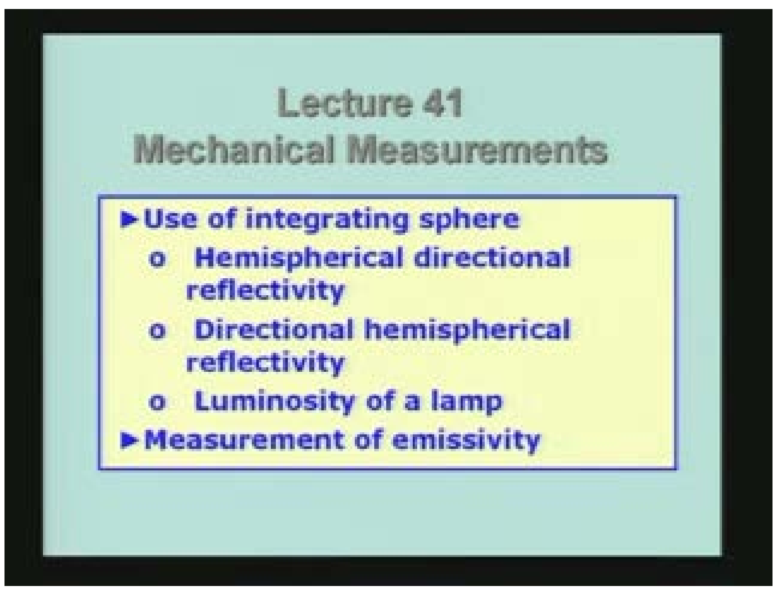
Mechanical Measurements and Metrology
Prof. S. P. Venkateshan
Department of Mechanical Engineering
Indian Institute of Technology, Madras
Module - 4
Lecture - 41
Integrating Sphere and Measurement of Emissivity

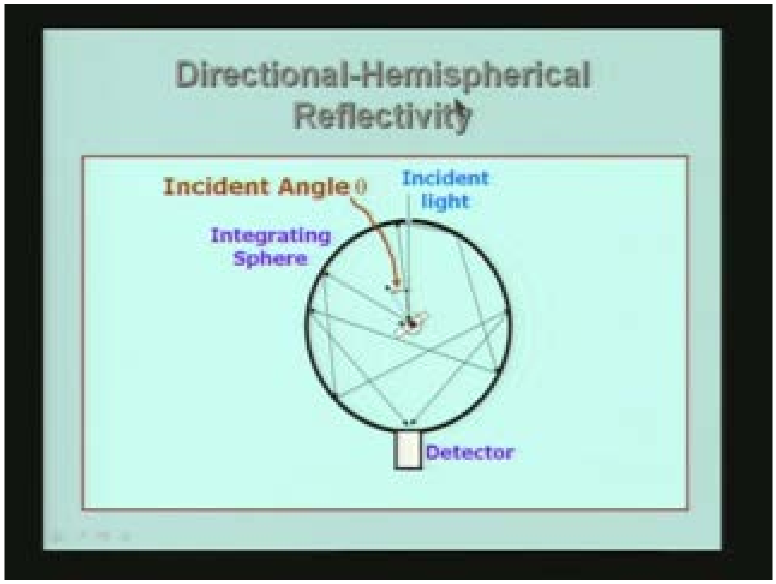
This will be lecture 41 on our ongoing series of Mechanical Measurements. Towards the end of lecture 40 we actually discussed about measurement of radiation proprieties of surfaces wherein we had given an introduction to surface proprieties and then we were trying to look at how surface proprieties like the reflectivity of a surface can be measured and as a part of that we had introduced what is called an integrating sphere. Essentially what I am going to do is to look at the use of integrating sphere for two things.

(Refer Slide Time: 1:09)



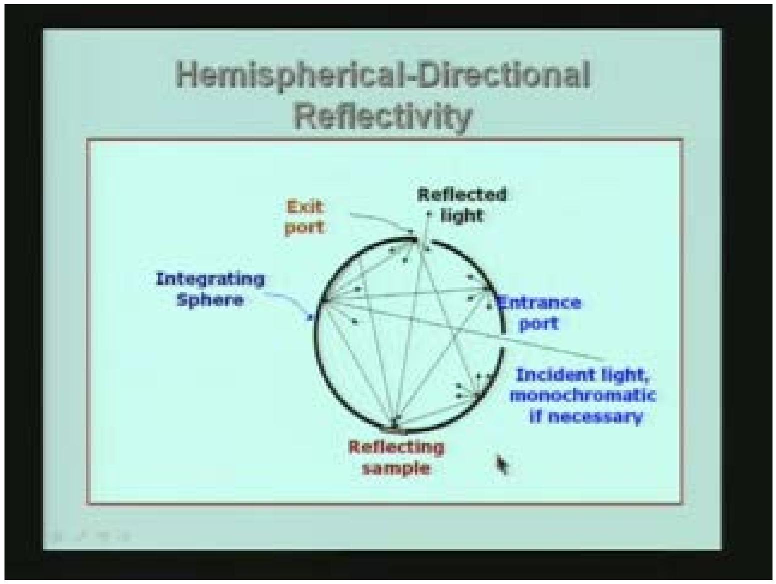
One is hemispherical directional reflectivity measurement, and the other one is the directional hemispherical reflectivity measurement and the third one is the use which is usually for the measurement of luminosity of a lamp. Subsequently, I will look at the measurement of emissivity by using various techniques. In the previous lecture we looked at the integrating sphere. Integrating sphere is essentially a spherical shell whose inner surface is given a suitable coating such that the coating provides a highly diffused surface, and also it has got a very high reflectivity more than 95%.

(Refer Slide Time: 2:31)



Such coatings are possible, for example, using barium sulphate magnesium oxide and so on and also some patented surfaces are there which are available from the manufactures which gives you essentially a very highly reflecting surface. Let us look at what might happen when you have an integrating sphere. In this case, what I am looking at is a beam of light which is shown by a straight line here. This is the incident light, which of course, may be monochromatic if necessary. That means if it is coming from a monochromatic source or it is from a polychromatic source which has been monochromatized using a monochromator. So as it comes and falls on the spherical surface it gets reflected in all directions as indicated by the arrows here.

