to lambda two plus lambda two to infinity epsilon one. Please look at this formula; there are three terms, epsilon three, I put epsilon one, epsilon one is equal to epsilon three, agreed? 0.2. Now, we will have to use the f function chart.

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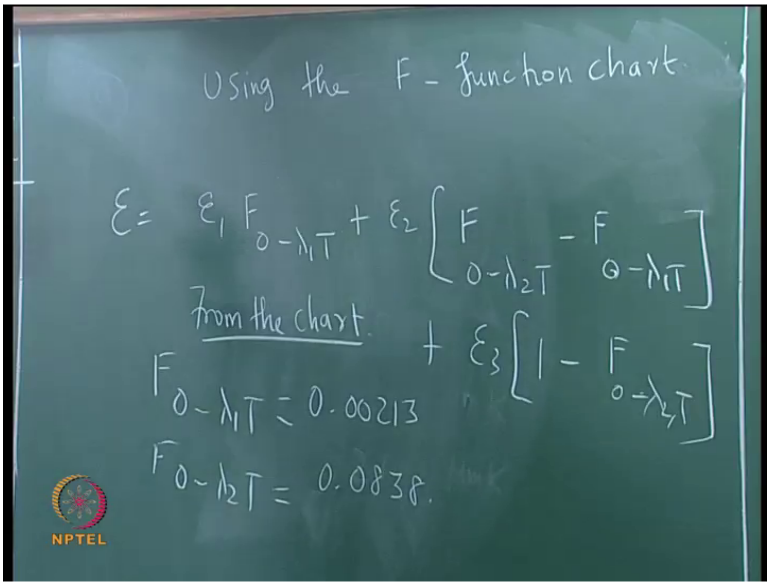

Now, f of, this is too much if I show like this; no, from the chart, from the chart, from the chart for 1200.

Student: Naught naught 2 1 3.

Naught naught 2 1 3; f of… that is for…

Student: 0.7 2.

2100, correct. 2100, you have to do some interpolation, what did you get?

Student: (( )).

0.08. So, we got these values. Now, we will insert all these values into the expression for hemispherical total emissivity.

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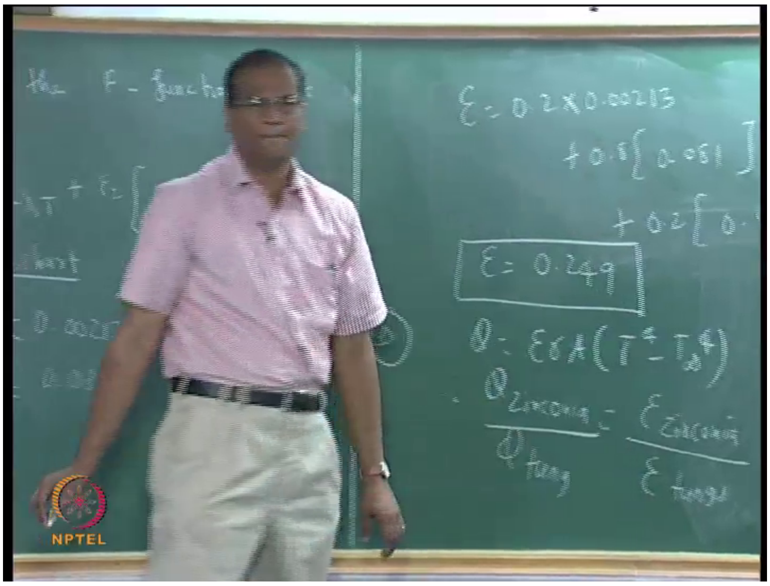

So, before that, this varies from 0 to 1, right? If I do not like you, I can give like this in the exam. So, you are sunk, 20 minutes to calculate; but it is pointless, see it is just a mathematical quantity, we can give; but I do not think there will be surfaces which are so fancy like this. So, surfaces will be like this, may be it will exhibit some other emissivity in one other portion of the spectrum. But these are all, but if you see radiation heat transfer books, such things are there, this basically in academic exercise. So, the student gets sharper there, they are very comfortable with f function chart. Now, epsilon is 0.2 into. So, what is this? Naught plus 9 1 no 9 1 (( )). Finally, after all these 0.8 only, is not or no?

Student: 0.2?

0.249.

