Mechanical Measurements and Metrology
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Module - 2
Lecture - 17
Resistance thermometry (continued) and pyrometry

This will be lecture number 17 in Mechanical Measurements. The discussion will continue from the previous lecture. We will be talking about Platinum Resistance Thermometer; how to make measurements using this. We talked about three wire, four wire arrangement for compensating the lead wire resistance.

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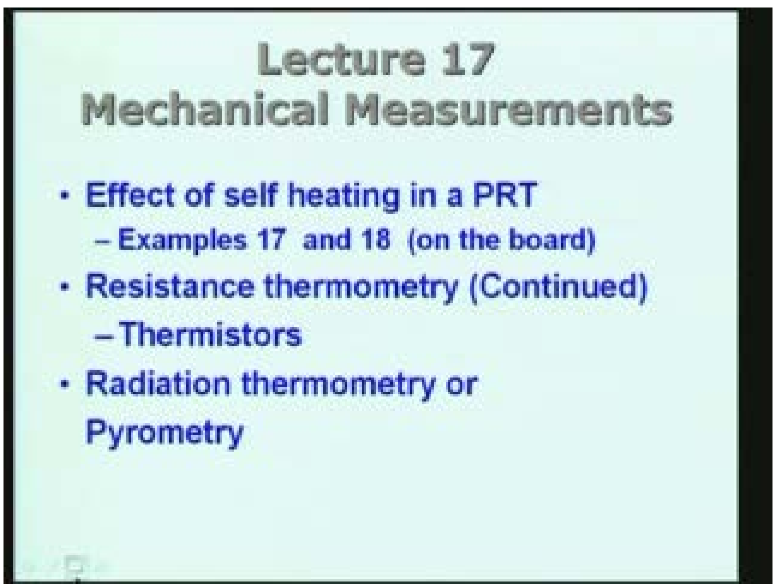

In the present lecture, what I would try to do is to take up to two examples, one of those examples is going to indicate how self-heating of a PRT, because we are passing a current through that, is going to affect the element; the other one is going to be an example which will give some idea about. What is the kind of instrumentation required for using a Platinum Resistance Thermometer? Subsequently I will look at, Thermistors which are also resistance thermometers, and we will discuss how to use them. And subsequently, you will start looking at radiation thermometry, or it is also called Pyrometry, and we have indicated earlier when we were talking about the temperature scale ITS 90, that above a certain temperature radiation thermometer becomes the method of measuring the temperature.

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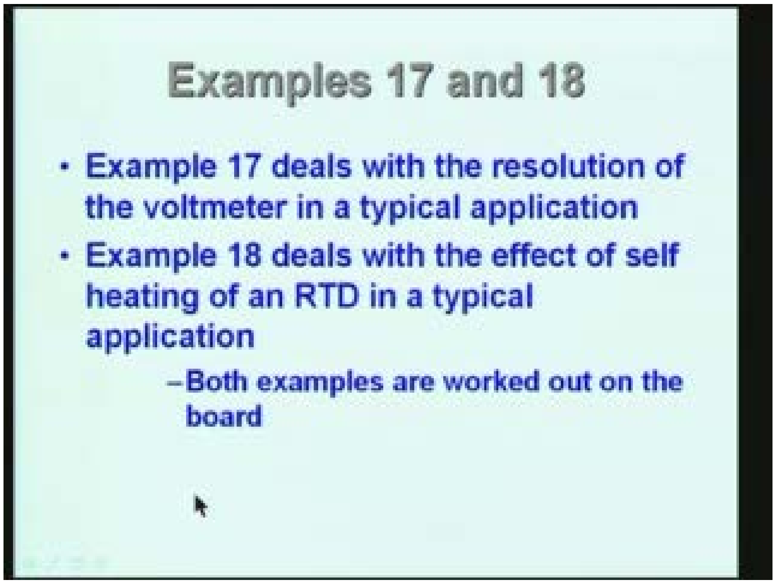

Thus, just to recapitulate, example 7 and 18, the first example, that is example 17 is going to deal with the resolution of the voltmeter required for a typical application, and the example 18 will deal with the effect of self heating of an RTD in a typical application. These both, both these examples I am going to work out on the board, and the idea is to indicate the kind of numerical which are involved in this kind of class of activity. Let me just go to the board and discuss the two examples.

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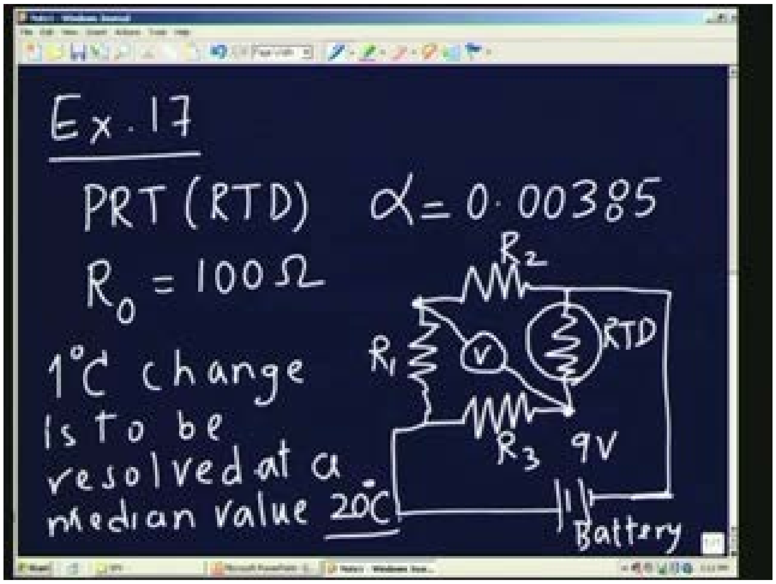

The example 17 considers an RTD and it is a PRT and we know that RTD is simply a Resistance Temperature Detector. PRT is a particular one, and it is Platinum Resistance Thermometer, it has an alpha value of point 00385 which is already familiar to us, and it has a resistance of 0 degrees centigrade equal to 100 Ohms. While it is connected in the following fashion, I will just make a diagram for the connection, that is, in the form of a bridge circuit. There are three. This is the RTD, you will call this R_1, R_2, R_3, and you have a voltmeter connected across these two terminals. And between the other two terminals there is a battery connected across.

This is a 9 volt battery, and you will notice that we can adjust such that, it will be in balance under some particular condition, and then when it goes out of balance there will be a potential difference across these two terminals here, and that will be because of the change in the resistance of the RTD with temperature. The other resistances remain fixed at the same value and, therefore, the change in the resistance of the RTD manifests as the change into voltage.

What we would like to do is to find out if I want to resolve 1 degree change is to be resolved. That is, if the RTD is exposed to some temperature, or is that some particular temperature if it changes by 1 degree, 1 degree Celsius, either up or down, I must be able to find out. I must be able to resolve the temperature. So what is the requirement of the voltmeter is what we want to do. And I want to check this 1 degree change is to be resolved at a median value of 20 degrees Celsius. So if it is a 20 degree Celsius, and if it changes to either 19 degrees or 21 degrees, what is going to be the state of affairs is what we want to look at.