(Refer Slide Time: 4:31)

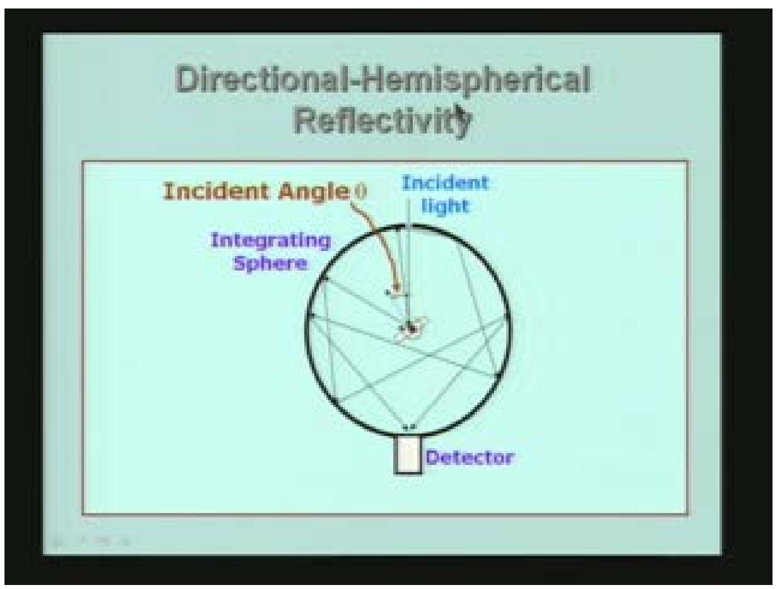


And because of the high reflectivity of the surface, most of the light is actually is going to be reflected and if you follow what happens to the one which is reflected in this particular direction, it is going there, and again falling on another part of the sphere getting reflected in all directions, and again one of them is coming here and getting reflected at this point, and then essentially it falls on the reflecting sample after several reflections. So you can see that, the light which is incident through this port or this hole which is falling on a small area on the sphere at this particular location gets reflected in all directions and the light which is received by the reflecting sample apparently comes from all directions. And because the light or the radiation is undergoing a large number of reflections, and reaching this surface it is somewhat integrated over all directions. Therefore, what you have is an illumination on the sample which is diffused, and coming from the entire hemisphere. That is why, the surface is exposed, or illuminated by radiation coming along all the hemispherical directions of the hemisphere.

So the incident light on the surface is coming from the entire hemisphere and now what I am doing is, I am looking at one particular direction by making a hole at another place on the sphere through which I am going to look at the radiation of this which is coming out. This radiation which is coming out is essentially coming from the reflecting sample at a certain angle to the surface. Therefore this is the directional reflectivity I am looking at but the illumination is over the entire hemisphere and therefore in this arrangement I have got a hemispherical directional reflectivity measurement. So what I have to do, is to measure the total incident radiation, and measure the reflected radiation and from these two, I will be able to find out the reflectivity of the surface for hemispherical directional reflectivity. This is just to explain the way the integrating sphere works, and then how it can be used for measurement of hemispherical directional reflectivity.

The second arrangement is slightly different. It is the directional hemispherical reflectivity. In the previous case the illumination of the sample was on the hemisphere was from all the directions of the hemisphere and the reflections were measured in one particular direction. In the second arrangement I am going to illuminate the sample which is held at the center of the integrating sphere, and I am illuminating by light coming at a certain angle. You see that the incident light or incident radiation is coming in this direction and the normal is shown here by this dashed line, and the angle between these two is the angle theta, this is the angle at which the incident radiation is coming and falling on the sample. So what happens at this sample? At the sample it gets reflected in all the directions. Of course, the sample may be fully diffused reflector; it may be a specular reflector it may be neither specular nor diffused, it is one of those intermediate cases.

(Refer Slide Time: 6:41)



We have already seen what happens at a surface, when reflection takes place for an arbitrary surface. So the radiation is going to leave in all directions, and now I am going to integrate the radiation leaving. In the previous case the radiation incident on the surface was integrated but in this case we are integrating the reflected radiation. Therefore it is incident at a given angle and then reflected along all the directions of the hemisphere. Some of the rays have been indicated here, they come here get reflected several times and then comes to the detector. The detector is actually placed against a hole on the integrating sphere.

It is very essential in this particular case to see that there is no direct incident light falling on the detector, and therefore, we must shield the detector from direct radiation. In this case, of course, the sample itself is shielding the detector from radiation which might fall directly on that so the sample is also doing the business of being a shield. What happens here is that the incident light comes here at a particular angle to the normal gets reflected in all directions, I have taken one or two different rays coming out, one is coming here, one more, second reflection, third reflection, fourth reflection and so on, so a large number of reflection takes place, and the light which is arriving at the detector is actually proportional to the amount which is reflected along all the hemispherical directions.

Therefore, in this measurement, I get the directional hemispherical reflectivity. That means it is illuminated at one angle, and what is leaving in all the other directions is measured. In the previous case, it was in the hemispherical directional. That means it is illuminated along all the directions possible and what is leaving in one particular direction or reflected in particular direction is measured. These are the two essential measurements which are made in practice. And if the sample is opaque, we can relate the reflection reflectivity and the absorptivity

We can relate them and therefore this can be used for measuring the absorptivity of the surface also. It is nothing but one minus the reflectivity. Of course, in this case, the absorptivity will be for directional hemispherical absorptivity or for the previous case it will be hemispherical directional absorptivity, because absorption plus absorption coefficient absorptivity plus the reflectivity must be equal to one for an opaque surface. Let us assume that in all these measurements the sample itself is not going to emit too much radiation. Therefore, essentially we have to keep the sample at a lower temperature so that the emitted radiation from the sample itself is not going to be important.

In other words, if the incident light is of very high intensity compared to what would be emitted from a sample, then the emission from the sample can be ignored. Otherwise, we have to divide the method by which the emission has to be measured separately from the sample, because of its own temperature and then we will have to account for it. So, that will be a source of error in this particular measurement. Here is an image of the integrating sphere. Here is the integrating sphere with an opening. For example, in this case the application for which this is been used is to provide a uniform intensity radiation coming out from this port.

(Refer Slide Time: 11:33)

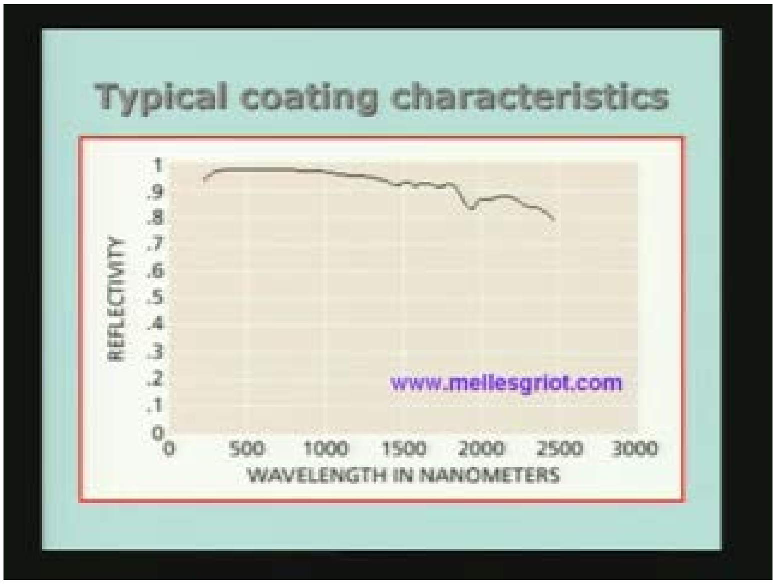
Essentially what has been done is, inside the integrating sphere a lamp whose output we want to measure is placed and the lamp gives out radiation in all the directions, and because of the integrating sphere the radiation leaving through this hole essentially is proportional to that which is leaving in all the directions. This can be used for measuring the luminous output of a lamp. Suppose, we have a standard lamp for which the luminous output is known, we can place this standard lamp inside this integrating sphere, and find out the intensity of the radiation leaving this just by looking at this port and measuring it using a detector to detect the radiation so you get a reading, corresponding to a source of known luminous intensity.

