**Radiation Heat Transfer**
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**Lecture - 25**
**Gas Radiation in Complex Enclosures**

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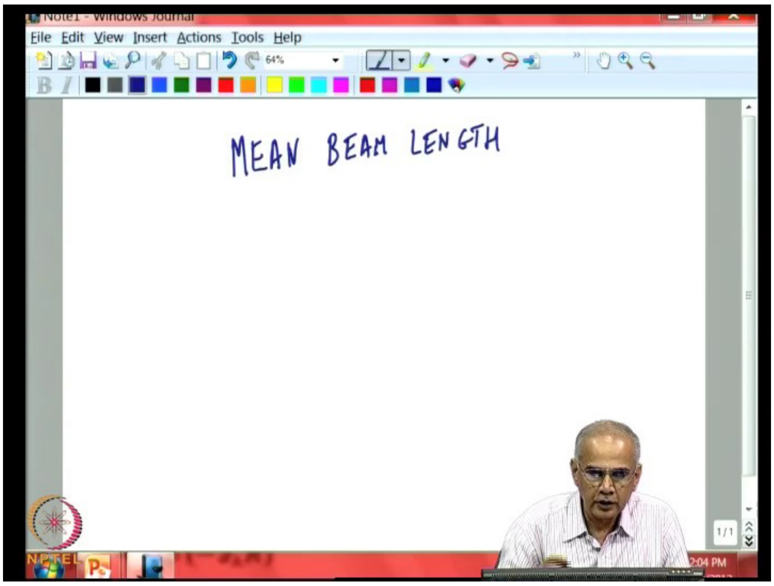


In the last lecture, we were talking about the concept of mean beam length for the calculation of transmittance in enclosures or in furnaces. And let us now elaborate more on this concept. To do that we first had look at a simple geometry.

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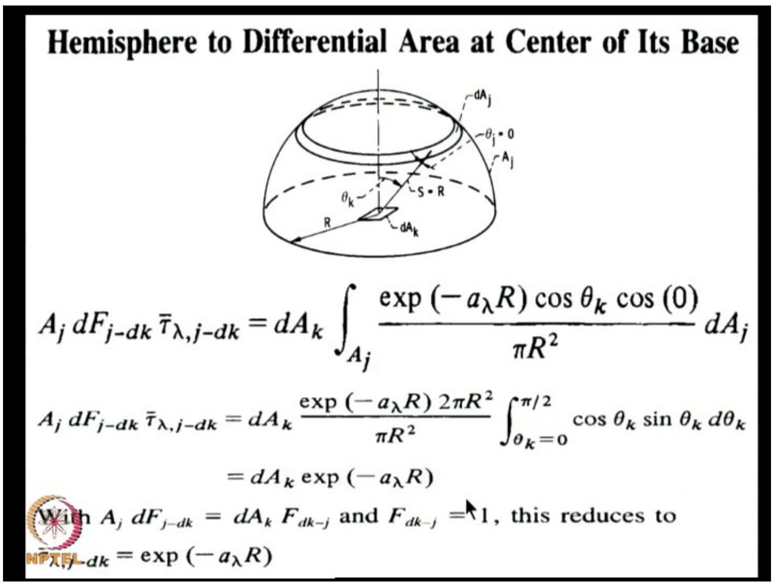

Let us look at hemispheric enclosures. The gas is enclosure along with the surface, this entire gas is emitting to its base. From the concept we discussed in the last lecture, A j F A j d A k, that is the radiation from all the gas elements to the base here, and we can do the integration over A j. The expression is like this and cos theta j is one, because the rays living the surface j are always normal to the surface. Now, because this is a spherical system, the integration is always very simple in these calculations. All these are independent of theta k, so they come out We can express d A j in terms of theta k.

Finally, we have a result which can be integrated very easily we get A j F d A j d A k in the transfer equation which is what we want. Using reciprocity, which is always valid and knowing that all the radiance leaving d A k has to reach dAj. We conclude that the mean transmittance is nothing but e to the power of minus a lambda R. When a hemispherical enclosure is radiating to the center of the base, then the expression for transmittance is very simple is nothing but e to the power of minus a lambda R. Now for other geometries life is a lot more complicated because in other geometries the simple application which we had here(i.e., cos theta j is 0 and elements are simple is not there). Let us take an example of slightly more complicated situation.

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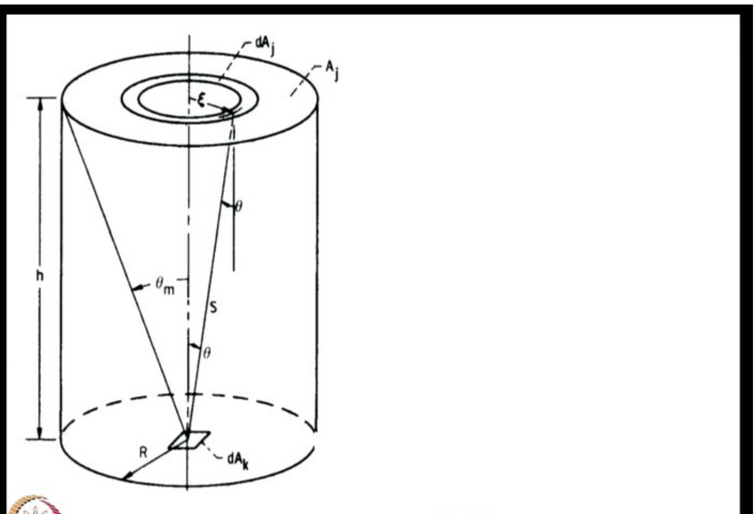


$$A_j dF_{j-dk}\bar{\tau}_{\lambda,\, j-dk} = dA_k 2h^2 a_\lambda^2 \int_{a_\lambda h}^{a_\lambda\sqrt{R^2+h^2}} \frac{\exp(-\kappa_\lambda)}{\kappa_\lambda^3}\, d\kappa_\lambda$$