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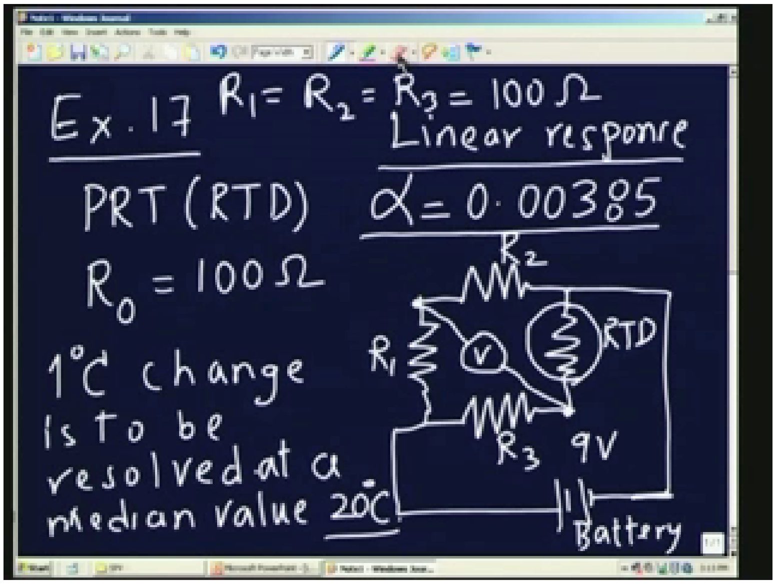

And of course we will assume that the Callendar correction is not important, so we are going to use a constant alpha model, which means that I am going to use a linear response model. That means, alpha is assumed to be constant. So we can look at it like this. If at some particular temperature it has been balanced, R_1, suppose I take R_1 equal to R_2, in this case, each one of them is 100 Ohms, R_1, R_2, R_3 equal to 100 Ohms, that means that the bridge will be balanced at 0 degrees Celsius. Now let us look at the state of affairs after we have changed the resistance, the temperature. So what I will do is I will remove some of the notations, here,so that I can use this figure because I will have to refer to that again and again. I remove this portion so that I can do that.

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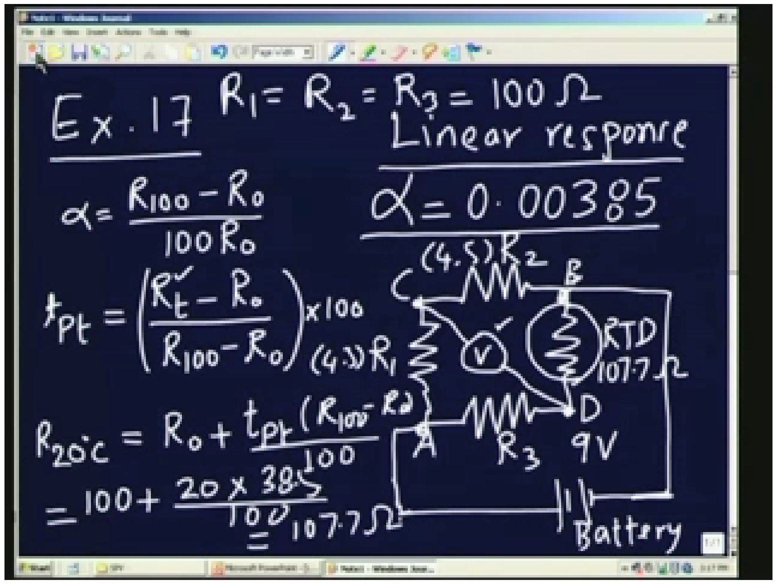

Therefore, by definition of alpha is nothing but R_{100} minus R_0 divided by 100 times R_0 which is given by point 00385, and we also know that the temperature, according to platinum temperature scale, is given by R_t minus R_0 divided by R_{100} minus R_0 multiplied by 100. You have already done this, therefore, I can find out the R_t at any temperature.

For example, I want to find out R at 20 degrees Celsius. I put t_{pt} equal to 20. This will be 20 multiplied by R_{100} minus R_0. There is a 100, so I will use the alpha value into R. R_{20} is equal to R plus t_{pt} multiplied by R_{100} minus R_0 divided by 100. So all I have to do is substitute the values and you will see that it is going to give you R_0 is 100, plus t_{pt} is 20 and R_{100} minus R_0 from here is nothing but 100 times alpha times R_0. This 100 will cancel off with this 100, therefore, that will give you into 38 point 5 divided by 100, and this gives a value of 107 point 7 ohms. So t is equal to 20 degrees, the value of the resistance here is 107 point 7 ohms.

Now let us just look at this circuit here. There is a 9 volt between these two points, let us say A and B here. Between A and B there is a drop of 9 volts, and there will be 4 point 5 Volt drop across this, and 4 point 5 volts across this because it is equally shared among the two resistances because there is, these are two resistances in the series, and half the resistance, half the value of the voltage drop occurs here. Half of it occurs here. Now, however, this resistance is different from this difference. Therefore, the 9 volts has to be divided in a slightly different way between this resistance and this resistance.So I can find out what is the voltage across, let us call this A,B ,C, D, I want voltage across C, D because that is what is going to be indicated by the voltmeter. So I need the voltage drop across from A to D here. This is nothing but R_3 divided by R_3 plus R_t, multiplied by the total potential difference. So we will do it in the next page.

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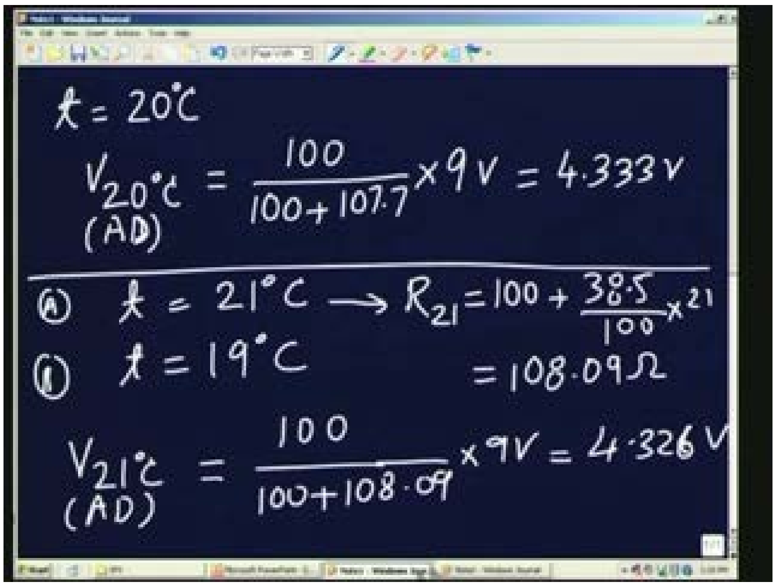

So when t is equal to 20 degrees voltage indicated by the voltage, which is, I will say that is AD, this is AD, across AD, is 100 divided by 100 plus 107.7 which is what we discussed, now determined, multiplied by this comes to 4.333. This is what happens at 20 degrees.

Now we will have to repeat it for two cases: case a will be t is equal to 21 degrees; case B will be equal to t is equal to 19 degrees because I want to see what happens when the temperature changes by 1 degree either to a higher value at A, or to a lower value. So I will use the same formula, and I will have to find out what is the appropriate resistance at 21 degrees and 19 degrees.

For example, the corresponding resistance at R_{21} is given by 100 plus 38.5 divided by 100 into 21 using the linear model. This comes to, and correspondingly V at 21 degrees centigrade across AD will be 100 divided by 100, plus I have to use this resistance 108 point 09 into 9 volts. This comes to 4.326 volt at a temperature of 21 degrees to get 4.326 volts. So let us look at the previous figure.