Now you replace the source of known luminous intensity with that whose intensity has to be luminous, the output has to be measured and then you do the measurement again. By comparing these two, we can find out the luminous intensity or luminosity of the light source. This is one essential method which is used by manufactures of light bulbs and so on because standards require such measurement. If you look at the size of this integrating sphere it can be anywhere from a few inches or few centimeters in diameter, to a few meters in diameter. In illumination industry, where you test out very large sources of light or large bulbs.

For example, you need a very large integrating sphere because the larger the integrating sphere, the more accurate is the measurement and the errors are minimized. For example, if I want to take a fluorescent fitting and look at what is the amount of light which is coming from the fluorescent fitting the size of the fluorescent thing may be a meter or so in length. Therefore I have to put it inside an integrating sphere which may be 2 or 3m in diameter. Such integrating spheres are actually available, but of course, they are very expensive. We can use them for measuring the luminosity of a light source. These are three uses of the integrating spheres. The first two being the measurement of reflectivity hemispherical directional or directional hemispherical and the third one is the luminosity of a light source.

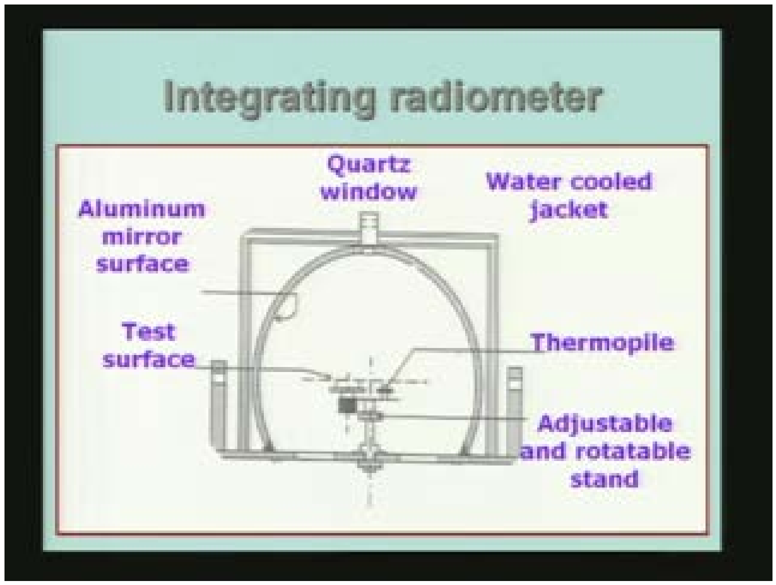
Let us look at the typical coating characteristic of an integrating sphere. The reflectivity is being used between about 300 or so nanometers to about two thousand five hundred nanometers visible and the infrared part of the spectrum. We will usually call this as the near infrared. The reflectivity is very high and more or less uniform but there are small variations here. But essentially what we have is a high reflectivity, uniform reflectivity and highly diffused reflectivity.

(Refer Slide Time: 15:01)



So this is the typical coating. This is the patented coating which they use in the manufacturing process. Let us now look at the apparatus known as the integrating radiometer. This is slightly different from what we have discussed earlier. In the earlier case, the integrating sphere was actually coated with a diffused surface or diffused coating, it is highly reflecting but diffused. Here, I am not going to use a diffused reflector, but I am going to use a specular reflector. Let us look at the operating principle, and describe what is going to happen. If you take this as the axis, this is the vertical axis, the sample is placed here, or the test surface is placed here and the thermopile which is the detector for radiation is placed on this side such that whatever light leaves this place after being reflected will impinge on the thermopile. It is a focusing arrangement, if you take this as the axis, this is the

(Refer Slide Time: 16:05)

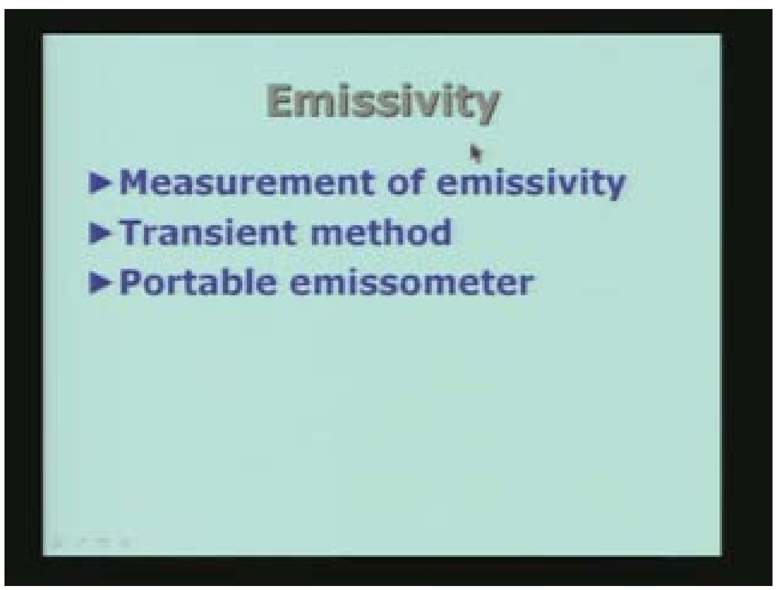


vertical axis, the sample is placed here or the test surface is placed here and the thermopile which is the detector for radiation is placed on this side such that whatever light leaves this place after being reflected will impinge on the thermopile. It is a focusing arrangement, the light will leave this surface through all the directions, and it will be reflected and after reflection it is going to fall on the thermopile. Therefore it is integrating because, it is going to focus all the radiation leaving the test surface in all the directions on to the thermopile. So integration is done by a slightly different method. Multiple reflections are not talked about here it is only the focusing arrangement. So we can make adjustments for the positions and so on, the thermopile is the element which is going to measure the reflected radiation or the emitted radiation whatever is emitted or reflected.