So, I repeat, if epsilon lambda versus lambda is given, do not make the mistake of taking some value of lambda, cutting the distribution and finding the area under the curve, and getting the average epsilon, that is not correct. Some people will miss lot of classes because, because they are very confident that they have cleared J E E, and all that; something is given like that, we have to get area under the curve divided by lambda two minus lambda one and I am getting epsilon, thinking that you are smart, it does not work because the epsilon must be multiplied by the f; because, it is sigma T to the power of four is there. So, fine epsilon is point… So, as is fine a part is over. So, the hemispherical total emissivity of zirconia is 0.249.

Now, we do not have; now, we will have to see whether it is good a candidate, that will be known, only if you solve the part b and part c of the problem; part b is the power consumption, what will be the power consumption? what will be the energy equation for the bulb when it is operating at steady state? You assume that convection and conduction, all those things are not there. What is the energy equation heat transfer equation for the bulb, for this bulb? Temperature.

Student: I squared r.

I squared r equal to epsilon sigma, I squared r can be written as q; that is, q is what is given by the, will coming from the supply. Therefore, q is equal to epsilon sigma a. So, vikram will again ask me, how you are putting epsilon outside, t infinity inside; you will have to wait for that story, assuming that is correct. Now, both bulbs are, both filaments are operating at 3000 kelvin; assuming the ambient temperature is same for both and stefan-boltzmann constant has to be constant for both filament and area is also the same therefore, the ratio of power consumption is just the ratio of the emissivity's fine. Now, therefore, q zirconium by yeah what is emissivity of the tungsten

Student: (( ))

Ah. So, how much use this

Student: (( ))

.7. So, the zirconium bulb consumes only 70 percent to be at the same temperature that is not our goal the goal is related to consume more energy less energy what about the light that comes from part c there also ultimately were interested in the amount of the light it produces in the visible part of the spectrum infrared and all it does not matter it will heat up it will heat us up that really does not matter infrared is also use in airports for this swine flu screening right these are all infrared it will give the color maps and then if certain body parts of individual or beyond the band then they will (( )) them and correct in the airports you can find out some person is having fever by taking infrared image correct you know that right that was was routinely going on, but now we talking about visible because the light bulb has to produce visible radiation we are interested in reading a book after sunset and all that right (( )) reading, but we need light right because you always want to a b we do not right. So, that is the goal of all this

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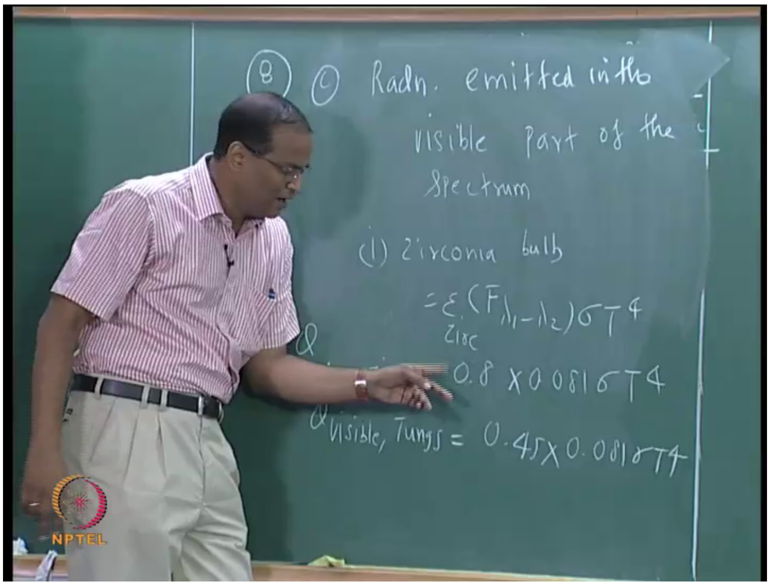

Now, what about the answer to the part C of the question part C of the question says with respect to the production of visible radiation which of the two filaments is more efficient what is that 1.7 here how do you do that

Student: (( ))

Not just emissivity you cannot do it like that what is the radiation emitted in the visible part of the spectrum

(( )) blackbody fraction multiplied by sigma (( ))