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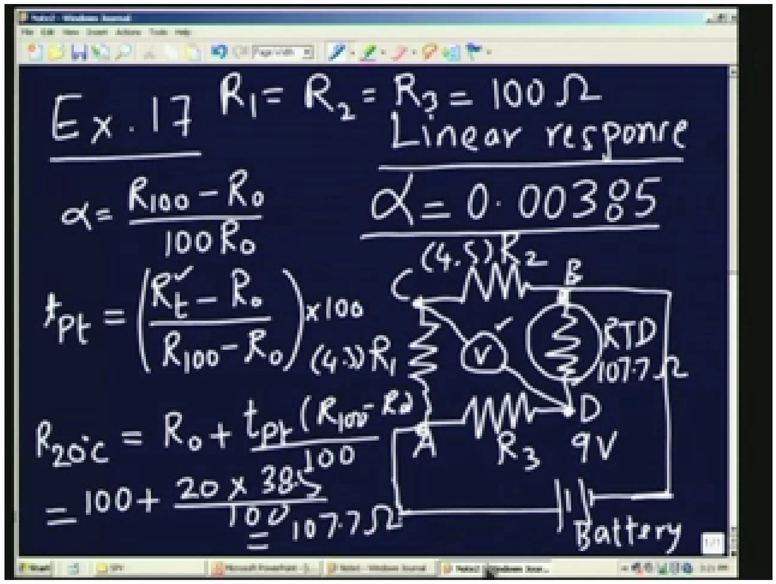

I have determined AD, the voltage across AD under two cases. First case, when the RTD was 100 that was, it was, at 20 degrees I have determined. And I have also determined when it becomes 21 degrees, what is the voltage. Therefore, the change in the voltage, what I want to measure is the voltage across C D. The first case it would be 4.5 across this minus 4.33. That will give you the voltage V. And in the second case, when it becomes 21 degrees, this would be the second voltage which I calculated 4.5 minus the voltage which I calculated the second time which was 4.326.

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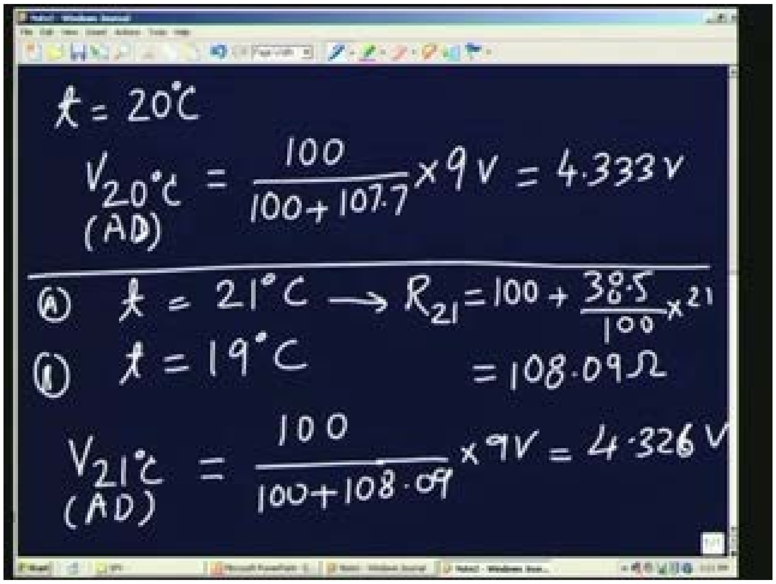

Therefore, the change in the voltage is what we want to measure. That is the resolution required to resolve 1 degree Celsius, and therefore, that will be nothing but the difference between these two quantities, one, 4.333, and 4.326, and you can see that it is the difference we have.

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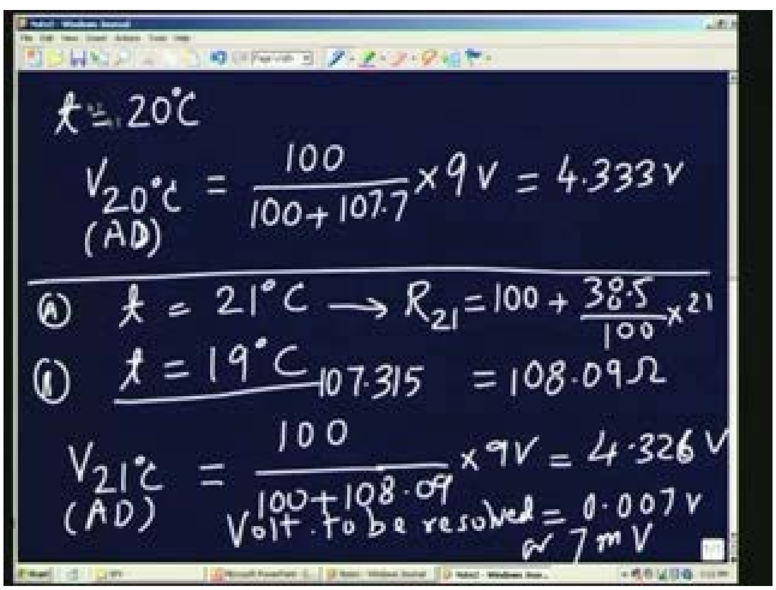

So the voltage to be resolved is the difference between this 4.333326 so that will give you 0.007 volts, or 7 millivolts. Actually, I can also calculate what happens when t is equal to 19 degrees, a repetition of similar calculation, and you can show that the value, the change required is about 8 millivolts. So we will see that. The student can do that one, and find out what is the change in the resistance. In this case will be 107.315, and the voltage resolution required will be about 8 millivolts.

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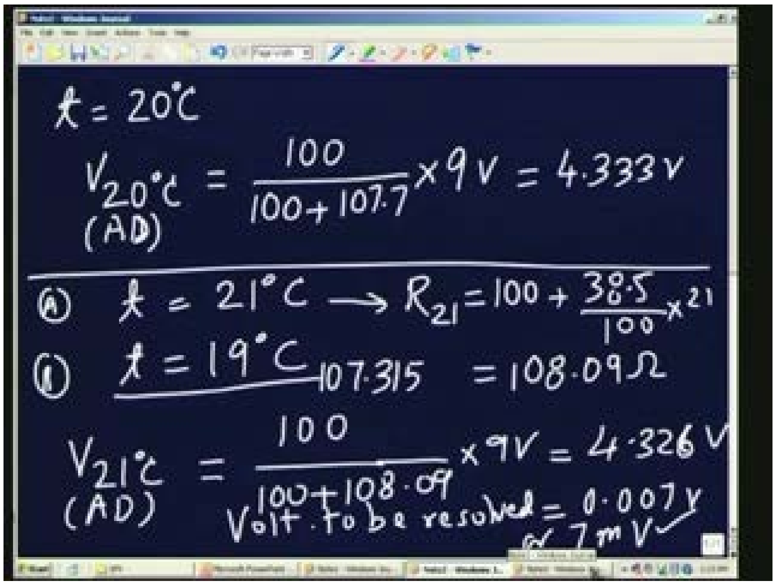

So in the case b, the temperature is 19 degrees, and the resistance at 19 works out to be 107.315 ohm, and the value of voltage across C D works out to be 4.341mV. And if you go back and check the resolution required, 4.333 and 341, so that 4.333 minus 4.341 is about 8 millivolts.