Suppose, I illuminate it from a particular direction then it will leave in all the directions. Like what we had earlier we can illuminate the sample by bringing in radiation from outside, or you can even put a surface there which is heated and therefore the radiation emitted from the surface will itself come to focus on the thermopile and therefore in a way this can be used for measuring the emissivity of the surface. So emissivity is nothing but the radiation emitted from the surface which is per unit area per unit time. If I compare it with a black body at the same temperature, that ratio is going to be called as the emissivity. Therefore in the integrating radiometer it is the self radiation from the sample surface or test surface which is coming out, because of its temperature and what I am doing is measuring the total amount of radiation coming from the surface and I am going to compare it with a black body.

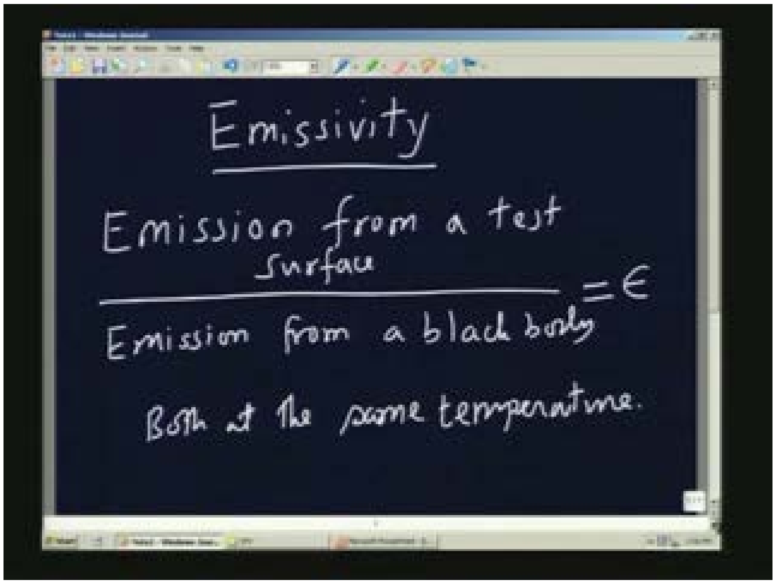
Sometimes the black body is also arranged here, so that alternatively I can have the black body and the test surface being exposed, so that I will measure alternatively the radiation from the black body source, and the radiation of the test surface so that the ratio can be taken, and then we can get the emissivity of the source. Now let us look at some specific methods in emissivity measurement.

(Refer Slide Time: 19:49)



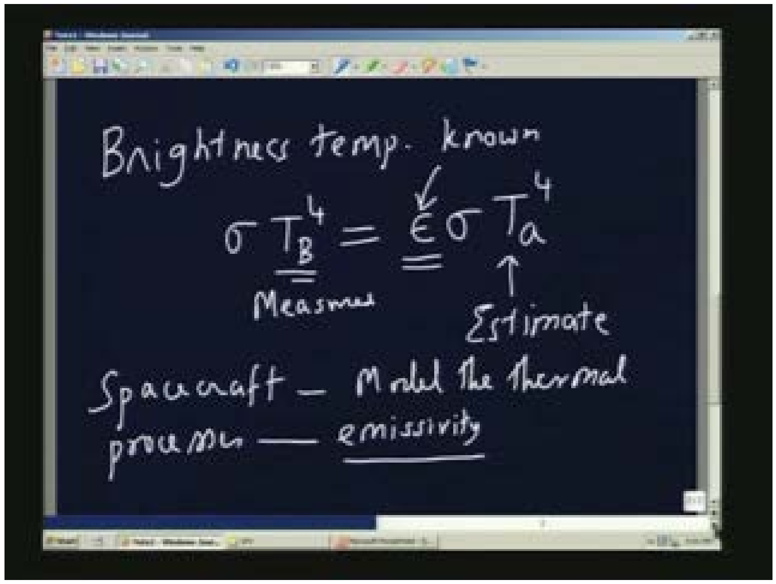
Emissivity is a surface property, so it is a comparison between emissions from a test surface divided by emission from a black body, both at the same temperature. This is very important. Remember that this is the ratio which we will represent as epsilon. Emissivity plays an important role in the measurement of temperature using a pyrometer because there again we were doing exactly the same thing. We were comparing the radiation coming from the test object whose temperature I want to measure, and I was comparing with a standard lamp whose temperature is known or whose current I vary such that its temperature can be altered and we were measuring what was called the brightness temperature.

(Refer Slide Time: 21:36)



We remember the idea of brightness temperature. It was defined in such a way that epsilon times sigma times (T_B) whole power 4 where T_B is the brightness temperature of the object, is equal to epsilon sigma T_{actual} to the power of four when I am talking about total parametry that means I am using the entire spectrum of radiation.

(Refer Slide Time: 24:33)

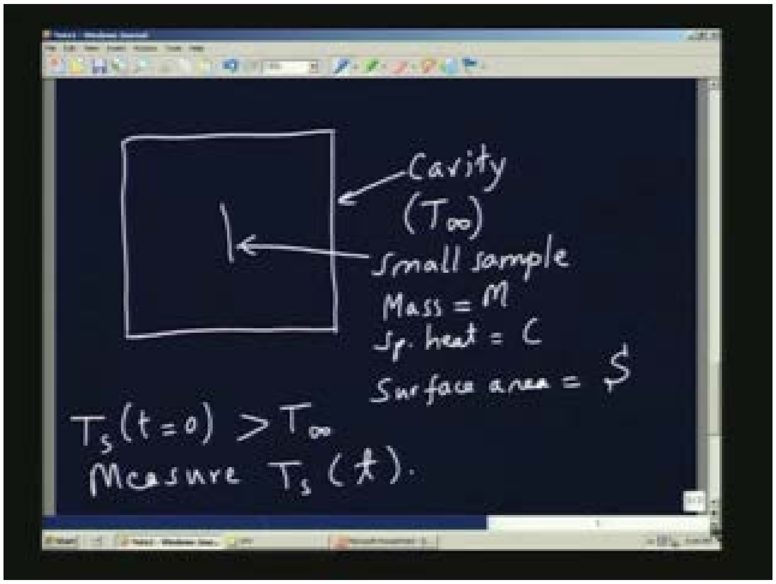


Here emissivity plays a role in this particular case. Therefore the knowledge of emissivity is very important for measurement of temperature, because I am going to find out what is this. This is measured and if it is known then I can estimate this. Therefore one important use of measurement of emissivity is in the application to measurement of temperature in pyrometer. Of course, there are other important applications also. If you have any surface which is subject to incoming radiation and it is subject to temperature difference of this ambient it will also lose heat or gain heat from the surroundings and therefore energy balance on such a surface requires knowledge of the properties of the surface.

For example, if you have a space craft and you want to model the thermal processes, the space craft may be actually generating heat inside, because of some process which is taking place, some electronic equipment may be there and so on. So you want to keep the space craft at a desired temperature level, so we have to model the thermal processes and the important thing we require is the emissivity.