Exactly blackbody fraction in the visible part of the spectrum multiplied by sigma t to the power of four multiplied by the emissivity are you getting the point the radiation which is coming out of the blub must be equal to sigma T to the power of four into blackbody fraction corresponding to point four to point seven micrometer band multiplied by the corresponding emissivity this we can work out for both the blubs and sigma if you want you can substitute sigma value for sigma and T and put it as a number I would much rather prefer to keep it as sigma T to the power of four because I am looking only at the ratio then I will be finally, convince the zirconium bulb is far more efficient just work it out right. So, radiation no this is eight C so, epsilon zinc into f of lambda 1 lambda 2 the sigma T to the power of four. So, what was emissivity .249 what is f of lambda one lambda 2.naught 81. So, Q visible zinc Q visible tongs is given by .36 same. Naught 81 here we are having trouble what is the emissivity in the visible part of the spectrum for tungsten

Student: (( ))

Ah what is the emissivity with visible part are you getting the point we cannot get the yes we should not put this I am changing lot of things just hang on. So, for tungsten tell me yeah sorry for small small slip this formula is correct, but I cannot put epsilon for the whole thing I should I should put the epsilon I should insert the value of epsilon or emissivity corresponding to the visible of the spectrum. So, it is point 8 for the zirconium filament, but it is only point 4 5 for that therefore, even though even though the tungsten filament has a higher hemispherical total emissivity as opposed to the zirconium filament the zirconium filament by virtual off with having a very high spectral emissivity of point eight exactly in the visible part of the spectrum it it gives us it gives better or more visible radiation compared to the tungsten filament and this power consumption is also .7 zirconium is infinitely better than tungsten of course, cost and other things availability that is separate then you have to do what is called multi-objective optimization you have to do pare to plot and all that right you know what is pare to plot is you have to plot the two quantities right you have to plot the two quantities and high low high low right for example, I C engine you want deficiency was emission high efficiency low emission you always want something which you cannot get then you compromise right you want to have C G P A war time spent correct there orthogonal right, but you want minimum time to be spend than maximum everybody wants to work at corner efficiency that is a problem props are always trying to work work at corner efficiency (( )), but basically often times the wants and the resources do not match. So, we will have to arrive at compromise. So, the pare to plot optimality like that

In this case thermally from radiation point of view this is better no doubt, but what about the availability other things we have to see, but I think we have moved away from tungsten nobody uses that blub now nowadays hostels you have changed changing everything to L E D now right C F L also is giving way to L D T fine. So, this gives you a good idea of this is. So, this is good problem if you consider only emissivity, but a surface apart from emitting it will also reflect and it will also reflect and observe and. So, on so, but because we are not studied absorptive we are not included absorptive in the calculation then once we formally define absorptive and reflectivity and transmissivity all these things will be included. So, good heater and radiation problem will take half-an-hour for you to solve epsilon lambda we will calculate you you will change it epsilon reflectivity you will change for absorptivity you will change then you will look at the overall energy equation and then if it is only one body it is fine and if there are two bodies you have to see view factor if there are three bodies you have to you will have system of simultaneously equation. So, it can take a longtime for multi body problem even surface radiation leaving the gas radiation, but if the median also participate then it complicates things further right now we will solve one more problem.

So, we have solved two problems where the spectral variation is taken into account we have solved only one problem where the direction effects are taken into account. So, we will solve one more problem where the directional effects are considered.

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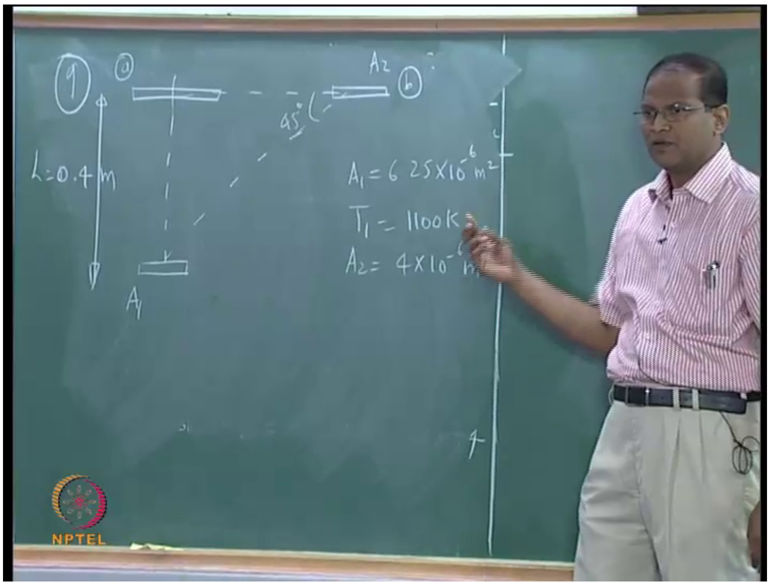