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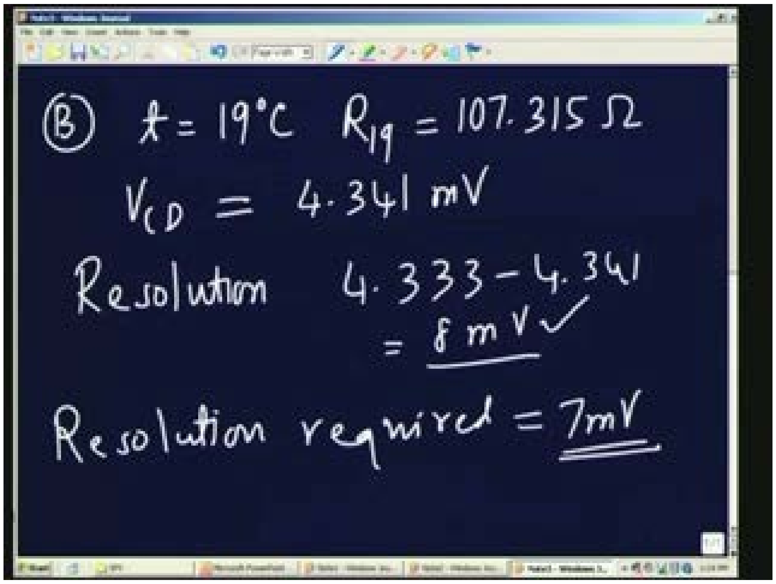

You see that in the previous case we had a 7 millivolt resolution, and in the case of temperature decreasing we require 8 millivolt resolution, and therefore, we can say that the resolution required is the smaller of the two, which will be 7 millivolts. That means that the voltmeter which we are going to have there must be able to resolve 7 millivolts. That means that 7 millivolt, we can choose a slightly better one, maybe 5 millivolts we can take as the requirement, and at least 5 millivolts must be resolved by the voltmeter, for the voltmeter requirement is easily indicated from this for a 1 degree Celsius resolution. If you want to go for a resolution of a lower temperature difference, the resolution also will become more strict and more stringent. Therefore, you see that measuring a temperature difference of 1 millivolt itself is quite a challenging task because you require a very good voltmeter.

The next example I am going to take up is the case of self heating. Let me just briefly explain what this self heating is about so that we understand what we are talking about.

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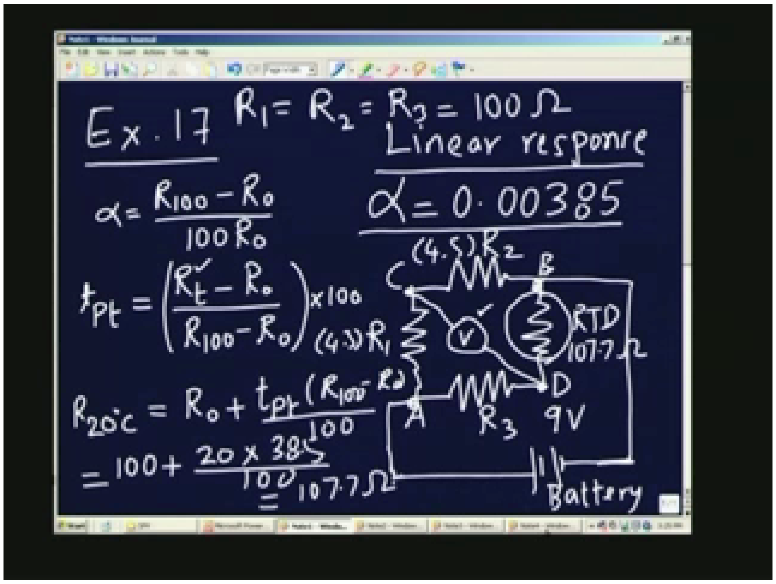

For this purpose, let me go back to the sketch which I did here is, I will redraw that sketch here.

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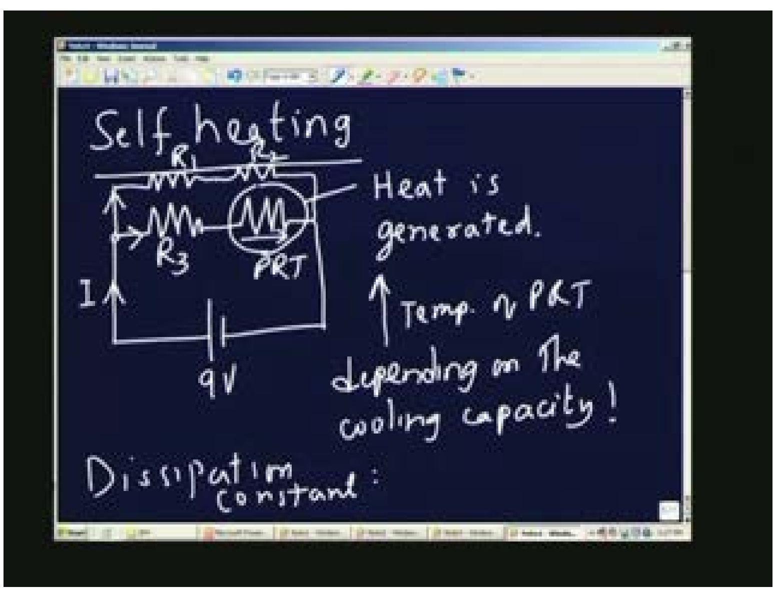

So you essentially see that there are two resistances in series across the battery. This is the PRT, RTD and this is the resistance R_3. Of course, there is one more limb in which there are other two resistances R_1 and R_2, and this was 9 volts, or whatever x y some voltage. So a certain current is flowing through that. Of course, this current is now shared between the other limb and this limb, R_1,R_2. So some current goes through this and some current is going through that, and because this current is flowing through this, heat is generated. Because heat is generated, the temperature of the PRT will increase, will increase the temperature of PRT depending on the cooling capacity of the PRT. This is called self heating. So the cooling capacity is usually referred, represented in the form of a dissipation constant, is called dissipation constant which indicates the amount of power it can lose for a degree Celsius increase in temperature. Dissipation constant is nothing but the power that the PRT can dissipate per unit temperature rise. That means it will be power per unit temperature rise so many milliwatts per degree Celsius.

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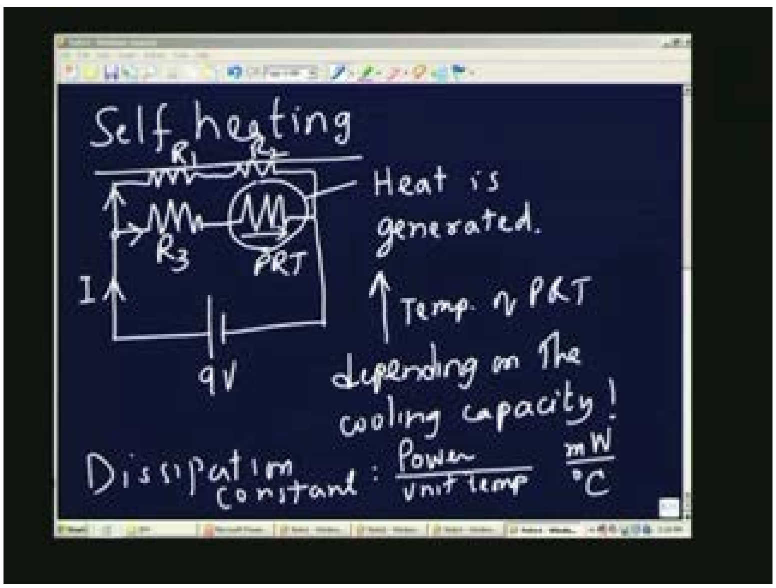

Let us look at a typical example. I am going to consider example 18.