Suppose we want to calculate the radiation from the top of cylinder to its base, we can write down the expressions and directly see that A j F d A j d A k into top cylinder which is what we want; We can write it in terms of d A k and all these quantities. Now this integral can be calculated, but only numerically. The relation between tau bar, the mean transmittance of all the rays and the geometry of problem, that is the radius of the cylinder is not very simple. It is very complicated. We can calculate that on the computer, but for practical engineer, this is a little messy. It will nice to express this as an equivalent hemispherical enclosure.

We look at all real life geometries that we encounter cylinders, parallel plates, cuboids or other things We do the integration immediately, but finally we would like to provide and expression which is easy to use. The idea is convert the numerical integration of these equations to an equivalent length, which is making this equivalent to this kind of system. That equivalent length is called the mean beam length. The mean beam length is nothing but the lengths scale which when use in this formula tau equal to it is minus a R; will give you same transmittance as the actual expression, which is much more complicated.

We are replacing the real geometry with an equivalent hemispherical geometry. The mean beam length is radius of that, fictitious hemispherical enclosure which will give you the same transmittance as the real geometry, which we are dealing with whether it is cylindrical or rectangular or something else. We want express this in terms. This is, of course , an approximation; so there is bound to be some error in this approximation.

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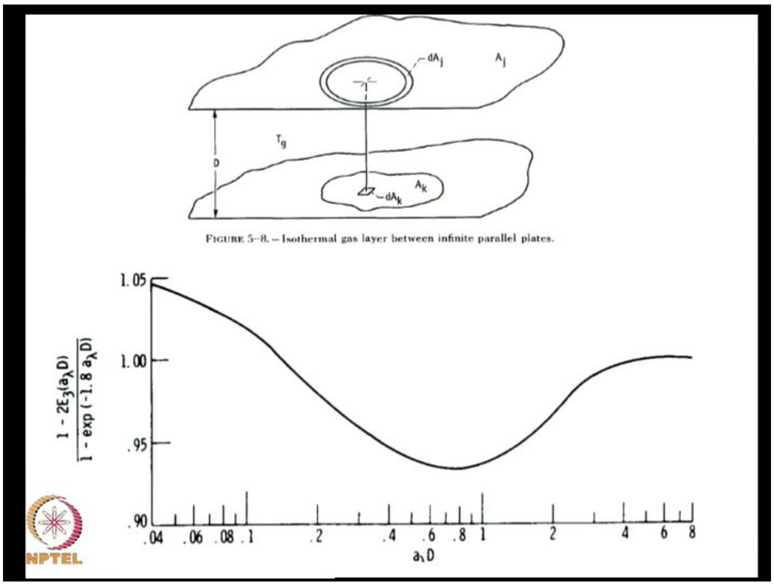


Now one example of this is given in this case. Now we have two parallel plates; We want to know the gas, which is emitting from all the gas layers emitting to this base here, What is the mean beam length? To do that, the exact expression for two parallel plates can be shown to be

1 minus 2 E 3 into a D, which is the exponential integral function which we encountered earlier. And here it is compared with simple expression, 1 minus E to the minus 1 point a D, where 1 point a D is the a mean beam length We see that this ratio is somewhere between 92 percent to 105 percent of the exact value. If we are happy with an error of the order of 5 percent, then we can replace the complicated expression in terms of exponential integral function in terms of a simple function in terms of an exponential.

The figure shows that the mean beam length concept is quite useful for a range of optical depths 0.04 to 8. It is within 5 percent of the exact result we can get by numerical integration.

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TABLE 5-I. – MEAN BEAM LENGTHS FOR RADIATION FROM ENTIRE GAS VOLUME

| Geometry of gas volume | Characterizing dimension | Mean beam length for optical thickness, $a_\lambda L_e \to 0$, $L_{e,o}$ | Mean beam length corrected for finite optical thickness,[a] $L_e$ | $C = L_e / L_{e,o}$ |
|---|---|---|---|---|
| Hemisphere radiating to element at center of base | Radius $R$ | $R$ | $R$ | 1 |
| Sphere radiating to its surface | Diameter $D$ | $\frac{2}{3}D$ | $0.65D$ | 0.97 |
| Circular cylinder of height equal to diameter radiating to element at center of base | Diameter $D$ | $0.77D$ | $0.71D$ | 0.92 |
| Circular cylinder of infinite height radiating to convex bounding surface | Diameter $D$ | $D$ | $0.95D$ | 0.95 |
| Circular cylinder of semi-infinite height radiating to element at center of base | Diameter $D$ | $D$ | $0.90D$ | 0.90 |
| Circular cylinder of semi-infinite height radiating to entire base | Diameter $D$ | $0.81D$ | $0.65D$ | 0.80 |
| Circular cylinder of height equal to diameter radiating to entire surface | Diameter $D$ | $\frac{2}{3}D$ | $0.60D$ | 0.90 |
| Cylinder of infinite height and semi-circular cross section radiating to element at center of plane rectangular face | Radius $R$ | .................. | $1.26R$ | .................. |
| Infinite slab of gas radiating to element on one face | Slab thickness $D$ | $2D$ | $1.8D$ | 0.90 |

Here is a table which gives you, the characteristic dimensions of various geometries that been countered in furnaces. First hemispheric radiating base is what we have done, sphere radiating to a surface circular cylinder radius centre of the base, then radiating to the convex bounding surface and various examples here and infinite slab. In all these cases, they are giving you the value of the mean beam length in the limit of optical depth being very small, one value and for find optical depth they are not same because there is some variation. The ratio of the finite optical depth mean beam length to the optically thin beam length The good news is that in most cases it is within 10 percent of the optical thin result.