Now, it is slightly tricky problem because, it was basic concepts. So, it is more a test of your funds. So, consider a situation like this. If you taken down the figure, I will start explaining the configuration. There is emitter a one, small emitter, area 6.25 into 10 to the power of the minus 6 meter square; it may be circular disk, you can have pi d square by 4 equal to, you can find out; everywhere this is vacuum, so that, you do not worry about convection and conduction and. So, this is intercepted by another area a 2, a 2 is the fellow, who is receiving the radiation. Now, when it is at position a, then it is normal, it is normal; and this is your theta; when it is normal, it is intercepting some radiation power which can be measured, I have an instrument to measure that, I will give you that value; from that value, you will be in a position to find out what will be the emissivity corresponding to theta is equal to 0, for this surface, are you getting the point? Now, I moved it horizontally, I moved it horizontally to position b, such that this angle is 45. Now, the D omega a one cos theta D omega will become D cos theta r square, all that. The r is also changing from point 4; suppose, I give you the power then you can also calculate the emissivity at the new position, and we can take a call on whether, this is diffused surface or not; if the emissivity in position a is different from the emissivity in position b, then it is not diffuse emitter. But if it is so also, we do not know whether it is, whether it is same in all the direction; but at least, you say between the 0 and 45, it is having the same, are you getting the logic?

Now, I will give you the data, you can take down the problem. Consider an arrangement as shown in the figure to detect radiation, consider an arrangement as shown in the figure to detect radiation emitted by an elemental surface of area a one is equal to, area a one is equal to 6.25 and 10 to the power of minus 6 meter square, and temperature T 1 is equal to 1100 kelvin, and temperature T 1 is equal to 1100 kelvin; the area of the detector a 2 is 4 into 10 the minus 6 meter square. All these data are given, a 1 6.25 into 10 to the power of minus 8 meter square, T 1 is 1100 kelvin and a 2 is 4 into 10 to the power of minus 6 meter square. For the radiation emitted by a one at theta is equal to 0, for the radiation emitted by a 1 at theta is equal to 0, within brackets, normal direction, normal direction, at theta is equal to 0, normal direction, close brackets; for the radiation emitted by a one at theta is equal to 0 within brackets, normal direction at a distance of l is equal to 0.4 meter, at distance of l is equal to 0.4 meter, the detector measures radiant power of, the detector measures radiant power of the detector measures radiant power of 1.5 into 10 to the power of minus 6 watts, the detector measures radiant power of 1.5 into 10 to the power of minus 6 watts. Determine the directional total emissivity of a 1, determine the directional total emissivity of a 1 for theta is equal to 0, are you getting the point?

We can only determine the emissivity of a 1, the emitting surface. Now, you will ask me sir, what about surface a 2 and all that, some internal calibration what is absorptivity, is not our point, is not our concern now.

I know what is the power which is coming from a 1, nothing is happening in between. So, there may be vacuum, do not ask me questions on what is the design of a 2, you will design if you become, if become expert in radiation measurement and all that.

So, the first part of the question is, get epsilon dash theta, epsilon dash theta at theta is equal to 0. Now, the detector is moved horizontally, now the detector is moved horizontall,y now the detector is moved horizontally to position b, now the detector now the detector is moved horizontally to position b, such that, theta is equal to 45 degrees, such that, theta is equal to 45 degrees. For this position, for this position, the detector measures, the detector measures the radiant power of 1.46 into 10 the minus 7, 1.4 6 into ten to the power of minus seven watts.

Can you comment, the question is, can you comment on whether surface one is diffuse emitter, can you comment on whether surface one is diffuse emitter. You may use Stefan's law, you may use the concept of solid angle; and then, originally when I started out with solid angle, I gave you the emissive power; now, we have gone through ten or twelve hours of this course, I give you the temperature and you have to multiply it by the emissivity. Now, using solid angle and all that, your right hand side, you will get an expression, where only one unknown will be there, that is epsilon dash of theta; left hand side, you know what the power the detector is measuring, solve for only one unknown, that is epsilon dash theta; theta is equal to 0, please do it first part, second part it will automatically flow, but the radius will change now. So, what is E b? 83000, you did not do this 83014.5. Yeah, please tell me.