Of course, emissivity means other properties like absorptivity because, they are related to each other, and then the reflectivity and so on. Emissivity measurement is important. Therefore we want to look at some of the methods which can be used. So one way of doing it is, if you take a cavity, cavity is simply a closed vessel and if I put an object inside and let us assume that the temperature is constant maintained at $T_{infinity}$ and I put a surface inside a small sample whose emissivity I want to measure, so this sample has got a certain mass then specific heat C, surface area S so let us look at what is going to happen.

(Refer Slide Time: 27:03)

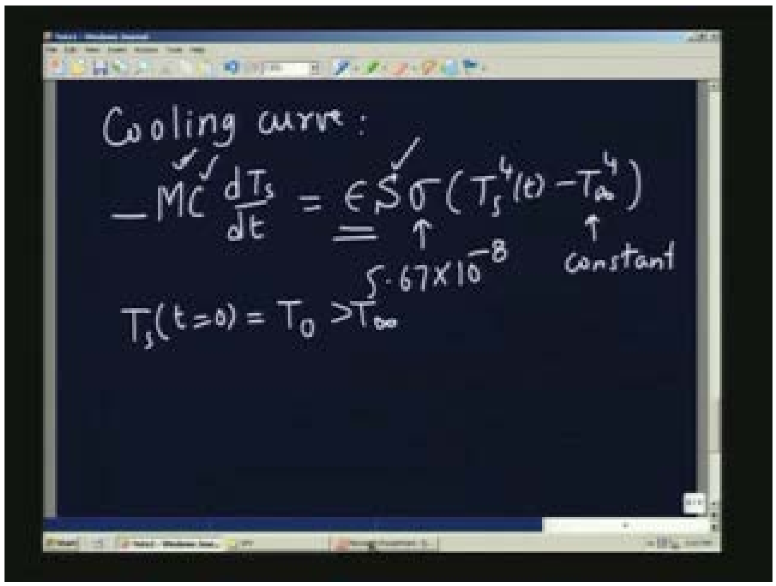


Suppose, I heat the sample by some means, and at T equal to 0, I initially bring the temperature of the sample to some value greater than $T_{infinity}$. So T sample at T equal to 0, is greater than $T_{infinity}$, and I will remove the source of heat so initially the sample is heated to a temperature greater than $T_{infinity}$ may be for 25 degrees 35 degrees 40 degrees or whatever above the $T_{infinity}$ and, I start allowing it to cool, and if I assume that the sample is very small, and there are no temperature gradients within, I can assume that the sample is at a uniform temperature, and I can measure the temperature as sample measure temperature T_s as the function of time. So what you get is a cooling curve which will mean that the temperature of the sample which was higher than the $T_{infinity}$ to start with will start reducing, and of course, if we wait long enough it will come to the same temperature as the cavity temperature.

We will assume for the moment that we have a high vacuum inside. That means, there is no heat transfer, or heat loss from the sample by conduction or convection that is conduction to the medium, convection to the medium and we will also assume that for heating this sample we need some method of bringing the heat into it we can bring it through very thin wires and electrically heat the sample. So if the wires thin enough we can assume that the heat loss through the wires is very small so we ignore them in the limit.

Of course, you can account for it by the final measurement, but we will just assume it to be. Therefore cooling curve will be governed by the following equation. This is nothing but the first order system, MC dT_s by dt the rate of change of temperature multiplied by the mass of the specific heat this should be equal to the heat loss from the system or if you want you can say this is equal to minus MC dT_s by dt equal to epsilon of the surface then the surface area of the surface then sigma T_s power 4 which is the function of time minus $T_{infinity}$, this is constant so we will say this is constant and these are measurable.

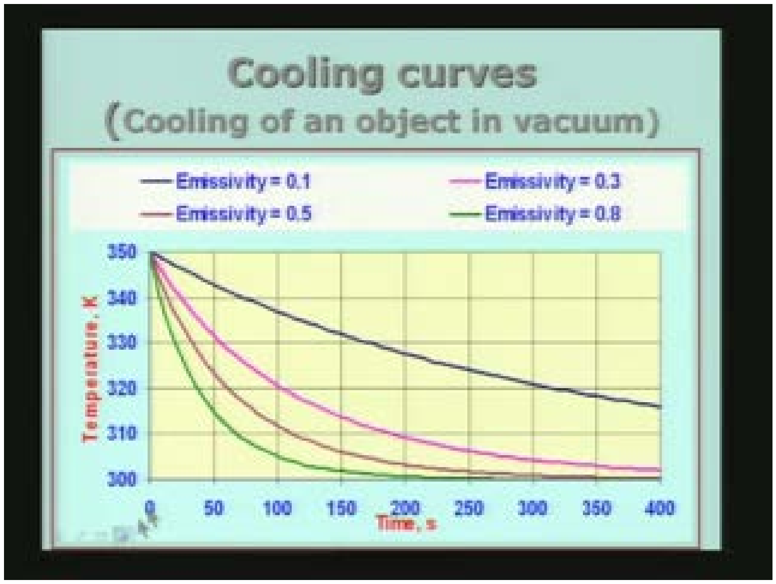
(Refer Slide Time: 30:48)



I can measure the mass of the system, specific heat If I know the material and characteristic and I can perform another experiment to measure the specific heat, the surface area is measurable, sigma is the Stefan Boltzzman constant this is 5.67 into 10 to the power minus 8, $T_{infinity}$ is held fixed then T_s can be measured as a function of time. Therefore essentially what you get is that with T_s at T equal to 0 this is also T_s here is equal to T_0 greater than $T_{infinity}$. When you integrate this equation you will get the cooling curve. So the cooling curve will have a characteristic which is depended on the magnitude of epsilon. If epsilon is small the cooling rate will be very small so it will take a long time for it to cool down, and if epsilon is large. it will cool down more rapidly.

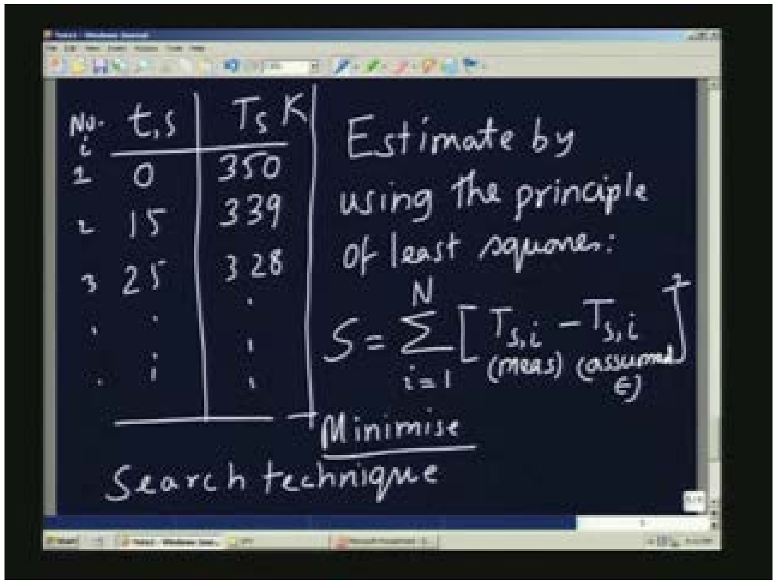
Therefore, the rate at which the cooling takes place or the temperature variation with time has the information about the emissivity in that particular curve. The curve is specific or has a specific dependence on the emissivity of the surface. Let us look at a typical cooling curve. I just solved that equation for a typical system with a small mass and specific heat and so on. If I plot the cooling curves for different values of emissivity, I have taken 0.1, 0.3, 0.5 and 0.8 these are the four values, all the other parameters the mass, the specific heat and the surface area I have held fixed and therefore only emissivity is going to change the cooling curve.