If we have no access to these detailed calculations and we want estimate the mean beam length, then if you use the mean beam length for the optically thin limit; you would not have more than 10 percent error at most. Expect this one case, which has very larger error(around

20 percent). If  the situation in which some geometry is not covered by this table We  would like to estimate the mean beam length. Then we are forced to use this mean beam length expression for the thin limit That we will derive now. So, what is the mean beam length in the optically, thin limit.

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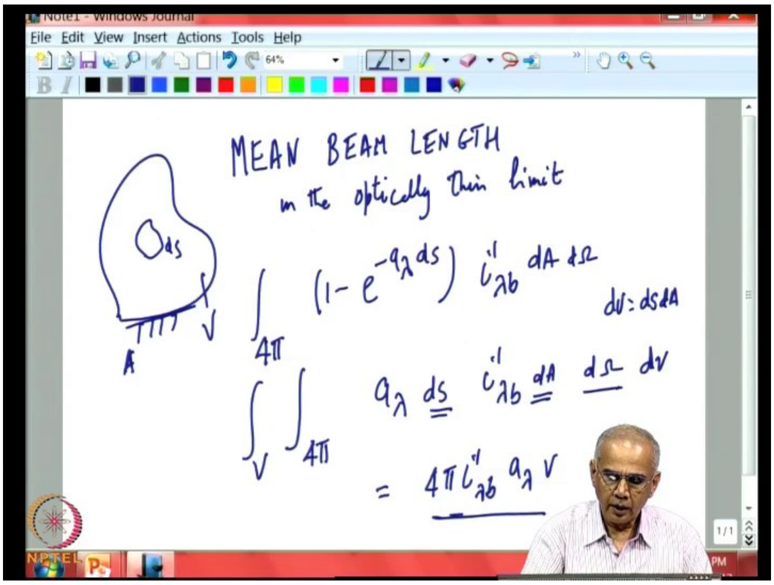


The idea is we have now arbitrary shape, maybe anything, radiating to the boundary and we want to calculate the mean beam length in the optically thin limit.  A radiation that is emitted from the volume to the base is the emissivity of the volume, this is your d s here and in terms of black body intensity into d A into d A mega; is general expression. Now because we are talking about optical thin limit this becomes a lambda d s i prime lambda b d A d omega. We will assume that approximately d A into d s is equal to the volume of the gas element, this is an approximation. Everything is independent of angle here so this will integrate to four pi. Finally we get an expression which is, 4 pi i prime lambda b a lambda v integral all with it, do also volume integration.  If we have this arbitrary shaped object; the volume v an area surface to which it the geometric area a then the radiation emitted is a base of that is this much.

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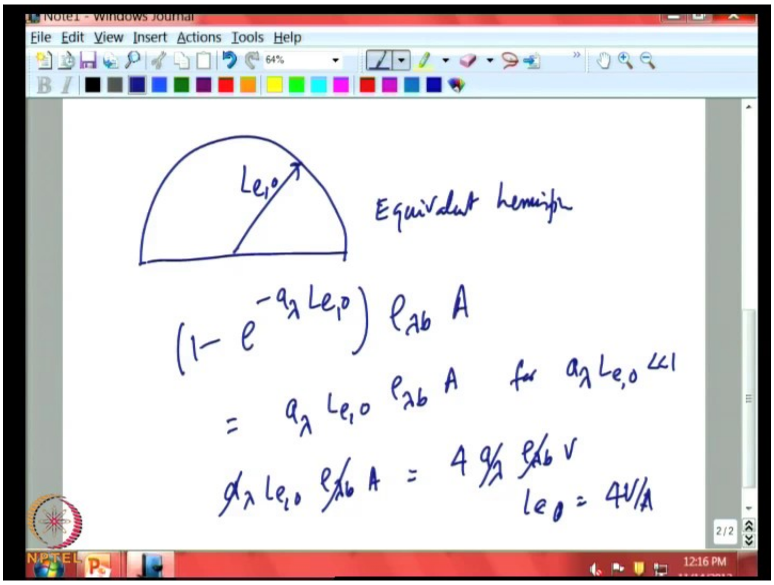


Now this is the exact expression obtained with, now this is being compared to an equivalent hemisphere. The equivalent hemisphere will have radiation to the base, based on this length L e is the equivalent length and L e is 0 because here doing in the going doing now in the optical thin limit into A lambda b in into A. This will come out as a lambda L e o, e lambda b into A for a lambda L e o much less than one, this is our assumption. We compare this result with the previous result, that is a lambda L e o, e lambda b into A is equal to 4 e lambda e lambda b into V. This is canceled out. The optically thin mean beam length comes out as 4 V by A. This is animportant derivation.