Student: 80014.5 (( )).

0.5 watts per meter square. I b is equal to sigma t to the power of four by pi. You can keep it like that, but of course, for the sake of completeness, let us do it. 26000 watts per meter square per?

Student: Steradian.

Steradian, good.

So, first part, now, we have to say Q is equal to, is measured, that I gave you. Now, we have to write a formula for Q, in terms of our fundamental quantities; hopefully, in that expression epsilon dash theta will be there. Now, Q is also is equal to a 1 epsilon theta is equal to 0 I b d omega.

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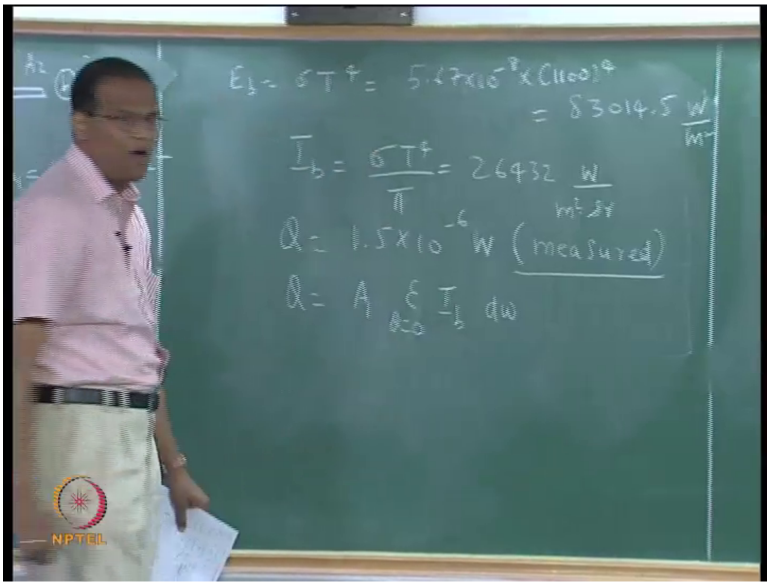

What I am assuming is, this solid angle will be, will be the same anywhere, at any point this solid angle will be the same; because, that is why, I gave elemental area; if I give a big area, then this will cup, then I have to subdivide and then do some integration, have a raising that will be nuisance. We will stick to incremental area, elemental area. So, now, D omega a 2 cos of?

Student: 4 (( )).

Please tell me, a 2 is.? So, how many steradian I have? 2.5 into 10 to minus 5. Is this correct? a 1 is also there, so... Not, 83000. I am just checking, whether I am making some mistake. It is good practice to check from the dimension to the units. Now, I hope, I did not give problem where epsilon is greater than one point. So, epsilon.

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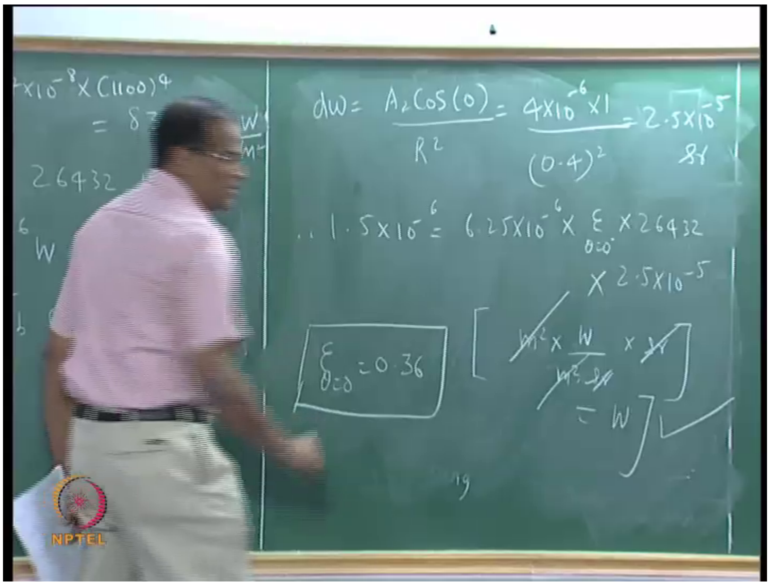

So, the normal emissivity is 0.36. We got a decent answer. So, fine, this can also be treated as, this one possible way by, with one possible way by which, we can measure emissivity if you are able to have detector arrangement, you have this thing and you can have vacuum and all that; this this way, you can, if you can able to eliminate all surrounding, the affect of conduction and convection, it is possible to get this.