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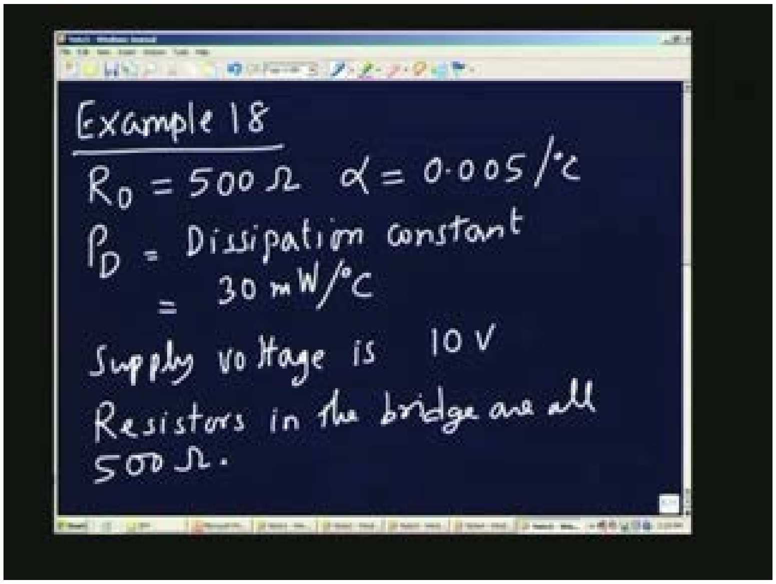

We have a PRT of 500 ohms resistance, and alpha value of 0.005 per degree Celsius, and dissipation constant is specified in this problem equal to 30 milliwatts per degree Celsius. We are also given that the supply voltage is 10 volts, and all the resistors in the bridge are 500 ohms, and suppose that the PRT is exposed to 0 degree centigrade environment, so the point to notice that is that.

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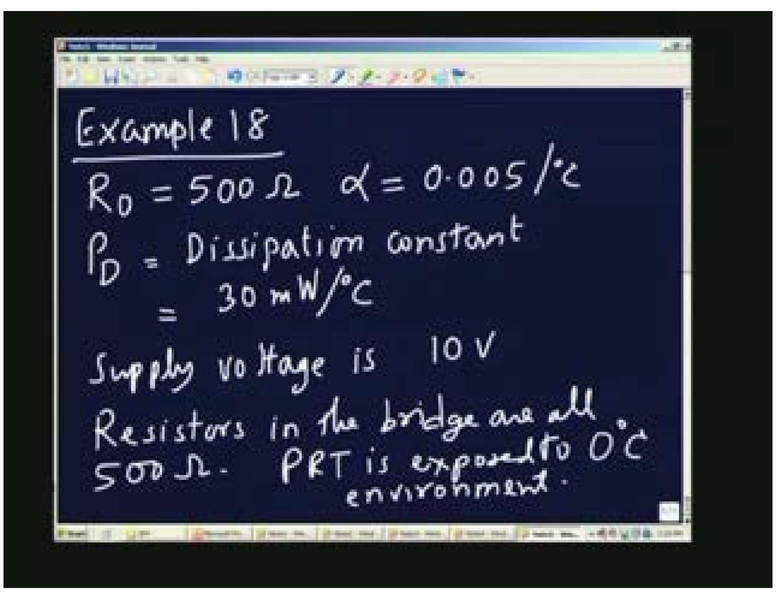

Even though the PRT is exposed to a temperature of 0 degree Celsius the ice point, the PRT is not at the ice point because certain amount of heat is dissipated, or heat is generated, and because this heat is to be dissipated it requires a certain temperature change, and therefore, the resistance of the PRT will not be exactly equal to 500 ohms because it is now running a little hotter so it will be at a higher temperature. You would like to find out the status of the thing, and what will be the value of……, in the previous case I want to find out, if I make a variable resistor there, what is the value of R_3 for which there will be a null.

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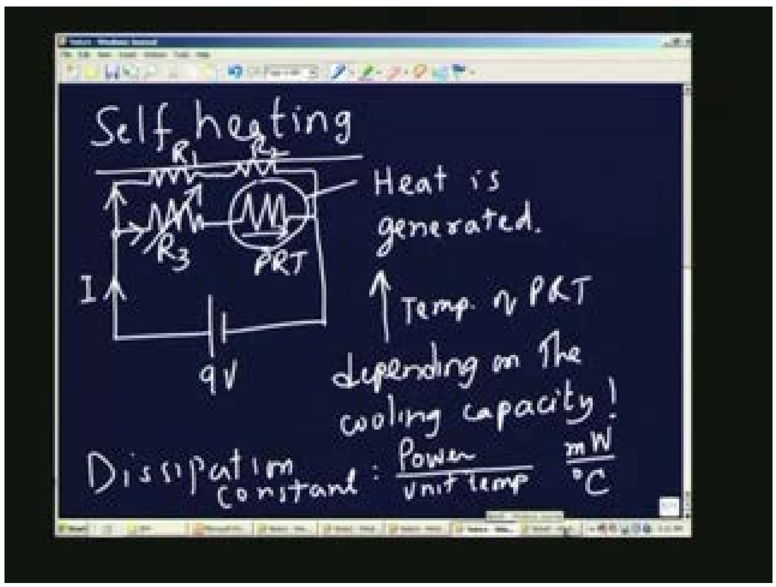

That means that I want to see what is the value of R_3 which will make the bridge come to balance. So that is the problem, and as I have explained, if R_1, R_2, R_3 are all equal to 500 ohms, then of course PRT will have a slightly different resistance because of self heating, then it will of course be not in balance. To bring it to balance what I have to do is to change the R_3 slightly, and I want to find out what is that value of R_3 which is going to make it come, to make the bridge circuit come to balance, and let's look at how we are going to work it out, so we know how to do that because all I have to do is to take into account the following.

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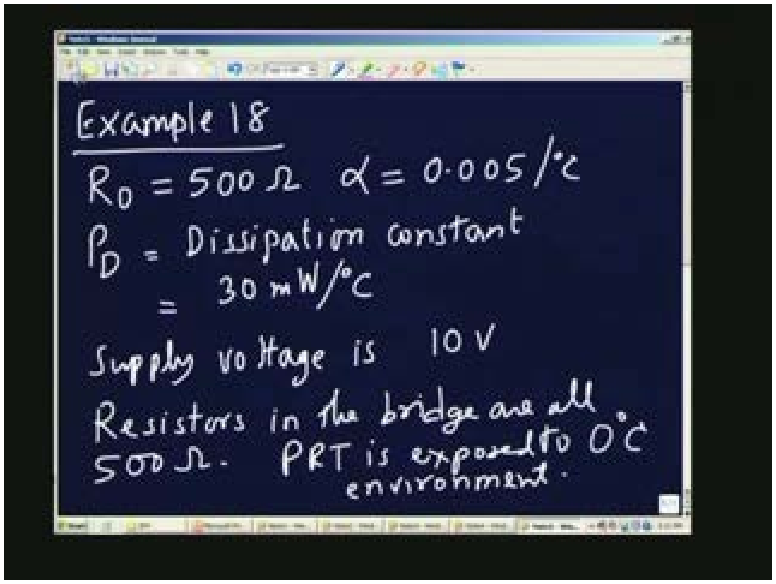