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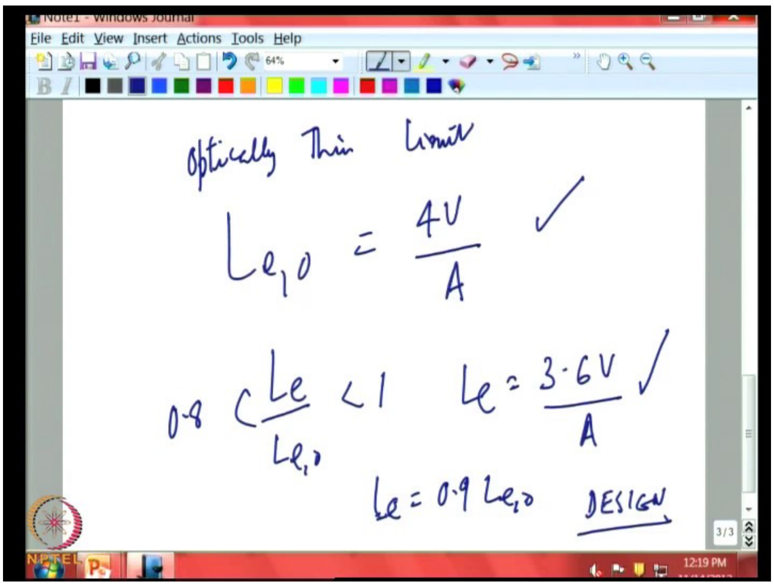

In the optically thin limit, we can derive a general expression L e o as equal to 4 V by A. This is the very useful result because any geometry that we take once you know its volume and area to which it is emitting, then the mean beam length is 4 V by A. So this useful for any arbitrary shaped object. Now we saw that L e by L e o, is typically in the range from 0.8 to anywhere between 1,2. So, for example, the mean values are 0.9. So people who use L e , like Hottel has done, use the value 3.6 v by A, because he assumed that L e is approximate equal to 0.9 times L e o.

We will use 3.5 but some use 3.6 depends on the particular application and situation. This is a commonly use method, to estimate emissivity and transmissivity of gas of arbitrary volume and shape, by which do not have readymade integral available. It is very useful in the design applications and estimate of radiative fluxes in commercial furnaces; so this is a typical engineering treatment of the problem. We are treating the entire gas to be isothermal, which is not always a good approximation; but we do that in order to be able to estimate fluxes in a simple way. After we assume the furnace to be isothermal we need to make estimate of the emissivity and transmissivity of a gas in the furnace. For that we have a general expression which we discussed in the last lecture; The expression can be integrated for certain standard geometry likes cylinders, spheres and parallel plates and so on. But for other cases the integration can become quite tedious. So, for such cases, the simple expression for the thin limit and approximation for any other optical depth is utilized in practice. Now remember these are basically approaches which are meant for design, not for accurate estimate of fluxes.

These are useful because at the design stage, you need have rough idea about the fluxes that will be encountered in that application. At the stage in design we are not looking for accurate data, it is merely initial estimates; so this kind of methods work quite well. But later on once a furnace is designed we want a accurate estimates of fluxes in the furnace to evaluate its performance you may want to do it in a more accurate way, for which we have to use standard radiation codes and many of the codes these days are Montecarlo codes; and so you will use this codes which will handle all the complexities related to the the gases that are non-gray and may be for non-isotropic surfaces.

But, that kind of elaborate use of software is warranted, if an only if you need high accuracy. At the design stage normally, one is quite happy to get an estimate within 10 percent of the actual because there are going to be various adjustment at the design stage, but once the furnace is constructed we want to estimate its performance and then you need more accurate analyses and for that standard more complex radiant packages are used. So, in engineering we adopt both an approximate as well as exact method and approximate methods are normally for the design stage and exact at the performance stage because when you are judging the performance of an engineering device against competing products. We need to provide fairly accurate estimates of the performance of your device. We may not be satisfied with 10 to 20 percent accuracy, we want more like 1 percent accuracy. For which we will use standard complex radiation quotes to estimate that. So, with that we conclude our discussion on radiative transfer for engineering application in furnaces.

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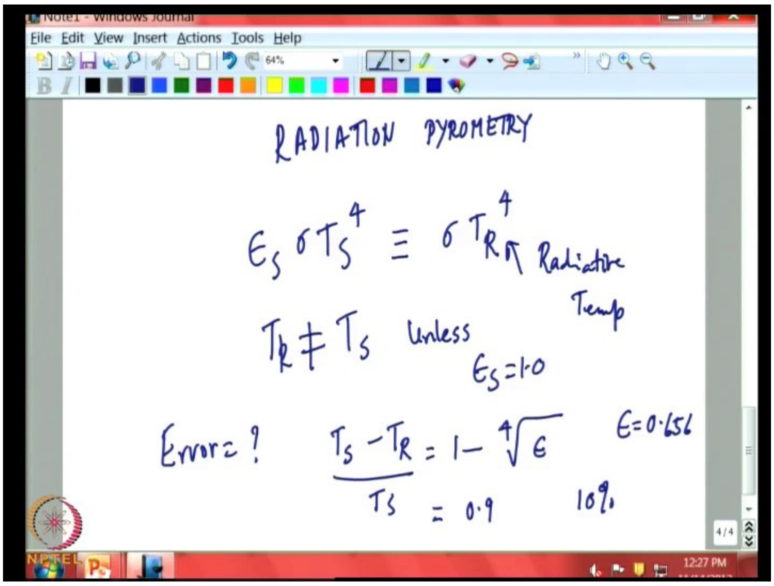


We will later on take of some examples illustrate this further. But now, we go on to a new topic called radiation pyrometry. Now one of the important applications of radiation is to sense the temperature in furnaces remotely. In most cases in engineering practice temperature is measured using thermometer, thermocouples or other devices which contact the surface whose temperature we want to measure. But there are situations especially at high temperature conditions, where it is not possible to actually touch the surface. We would like to measure temperature remotely. That is you measure the radiation emitted by the surface and using that you want to infer, what the temperature of that surface is.