Now, the more difficult is, this detector is now moved horizontally. So, that cos 0 is no longer cos 0, it is cos of theta now, and this distance 0.4 meter is also changed; because now it is at an angle, and because the distance is also increased, expectedly the power, radiant power intercepted by a two has to go down; if I have given value greater than this title, we can say answer is wrong, and the problem itself is wrong. Now, from ten to the power of the minus 6, it become 10 to the power of minus 7; that does not mean emissivity is exponentially going down, because other factors are not helping it receive more radiation, like the radius has increased, and the angle is also changed from 0. Now, please apply the formula again; but now, we may have a 1 cos theta also is there, please do not forget, a 1 cos theta will also come.

A 1 cos theta (( )) cos theta both. A 1 cos theta a 2 cos theta, both will come. Because the radius is like this, this radiation is like this, a 1 has to be aligned like this; please remember, we always, because that r means that, we have talking about normal to that radius vector.

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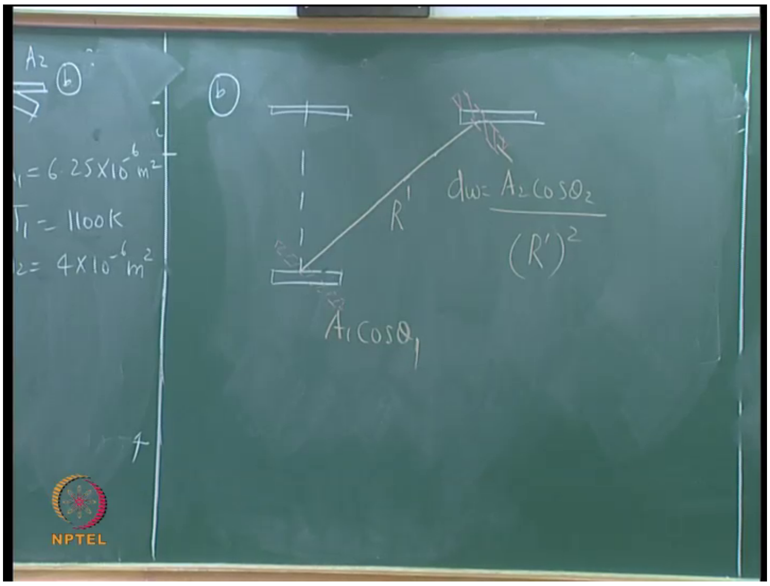

Now, let us do this part B. It is now, first we have to get the r dash, did we call it l or, does not matter. one by root two; root two l, 0.56. Now, D omega or you want set D omega dash, a 2; I expect the solid angle to come down, solid angle has to come down; because, it is seeing less and less of this, because the distance is increasing, and the angle also changes. What is the 8.?

Student: 1.48.14 8

Minus x steradian.

Rajesh, you are able to get? Samarjit? Leo, you are able to get? Now, what we will do, q is equal to, Q dash is now, what is given? 1.46 into ten the minus seven. Q dash, Q dash is also equal to D omega dash I b; should we put the dash for the other one also? Yeahm you can add that. Therefore, 26000?

Student: 4 (( )),

4.

Suppose, had we got an answer of 0.36, we could have conjucted that there is a possibility there it is diffuse surface; but now, I know for sure that it is not a diffused surface. Because with two angles, you cannot decide; but now, just two angles are giving different answers, that is why it surely not a diffuse surface. Since, since epsilon dash is function of theta, and at this point in time, I am not able to get the f; because, if I know the how it, how much power is intercepted at 4 or 5 angles, I can use the lagrange polynomial or cubic polynomial, quadratic polynomial, and get a function form f. I do not know the function form f, but I know that it is function of theta, the emitter a 1 is not diffused. So, it gives fairly good idea of how to handle problems involving directional emissivity, we have seen some problems involving directional emissivity, as well as, problems involving spectral emissivity. Tomorrow's class, we will start with absorptive and followed by problems; then we will do reflectivity, and transmissivity. Before, we get on to view factors, tomorrow nine o'clock.