(Refer Slide Time: 30:53)



Here you can see the cooling curve for very low emissivity, epsilon equal to 0.1, epsilon equal to 0.3, and then we have epsilon equal to 0.5, epsilon equal to point 8 so you see that the cooling is more and more rapid as the emissivity is becoming larger and larger. In other words, I can note down or measure the temperature as a function of time. Let us see what is going to happen when you do that. If I measure the temperature as function of time, so I can prepare a table like this. It is the time versus the temperature T_s and I can say this is 0, and this is 350 Kelvin and let us say 15 seconds, and this is 339, then 25 seconds and 328, and things like that, you make a table like this.

(Refer Slide Time: 35:19)

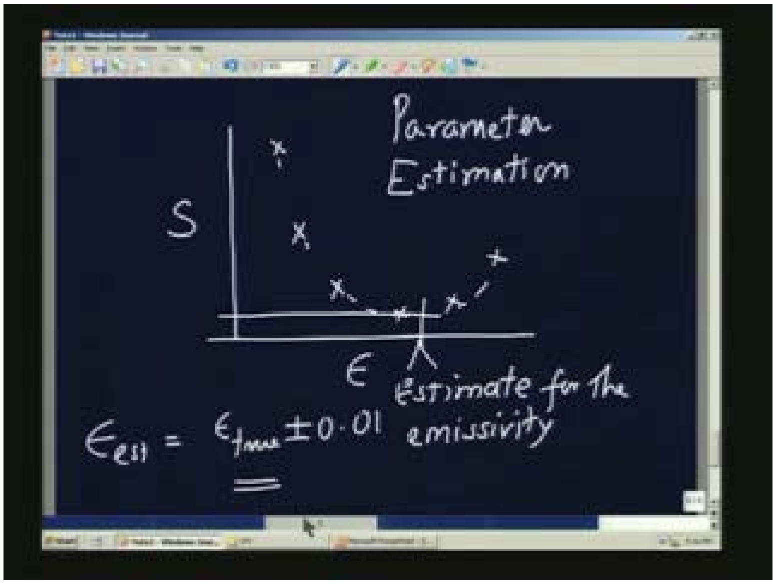


So how do we get the emissivity from such a curve?

Now what I can do is, I can solve the equation for different values of epsilon and I have to find out that particular value of epsilon which gives you the best match with the data you have got. For this what we will do is, to estimate emissivity by using the principle of least squares, so this is number 1, 2, 3 etc, this is the identifier so we will say this is the number, I will call it i. So what I will do is I will take the sum of the squares of the following from i equal to 1 to N [$T_{s,i}$ measured minus $T_{s,i}$ assumed epsilon] whole square so I have the measured values here I will assume a certain epsilon and find out these values for the same T values ($T_{s,i}$) corresponds to T at measured at these time values and ($T_{s,i}$) assumed with assumed epsilon I am going to calculate so I require that the sum of these squares must be smaller so minimize s.

What is done in practice is to use some kind of a search technique, because the solution is not straight forward, it is nonlinear so we can use a search technique. What does this search technique do? It starts with some assumed value of epsilon and then calculates this sum of squares and finds out the value and then again with a small change in epsilon, it recalculates the whole thing, finds out, whether it is going up or down, that is, you locate the way S is changing. So what we do is we go in the direction of reducing S and then we keep on changing epsilon by smaller and smaller amount, and, when graphically presented you will get some thing like this. S is calculated with the values of epsilon, so I might get a value like this, like this like this and, after some time it will again start going up. Therefore, what I will do is, I will go to the bottom of this curve so it is supposedly a curve like this, and I will go to the bottom of this curve, and find out the estimate. So we will call this as the best estimate for the emissivity. Basically, the method I have given in brief is called parameter estimation. It is a parameter estimation problem.

(Refer Slide Time: 39:40)

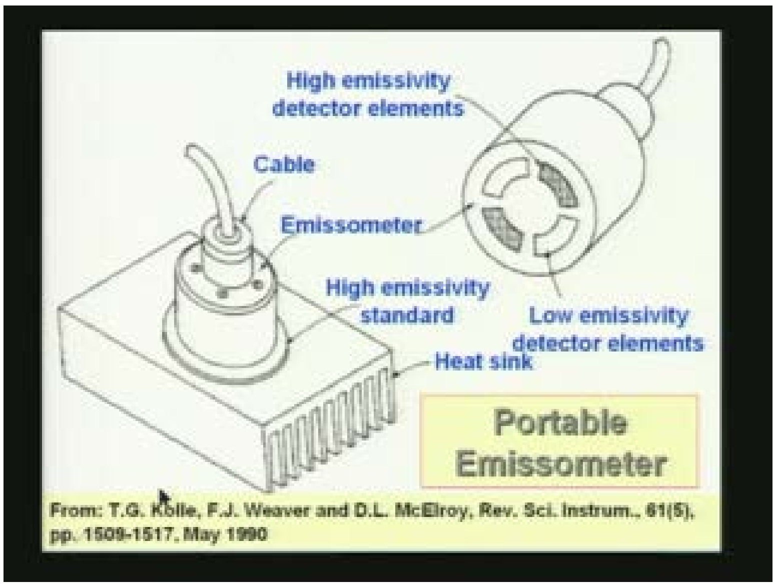


It is also referred to sometimes as the inverse problem because, we are solving the direct problem with different values of epsilon, and finding out that value of epsilon which is the best from the view point of minimizing the sum of the squares of the errors. Because, in the previous slide if you see what you have done this is nothing but, the error with respect to error between the measured and the assumed value, this is obtained with an assumed value epsilon so the difference between these two value can be looked upon as an error because if the value of the epsilon is the correct value I should get the smallest error because then these two should be closest to each other.

We are using the least squares principle because there is no other better way of doing it, because epsilon is truly unknown and the only way we can do that is to use a method like this which is parameter estimation. This is just like fitting a curve because, we are trying to fit a curve such that the value of S comes to a particular position the minimum possible. Of course, if you change the epsilon further it will go up. And in many of the applications of this method for determination of emissivity, we can get plus or minus 0.01 accuracy. That means I can say epsilon estimated is equal to epsilon true plus or minus something like .01 that is possible.