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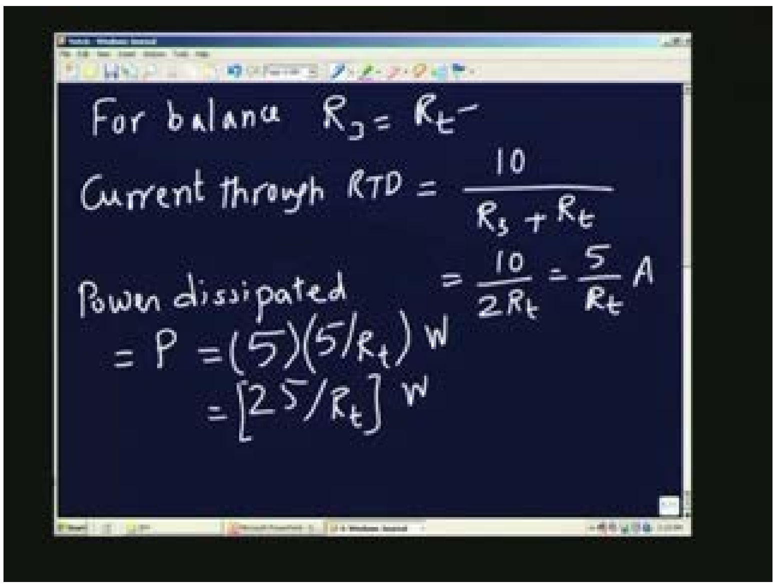

For balance,obviously, R_3 is equal to R_t because R_1 is equal to R_2 equal to 500 ohms. Therefore, the ratios of the two resistances in one arm must be exactly equal to the ratio in the other arm. Therefore,R_3 must be equal to R_t. So now, I can find out the current through the RTD current. Through RTD is nothing but 10 ohms divided by the sum of the two resistances, R_3 plus R_t, because R_3 is equal to R_t. From here, this is nothing but two times R_t, therefore, this will be 10 by 2 R_t which is equal to 5 by R_t is the current, so many amperes. So I can find out what is the dissipation power dissipated. We call it equal to P.

The current is known, the voltage across when the current, when the R_3 equal to R_t, the potential difference of 10 volts is equally shared between the two resistances, and therefore, 5 volts is the potential drop across the PRT. Therefore, P equal to (V I) which is 5 volts into 5 divided by R_t, so many watts, to 25 by R_t, and notice that I have used the symbol R_t here because the temperature should have been R_0 0 degrees Celsius, but because of self heating it is not 0 degrees, but slightly more. Therefore, it is R_t, this temperature is still not known, that is what we would like to first determine as a part of the problem.

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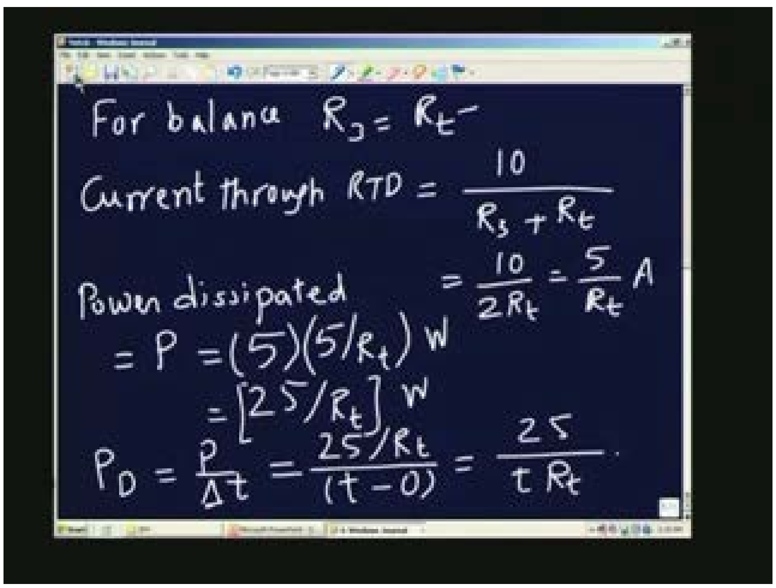

R_t can be determined if you know the temperature of the resistance, and R_t is equal to R_0 into 1 plus $alpha_0$, which is given, multiplied by, before we do that let me just go back, so the power dissipated node…….. so if you remember, P_d equal to power dissipated, divided by delta t, the change in the temperature, and in this case power dissipated is 25 divided by R_t, and delta t is what I want to find out. Delta t is nothing but t minus 0 because the ambient is 0. Therefore, I can write it as 25 by t times R_t, and P_d is already given, and therefore, I can write, I get the value of R_t from here, so let us go to the next page.

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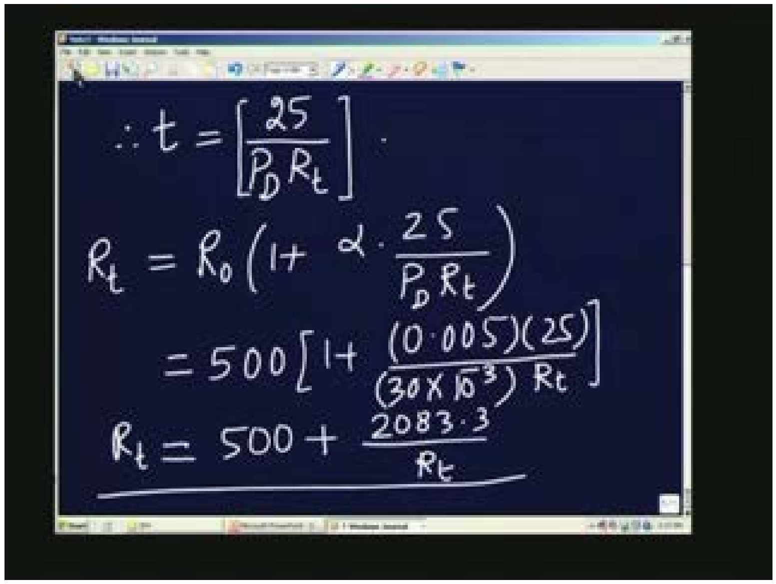

Therefore, t is actually equal to 25 divided by P_D into R_t. Suppose we make sure that all the appropriate quantities are given in the proper units so that I get the proper value for that.

Now I also know that R_t is nothing but R_0 into 1 plus alpha into t, t is nothing but 25 divided by P_D into R_t. So I can substitute the values here and what I want to know is from this equation and find out the value of R_t. It will come out to be a quadratic equation, and let me just put the values here. This will be 500. R_0 is given as 500 plus 1 plus 0.005 into 25 divided by 30 into 10 to the power of minus 3 because it is given in milliwatts multiplied by R_t which is not yet known, R_t equal to 500 into 1 plus 0.005 into 25 divided by 30 into 10 to the power of minus 3 into R_t. This comes out to 500 plus 2083.3 divided by R_t. So this is the equation.

Now I can multiply by R_t throughout, I will get R_t squared equal to 500 R_t plus 2083.3. Solve this quadratic to get the value of R_t. So solve the quadratic to get the R_t, actually it works out to 504.13 ohms. So the answer to the problem is R_3 is equal to R_t, equal to 504.13 ohms. This is the answer required.