This is getting quite common now and infrared thermometers are available for many applications where you will estimate the temperature of any hot object, by merely directing the thermometer towards it measuring the radiation coming in and from that inferring the temperature. In that context various quantities defined and some of them are called radiation temperature or brightness temperature or color temperature. In this lecture we will elaborate on that so that, it can be used in practice. When we measure quantity of radiation coming from the surface; what we are measuring is emissive power of that surface and, the black body emission. If we equated it to black body, then this temperature is an effective temperature and is called as radiative temperature.

So, what are flux coming from that source we assume is the black body. We write it as equal to sigma T two power of four and estimate the T r, but T r will not be equal to T s unless epsilon s is 1. The emissivity surface whose temperature we are measuring is unity then it is very simple we can estimate by saying the radiative temperature equal to actual temperature. Now this is quite true for a water body. A typical water body like a lake or ocean has emissivity very close to one. So we can assume it be equal to 1 This method will work quite well. But we will like to know what is the error in measurement. Any time we make any measurement, we want to know what is the error. In this case error is nothing but the actual temperature of the object minus what you are measuring (i.e., radiative temperature) by actual temperature and from that equation we can see which is equal to 1 minus fourth root of epsilon.

Let us estimate what this error what this error is if we suppose that the emissivity of the surface is somewhat low let say 0.656 for convenience. We substitute that here you will find, it is 0.9. We can see that the error in temperature is 10 percent when the emissivity as low as 0.656, but many surfaces that we deal with have emissivity is closed to 0.8, 0.9, 0.95 and so on. For all those cases the errors will be much lower.

If you are satisfied with measuring temperature with accuracies in the range of 5 to 10 percent then measuring radiative temperature and assuming the surface to be blackbody should work quite well. We assume 10 percent accuracies may be adequate in some cases, but if you are measuring the temperature of a surface which is has 800 degree Kelvin and error of 10 percent will be 80 degree Kelvin that may not be adequate for some applications. If we want higher accuracies then you have to do something else either you have know the emissivity surface that is always difficult as we saw earlier, that emissivity of any especially a metallic surface at high temperature depends on the level of oxidation which can change a lot with time. It is difficult to presume that you will know the emissivity of the surface whose temperature you are trying to measure that you will know it in advance. If the emissivity surface is unknown and is not high then you have to use some other tactics. Now the method we discussed is based on measure of total radiation of the surface.

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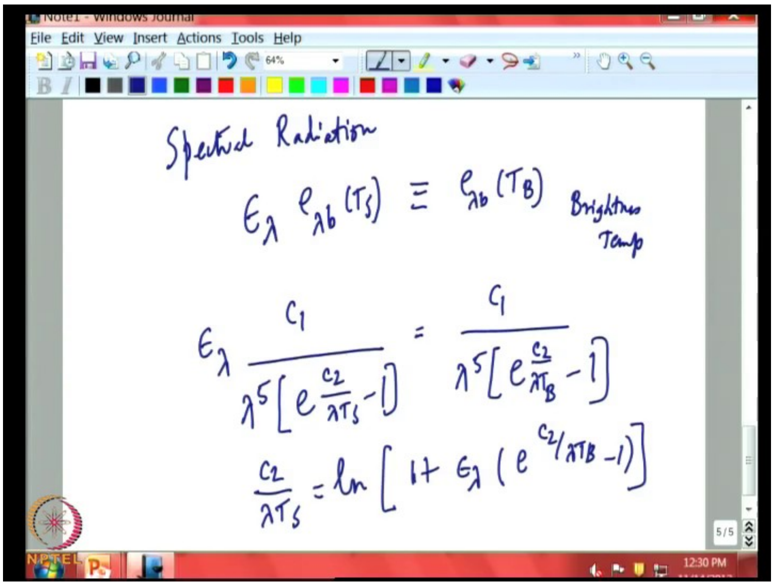


Now we can go little differently, we can measure spectral radiation. We use a radiometer with a filter to measure the radiation emitted by a surface at a particular wave length. That is, we equate the emissive power of a surface to that from a blackbody at the same temperature and wavelength. This quantity is called brightness temperature. So, brightness temperature by definition is the temperature of an object assuming that all the radiation emitted by object is from a black body. It is a equivalent black body temperature, which gives the same flux as what you are measuring and once more if the the emissivity of the surface at that wave length, is quite close to 1, then your accuracy is not too bad.

For example we know the black body emission and we are equating this to the brightness temperature of the object which is assuming that it is as a black body. We want again to estimate what is the error. We want to rewrite this as follows we can rewrite c 2 by lambda T s is equal to log of 1 plus epsilon lambda into e to the power of c 2 by lambda T B minus 1. If emissivity is 1 of course, T s equals T B that is by definition. Now the question is what is the error in assuming T B equals T s when emissivity is not equal to 1.