If you do the experiment carefully and if you use the parameter estimation method by taking the data and then doing the least squares analysis one would be able to get a value like that. This is one way of doing the emissivity measurement and here you see that you are using a transient method, you are allowing some object to cool and we are using a evacuated vessel, and the sample is very small compared to the size of the vessel therefore the reflected radiation, or the radiation reflected from the walls do not come on to the surface of the thing. Therefore, you need to have a small sample. Small sample also means that it will probably cool more uniformly throughout, and therefore it is also better from the point of view of the assumptions we have made in the analysis. This is one method.

(Refer Slide Time: 39:47)



The next method to look into is the use of a portable emissometer. This emissometer is made by a company called Devices and Service Company. Let us look at the principle of operation of the portable emissometer. I have taken this sketch from the paper by Kolle, Weaver and McElroy in review of scientific instruments which appeared in 1990. What it consists of essentially is,an emissometer, this is the emissometer placed on a heat sink, and the sample whose emissivity I want to measure so that the temperature of the sample remains close to the temperature of the ambient that is the requirement. For example, it could be a thin sample in the form of a plate whose dimensions could be 50 to 100 mm or even smaller than that, because we are going to use a very small area of the sample for the measurement itself.

(Refer Slide Time: 39:55)

And the emissometer head itself consists of, there is an arrangement by which we can heat this, and there are two high emissivity detector elements, these are high emissivity and these are two lower emissivity detector elements. They are basically thermopiles arranged in this particular fashion, and we can supply heat to the head so that the entire thing comes to a certain temperature. The temperature usually is about 350 Kelvin. Now let us look at how this portable emissometer works. Suppose, I keep the emissometer like it is shown here, I have a standard material here whose emissivity is known, and I have kept the head of the emissometer inverted down on that. Therefore, we have the low emissivity and high emissivity detector elements placed in close proximity of the surface whose emissivity I want to measure.

So what will happen if I have two objects close to each other?
If the heat transfer between the head which is heated and the surface of the sample which is not heated which is at the room temperature, the heat transfer between these two elements will depend on the difference in temperature to h power 4 t power 4 of the detector minus the T sample power 4 and t sample power 4 is a constant because it is going to be in the room temperature. In the case where the sample and the detectors are very close to each other, the heat transfer is only by radiation, and depending on the emissivity of this object, the amount of heat transfer will be different for the low emissivity detector elements and for the high emissivity detector elements. So what will happen is, there will be a small

temperature difference between these two because of the different rates at which heat transfer takes place between the elements and the surface.

So we are going to measure the temperature difference between the high emissivity detector elements and low emissivity detector elements and this is going to be related to the emissivity of the surface. How is it done? You place the head first on a high emissivity standard of emissivity equal to .89 this is supplied by the manufacturer and then adjust gain of the amplifier so that the reading of the millivoltmeter which is connected is going to be exactly .89. And then, you remove the high emissivity standard, and put a low emissivity standard, and there is an adjustment for that so that the value you get will be equal to .06 corresponding to the emissivity of the low emissivity standard.

Of course, this process could be repeated again and again, so that you finally get a condition where, when you change it from the high emissivity to low emissivity the readings do not change. Essentially the head requires about half an hour of heating time so that it is heated and before you start the measurement about half an hour time is required. Once it is done, then the measurements can be done almost in real time as 15 to 20 seconds is what is required for the measurement.

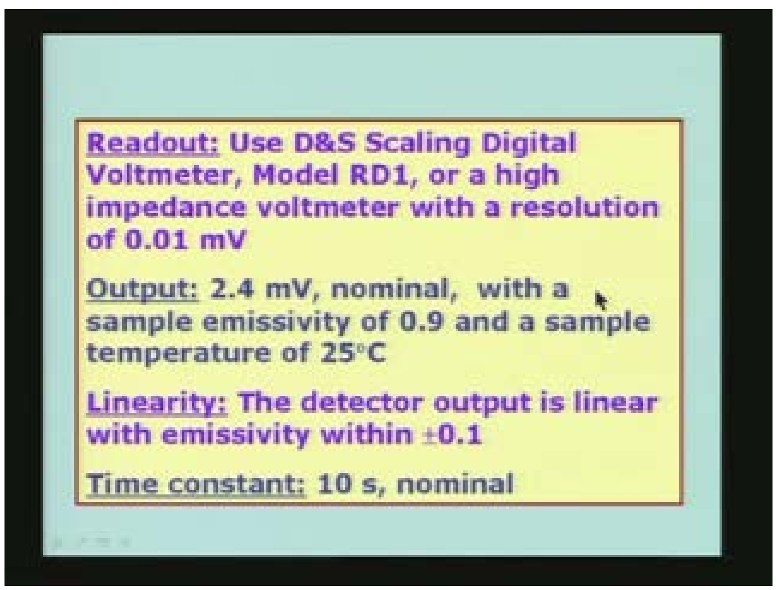
So why do we have a heat sink? The heat sink is to make sure that, the sample which I am going to use is going to be at the room temperature. Therefore the heat sink is going to remove any heat which is falling on it, because of the proximity of the heated head. Whatever heat transfer takes place the heat has to be removed quickly, so that the temperature remains more or less fixed at the room temperature value. So the instrument is supposed to be very dependable, the measurement is at room temperature, the emissivity we are measuring is at room temperature, and not at elevated temperatures. The emissivity is accurate to within plus or minus 0.01 and that is also the least count of the millivoltmeter which is going to be connected to the instrument.

Now let us look at the way the instrument looks. In this image, this is the head of the emissometer and the cable which is going to be connected to that and this is the heat sink on which it is placed and this is the millivolt meter which is directly connected to that and the reading here directly gives the reading of the emissivity of the surface. It is a very simple instrument and it is very small in size. The diameter is something like 50 mm, and it does not require too much of power, and the power consumed is very small. It requires very little of maintenance, and so on, and it is a very highly reliable instrument.

(Refer Slide Time: 46:00)

The specifications given by the manufacturer is as follows: It is a read out type instrument. That means you use the D and S scaling digital voltmeter. It is model RD1. A high impedance voltmeter with a resolution of .01 millivolts is required.

(Refer Slide Time: 46:50)



The output is 2.4 millivolts nominal with a sample emissivity of 0.9. That means if you use the high emissivity sample the output of the instrument is 2.4 millivolts and a sample temperature of 25 degree Celsius as we have taken in this particular case.

The linearity is very good, the detector output is linear with emissivity within plus or minus 0.01 and the time constant is ten seconds nominal. That means, that you should give a little more time than 10 seconds may be 30 or 40 seconds and by that time the value will stabilize, and you will be able to take a reading of the emissivity of the surface.