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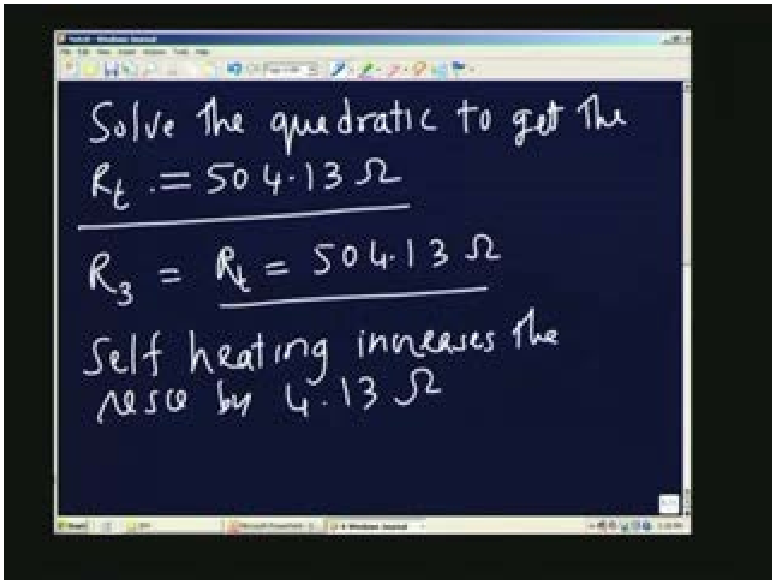

That means the self heating of the RTD increases the resistance by 4.13 ohms, and correspondingly of course it will be at a certain slightly elevated temperature which can be determined by simply going back and calculating. So in essence, what happens is that because of self heating, because the resistance is different, I will be actually inferring 504.13 ohms as 0 degree Celsius. That means that there is a systematic error because of self heating in this particular case. So with this we will go back to our discussion on the other types of resistance thermometers which we talked about earlier, that is Thermistors.

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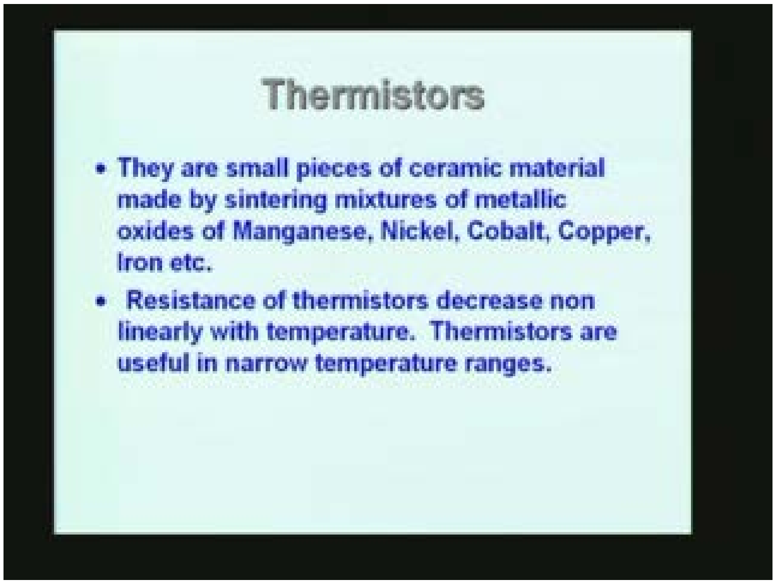

These are all small pieces of ceramic material which are made by sintering metallic oxides of manganese, nickel, cobalt, copper, iron, etc and they are made in the form of very small elements. I will look at it in the next slide. The important thing is that the resistance of thermistors decrease nonlinearly with respect to temperature, and because of this, and also the temperature variation is very large over a small temperature range, and therefore, Thermistors are useful only in narrow temperature ranges. Let us look at the behavior of thermistors.

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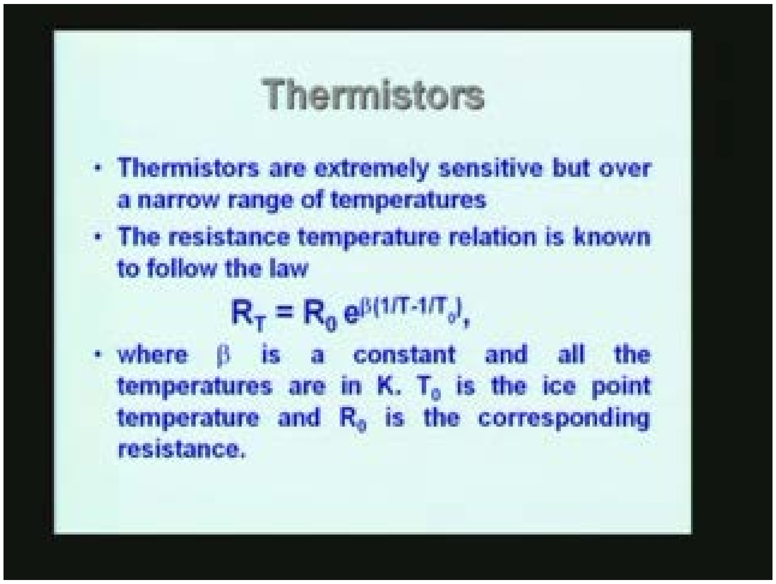

These are extremely sensitive, as we just now indicated, but over a narrow range of temperature. The resistance temperature relation follows the relationship given here, R_t is the temperature, the resistance at any temperature, T. I have deliberately used capital T here, because in these equations the temperature must be used in absolute temperature scale, not degrees Celsius, but absolute degrees must be used. Therefore, I deliberately use r cap, r subscript capital T, equal to R_0 which is usually the resistance of the Thermistor at 0 degrees Celsius, or the point multiplied by e to the power of exponential of beta. Beta is called the Thermistor constant multiplied by 1 over t minus over 1 over T_0.

Actually the value of beta is the unit of absolute degrees, or Kelvin, in this particular case. So beta is a constant, all the temperatures are in Kelvin, T_0 is the ice point temperature, and R_0 is the corresponding resistance. So let us take a look at the different types of Thermistors which are usually made.

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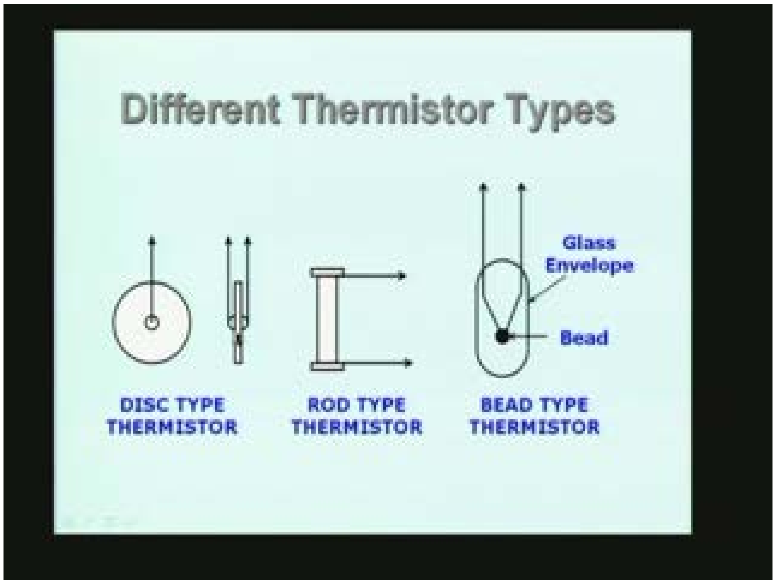

We have a disc type Thermistor, is in the form of a disc, and the contact is on the two sides like it is shown here. It is just a resistance element, and this rod type Thermistor just looks like a resistance which is normally used in electronics circuitry. So the rod is in this form of a rod, and the two terminals are taken like this, or it could be a bead type Thermistor that the bead is in the form of a small spherical bead and the two wires are connected like this, and the bead to make it withstand the rough wear and tear in its surrounding, it is encapsulated in a glass envelope, and the entire thing may be only a few millimeters in size. And here also the rod type Thermistor may be only a few millimeters in length may be a couple of millimeters in diameter and that means that they are very small elements, and usually it is possible to place them or to fix them on the printed circuit board themselves, if you have printed circuit board with other components, the Thermistor can also be mounted on it very easily, and therefore, that is how it is usually done.