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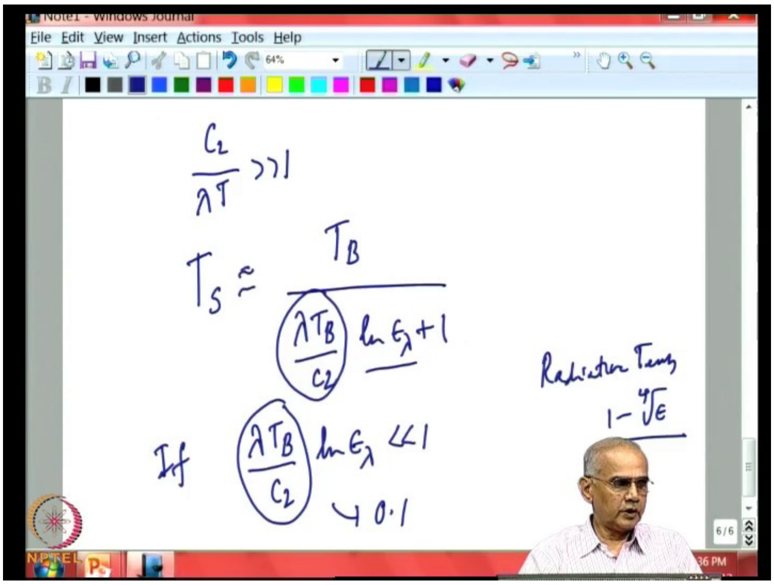


Now to do that, we will take a simple case. Now there are many applications where this quantity will be much greater than 1, most application that we deal with in engineering this is valid. In that case T s becomes approximately T B by lambda T B by c 2 log epsilon lambda plus 1. If epsilon of the one of the term goes 0, you are back to this design. Now can see that, this very close each other if this quantity is much more less than 1 then we have very close. For example if this 0.01 then you are making only in error of 1 percent it is 0.05 may be error of the 0.5 percent. So, I want to highlight the fact that, this quantity typically is around 0.1.

Even epsilon was not 1 let us say was 0.6 or something, this quantity will be quite small. And so that is the great merit of this concept of brightness temperature and has been used widely in satellite applications. Satellite from the space you are measuring the let us say temperature of the ocean and we are measuring not totally, but in a certain region, certain wavelength range where the atmosphere is transparent. We are inferring the brightness temperature and since the emissivity of the ocean is quite close to 1 this quantity is very small. The estimate of the surface temperature can be quite accurate.

Today satellite derived estimates of sea surface temperature can be as accurate as 0.5 degree centigrade accuracy. The inaccuracies that coming that you nothing do with this approach which is suggestion is more due to absorption by water vapor in the atmosphere and others from the clouds and so on. But otherwise, measurement of brightness temperature from space has in a very useful technique to estimate the surface temperature of both land and ocean from satellite. In the case of land the situation little more complicated in the case of ocean emissivity is close to one. This is very accurate, but in the case of land desert regions can have a emissivity as close to 0.7. Inaccuracies can creep up in such a situation.

We can see that the measurement of brightness temperature, will give you a more accurate estimate then the measurement of total radiation; that we saw in the definitional of radiative temperature. That is because in the case of radiative temperature the error went as 1 minus fourth root of epsilon. Here the error depends on logarithm of epsilon which reduces the problem. Further there is a quantity in different which makes it a very low estimate of this quantity. This quantity is already 0.1. The emissivity can be quite low. Even if the emissivity is around 0.6 or 0.5, we saw the errors can be of the order of 10 percent here we much lower because the quantity multiplying in front is much lower than unity. Now suppose we encounter a situation, where in emissivity is quite low and the accuracy that we can obtain by measuring the brightness is not good enough; then one can adopt a more elaborate method, this method uses two wavelengths.

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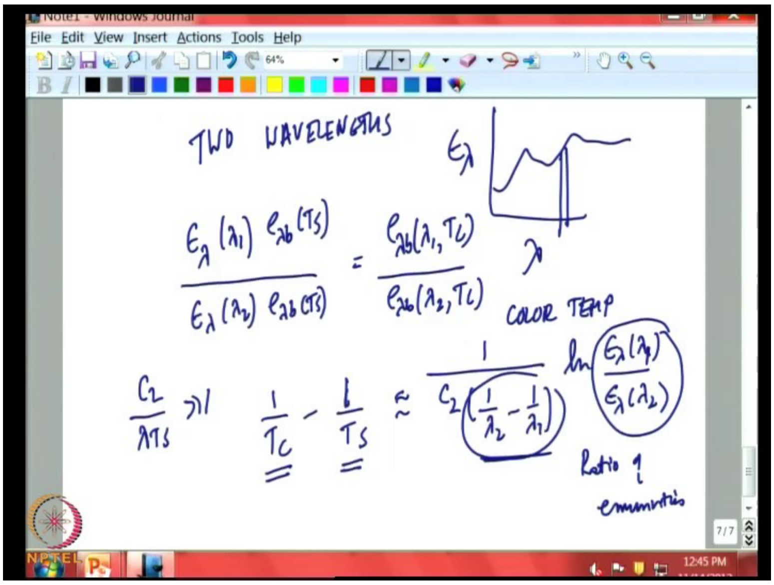


The idea of using two wavelengths is the hope that for a given surface emissivity may vary a lot and it may be quite low, but if you choose two adjacent wavelengths, nearby the assumption is, epsilon lambda does not very much. If we take a small change difference in lambda we 0.1 micron and 0.2 micro; the emissivity is not going to stay low. If that happens that so offer the case for most surfaces even the emissivity not equal to 1. The variation absolutely lambda around a certain a region may not be large.  This idea is exploited by looking at the ratio of the emission at 1 wavelength, to an adjacent wavelength; and compares it with the ratio of the black bodies at those two wavelengths. This is called a color temperature.

A color temperature of an object is that temperature at which the ratio of the emissive power at the two wavelengths is same as that of black body at the temperature T c. So, at the temperature T c, the ratio of emissive power of black body these two wavelengths, is equivalent to that in the actual object. Now one might wonder how this is different from brightness temperature. In the brightness temperature, you are equating the actual radiation received at a given wavelength to that of black body and ask what a black body temperature is. Because the color temperature you are not saying that emission from that body is equivalent to black body we are looking at the ratio of the two emissions, so which is a more complicated assumption.