To recapitulate; what we have done is, we have looked at the various ways of measuring reflectivity and then we have discussed two methods for measuring the emissivity specifically. One is the cooling rate method, or cooling curve method, where we allow the surface to cool in vacuum, because in vacuum the heat transfer is purely by radiation, and by parameter estimation methods, we are able to find out what is the emissivity of the surface, and then we have also discussed a portable emissometer which directly measures the emissivity by a read out kind of arrangement.

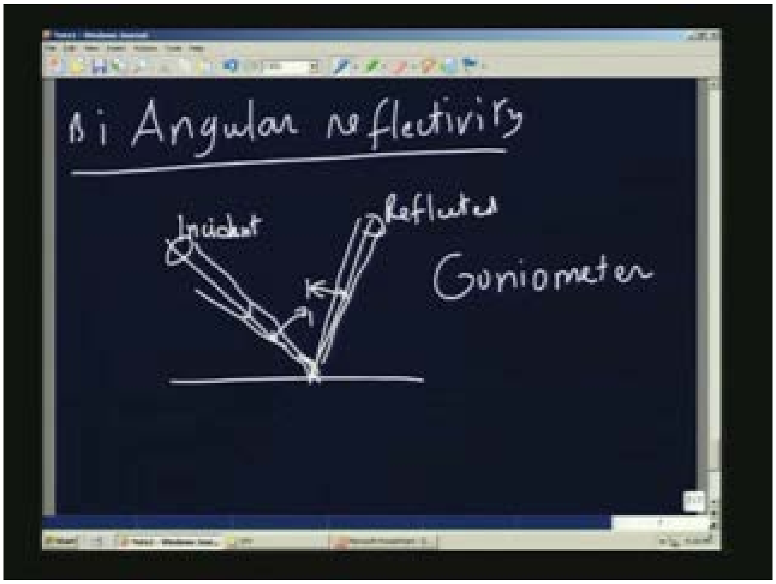
There are many other situations where emissivity may be required. For example, if you remember pyrometer we said that pyrometers are used for very high temperatures. So, if you want to know the emissivity of the surface at high temperature,there is no other alternative but to heat the surface to a high temperature so the actual surface whose emissivity I want at high temperature I must heat it to a temperature as high as required, and then we have to make the measurement of the emitted radiation coming from that compare it with the black body and get the emissivity value.

And in the case of pyrometer, we also know that we are going to use a specific wavelength of specific frequency of radiation. That means that, I have to make the measurement of the emissivity of the function of wavelength or it is the spectral quantity I am interested in. So some of the complications in radiation measurement are because we need high temperature sometimes, and sometimes we need the spectral measurements and therefore these require expensive equipments.

The method of measurement is not like what we have discussed but these are all simple techniques, but more complicated systems are required. One last thing about the measurement of surface properties is the angular measurement, angular reflectivity. It is also called as the bi angular reflectivity. If you remember, for any surface, if the radiation is coming in a particular direction here, it will reflect in all directions. Therefore, if you draw the normal here this is the incident, this is the reflected, so for each direction I have to measure the reflectivity. When I have incident light what I have is light coming in a small cone onto the surface and of course, I have to measure along the same cone which is reflected.

So, in the case of biangular reflectivity we require what is called a Goniometer which is an apparatus which allows us to illuminate the surface at any decided angle with respect to the normal, and at the same time look at reflected radiation at any angle to the normal. Of course, the way I shown the two angles on the same plane they need not be in the same plane. That is, I am talking about the plane of the figure as written here.

(Refer Slide Time: 51:41)

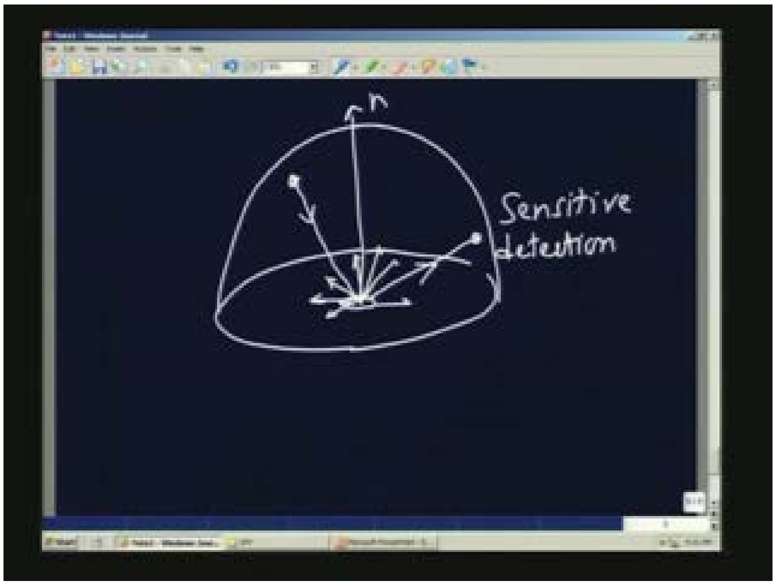


It can come in one direction, and go in any of the 2pi radians, the radians on the hemisphere. Here is the schematic of this: This is the hemisphere, the sample is here and this is the normal. It can come from this direction from the sphere and it can go out in this direction. They are not necessarily in the same plane. We are talking about biangular that means this is the incident radiation. Of course, this requires very expensive equipment. The Goniometer makes it possible to have incident radiation coming in this direction, and the reflected radiation at any direction can be measured.

And you will also see that, if the amount of radiation coming and falling here is some value the amount reflected in this direction may be very small. That means, because it is going to be going in all directions the amount going in this particular direction may be of a very small quantity, therefore a very sensitive detection is required.

What is the connection between this and the hemispherical directional or directional hemispherical?
If I were to integrate the radiation going in all the directions as we did in the integrating sphere case, that means, if I measure the reflectivity in all the directions and add all the reflected radiation in different directions together that will be the actual reflectivity of the surface which is given by this directional spherical reflectivity.

(Refer Slide Time: 54:19)



Directional hemispherical reflectivity will be given by the net radiation coming in any given direction, and the net radiation going in all the other directions. If I can integrate, or if I measure in all the possible directions, and then if I integrate that by numerical method I will be able to find out what is the directional hemispherical reflectivity of the surface, and this integration has to be done by making measurement along each direction and then summing them and then getting the integral value whereas if you have the integrating sphere it does this integration automatically, and that is a great advantage.

So, if you are interested only in the directional hemispherical or hemispherical directional we need not go for a Goniometer. But where do you require the Goniometer is for calibration because if you are using the integrating sphere to relate the measured values from that to the absolute values of reflectivity we require a calibration and that is provided by a Goniometer type of measurement which is done in a standard laboratory to characterize surfaces by actually measuring the directional properties and from that finding out the hemispherical directional or directional hemispherical property of the surface. Thank you.