Again if you assume that, C 2 by lambda T s is much greater than 1; which is again normally the case. Then we can show the difference between a color temperature and the actual temperature of the surface, is approximately equal to C 2 1 by lambda 2 minus 1 by lambda 1 log epsilon lambda 1 by epsilon lambda 2. So epsilon lambda at lambda equal lambda 1, to epsilon lambda at lambda to lambda 2.

Now notice that the difference between the color temperature the surface temperature, depends not on the emissivity of the surface, but on the ratio of the emissivity.  What we find is that is the surface can have quite low emissivity can be 0.1 or 0.2, as long as that emissivity does not very large between two wavelengths you are choosing then this conducive quite close to 1 and log one is 0 then color temperature will be very close to the actual temperature. The accuracy of measurement now is not depending on the value of emissivity, but assuring that emissivity does not vary very much with wavelengths.

But of course there is a challenge here, you would like the adjacent wavelength to be quite close to the one of the wavelength you have chosen, but the requirement to choose too close is that this conductivity will go to 0. This demands that two wavelengths should not be too close, but same time it cannot be too far, as the quantity will go up. There is a trade off in this choice of wavelengths; If we choose wavelengths too close to each other, this quantity go to 1, but this quantity will go to 0. So, will get 0 by 0 so we do not know, but if you choose well little far away, then this quantity may be departing from 1 may not depart much, but this quantity will increase. So, error will be kept down.

This is the most accurate method of measuring temperature from sources, by remote method. In the remote technique, you do not have to touch the surface. That is why it is so popular in satellite applications. In satellite application either we consider the brightness temperature, that is measurement at one wavelengths is used or more commonly they choose two adjacent wavelengths; and choose the wavelengths such that a difference between the color temperature and surface temperature is very, very small. There is a design freedom here in choosing the two wavelengths and so in most cases, you will able to choose wavelength sufficiently for a path so that this term is not going to 0, but in that wavelength range emissivity is not varying that much with wavelength, all though it may be low. This may be both be a case, but we can imagine that it is also a more elaborate technique. This instrument is more expensive because you are not just comparing the emission from a surface, you are comparing the ratio of the emission from the surface of two dimensional wavelengths with the same ratio for a black body.

The accuracy demanded for the measurement is little more demanding here because we are talking about ratios and but still we can see this method is definitely superior, to either the radiative temperature approach or the other temperature approach. Because we can measure the temperature of surfaces with very low emissivity, as long as the emissivity is not strong function of a wavelength. As long as in this kind of domain when emissivity is varying very slowly with wavelength, nearly choose two adjacent wavelength which you make this ratio close to one and make this ratio sufficiently large that error that is introduce is kept to a very small value. There is lot of design freedom because you have the freedom to choose the two wavelength such that the error goes to that value.

There are three ways in measuring temperature remotely, by sensing the emission from the surface. The simplest approach is the total radiation parameter, which measures the total radiation for the surface assuming as a black body, estimates its radiative temperature. This method can give accuracy of the order 10 percent; which is adequate for certain application. If one is not satisfied with that, one can go to measurement of the given wavelength and that method is called brightness temperature technique, and is used widely in satellite meteorology.

There in you are measuring only temperature at one wavelength and although emissivity may be low; we saw that the quantity multiplying this emissivity term is quite small.  Then we are dealing with logarithmic emissivity, which is a small quantity. And so the, total error that is introduced because emissivity is not equal to 1 can be quite low, but one is not satisfied with this also one can ultimate goes more elaborate method, which involves comparing the fluxes from a given surfaces at two different wavelengths adjacent wavelengths;  This  method will work very efficiently for even for low emissive surfaces because what the method demands only that the emissivity can be low, but will not change rapidly with the wavelength.

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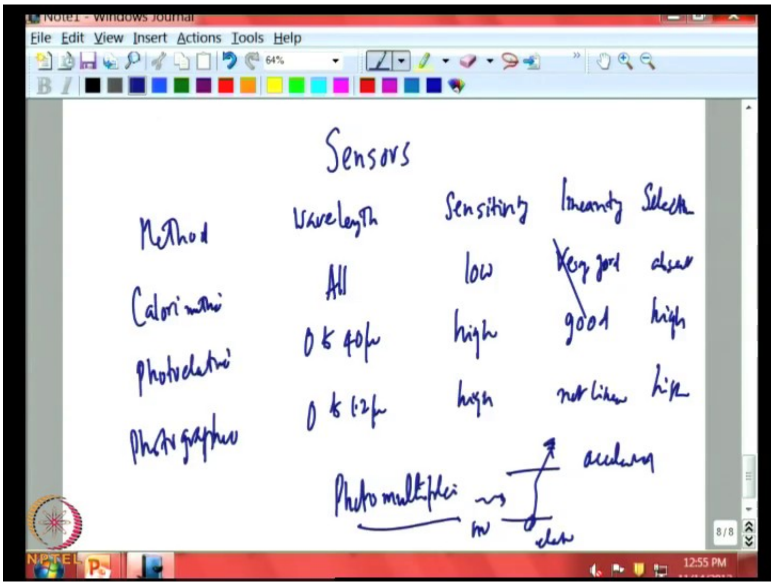


We have seen various techniques of measuring temperature remotely, it is also occasion to briefly mention; what are the sensors used in radiation measurements for these kinds of applications. Now the sensor that we use depends on your application; so we will typically talk about the method, talk about the wave lengths range, where we can use the method, its sensitivity and how it depends on temperature changes linearity and selectivity. For example, look at calorimetric method is a one most accurate; you merely observe that radiation coming from the surface by the temperature rise using colorimetric we can use all well in ranges.

We can measure temperature any wavelength, but some sensitivity is somewhat low because ultimately the accuracy depends upon the ability to measure temperature change in response to the radiation from within and so sensitivity can be quite low, but it is very linear; which we can appreciate, because the incoming radiation as a temperature change are linearly related. So this method is particularly linear, it is no selectivity in wavelength, but that can be overcome by putting a filter; so we want to measure only radiation in a certain wavelength range, then we can put a filter to block out those wavelengths ranges; then this method is still quite good.

It is the oldest method and still used as primary standard. The second method is photoelectric method, in which you convert the absorption of incoming photons to electrical signal. This operates well in though lower in the up to 40 Micron, beyond 40 micron the frequency is low. The photons may not able to dock and electrons out or do something substantial. There is difficulty in dealing with wavelengths beyond 40 Micron. This is a very sensitivity method that means, this is small change in incoming radiation given the last signal.

Its linearity quite good, but not as good as the calorimetric method; calorimetric method is the best for this thing and its quite selective because the in photoelectric method you are looking at photons absorbed by surface knocking and electron out of the ground state and take it higher. So it will respond only certain wavelength range. The last method is photographic method. Like in old method, but it is related only to the high wavelength, low wavelength region is not visible. So it is works only from 0 to 1.2 Micron range, it is very highly sensitive not linear and solution is better. Now this method is used for example, to detect fires from space. It is important for many applications to look at, how much of the surface earth any time is undergoing damage due to fire and we would like to measure from satellite the amount of area around the world which is influence by fire.

Now the amazing part is a satellite in space at a height of 1002 even higher heights, is able to detect very weak signal coming from forest fires. Now this possible because of special instrumentation, which enables 1) to amplify the signal millions of times so the signals are amplified million times; then you get a very, very strong signal. The technique which enables us to do this is called photo multiplier. These signals are use to convert the weak signal coming in the visible region, from forest fires to million times Then one can measure sources with very low intensity and based on this satellites have mapped a moment of forest fires across the world. They were shown on that in the continent Africa, there are large fires accessing 1000 kilometers across. They move north-south following the season, because most forest were set are instigated during the dry season and so they can be tracked from the satellite That was possible because of photo multiplier that is available; which increase the signal strength almost more than a million times. It gives a very accurate estimate of the surface condition.

Now these achieved in these photo multipliers in with essentially you have a photon, knocking electron out of the bound region and once the electron is free, they can be accelerated by a suitable accelerating devices.

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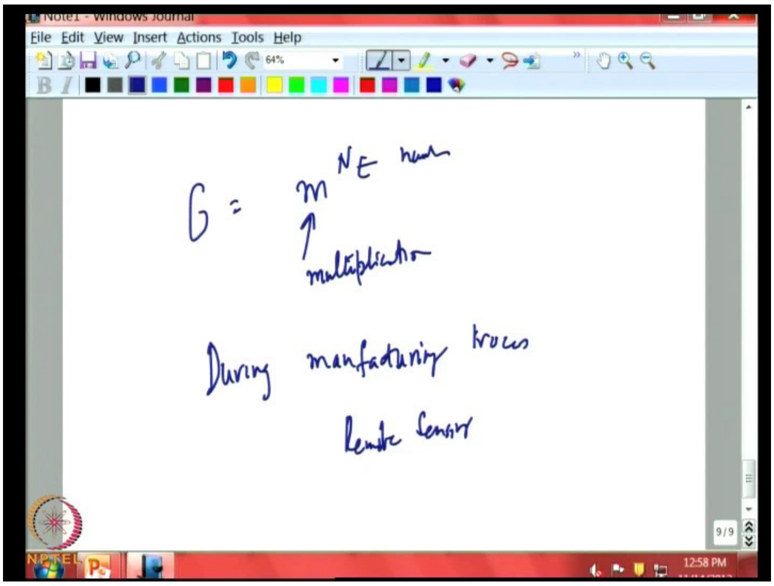


The total gain that you achieved in photomultiplier depends upon how much multiplication we can achieve and the number of such devices. Since it goes as m to the power of N we can reach fairly large values. Because if in one device, the gain is of the order 4 of 5 and there are 25 such devices one after under there, then your gain be 5 to power of 25 and can be very large. And so this has been routinely used to detect very weak signals from the surface. The other application of radiation measurement, other than satellite is to measure the temperature during manufacturing process. Now, in such a case like a steel industry and other industries when a billet or some other object is moving continuously it is difficult to measure the temperature of those objects by physically connecting into the thermocouple or a thermometer. So, for such application a remote sensing is desirable and that is well followed by radiative heat transfer.

Now the technique we discussed about reaching a high amplification, factor of the order million can only occur in those devices, where the electron is knocked into the conduction band of the substance and then it is allowed accelerate by providing voltage gradient. That is why these techniques are normally available only for visible, because the frequency available is very high so it can actually knock out, electron to the conducting state and where in it can be easily accelerated. If we add a photon in the far infrared it may not have adequate energy to knock electron into the conduction band.

This technique using photo multiplier and detecting forest fires is an example of use of visible radiation in photo multiplier and reaching very high level of detection. Now this is not impossible for infrared or microwave wave lengths. It is only a special feature of visible wavelength. Today we saw essentially discussion on engineering treatment of furnaces as well as a few practical measurement techniques based on radiation heat transfer. This highlights the some other further application. Now we will go back to more accurate treatment of a radiate transfer and finally, take up the more difficult problem of scattering.