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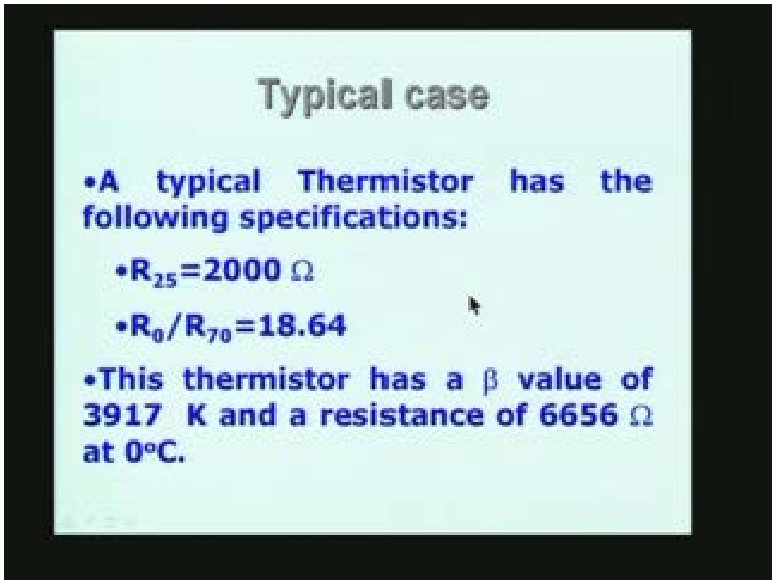

If you take a look at a typical Thermistor, it may have the following specifications, thus, a 2 kiloohm at 25 degrees Celsius normally. If you go through a catalog of Thermistors, this is how it is mentioned; the temperature, the resistance is mentioned at 25 degrees Celsius, it is 2000 ohms, and the resistance ratio, and I have already indicated the resistance decreases with temperature, therefore, R_0 is the resistance at 0 degrees Celsius, R_{70} is at 70 degrees Celsius. This ratio, if you look at this ratio, it is 18.64 for this particular Thermistor, and this value will correspond to, if you work out the using the relationship and work out the value for beta, it comes to 3917 Kelvin, and the resistance at 0 degrees Celsius comes to 6656 ohms. Now just compare this with what happens in the case of the PRT.

In the case of PRT, between 0 degrees and 100 degrees, the variation was roughly a part of 1.5 whereas here the factor is 18.64 between 0 degrees and 70 degrees which means that the variation of resistance is very rapid, and in fact, you can see in the next sketch how rapidly it is going to reduce.

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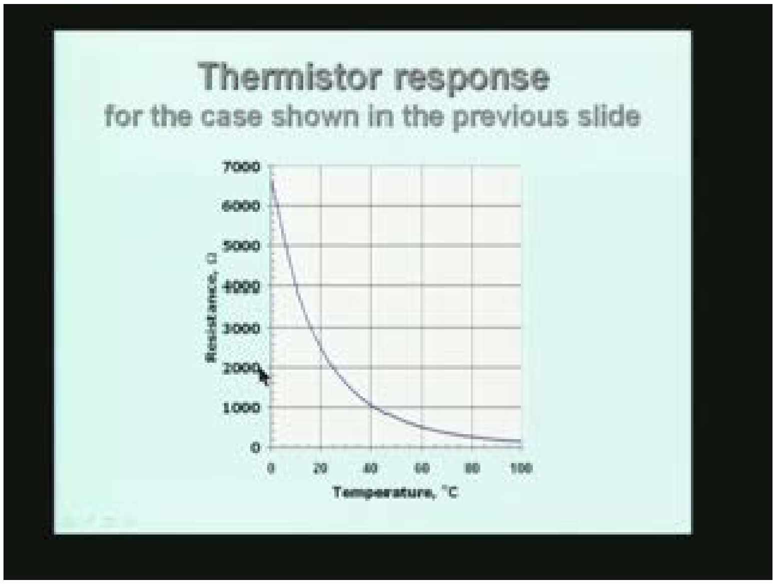

So the value 6600, or some value close to that, and at 70 degrees you see it is already very low, and it has become 1 kilo ohm, around 40 degrees, and at 25 degrees exactly equal to 2000 at 2 kilo ohm as I indicated earlier. What do we notice from this? What we notice is that the temperature variation, for a small temperature variation there is a very large variation in the resistance. That means that if you calculate dR by dT, the slope of this curve that indicates the sensitivity of this particular detector. The sensitivity is very very large. That means that there is a large resistance change for a small temperature change, whereas in the case of PRT it was given by alpha. $Alpha_0$ was equal to 0.00385 for every small value, whereas here it will be a large value. So how do we use a Thermistor circuit?

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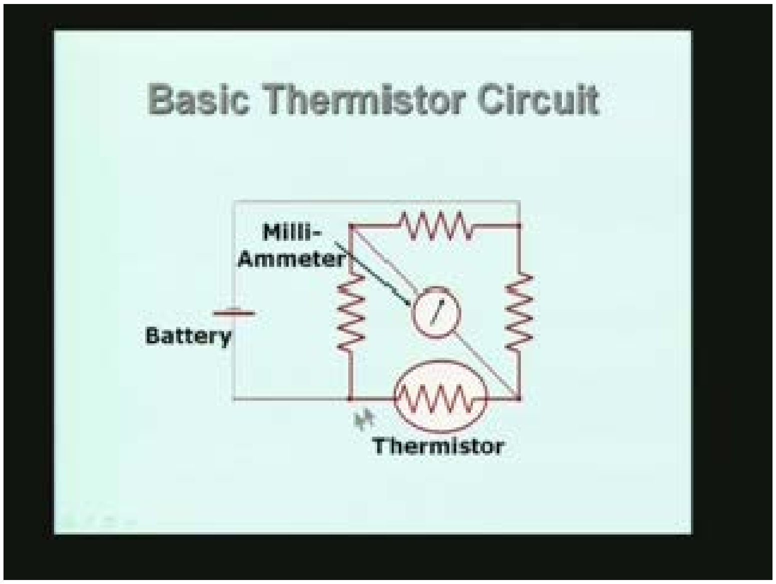

The basic Thermistor circuit I have indicated here is no different from what we had earlier in the case of a PRT. So you have a battery and you have a bridge circuit. The PRT is in one, the Thermistor is one of the limbs, and these three are fixed resistances, and what we can do is suppose we are going to use it at a particular temperature, and the vicinity of the temperature you want to measure the temperature variation.

I can have the balance at that particular temperature, and any out of balance will be indicated by the milliammeter. The current indicated by milliammeter directly can be calibrated in terms of the temperature, and therefore, I can simply directly take the value of the temperature and just as we had in the case of PRT, self heating is also going to be important here, and therefore, in fact, we may add resistance in series with the battery to limit the current to a low value. That is one way of reducing the current through the Thermistor. So this is a very basic Thermistor circuit.

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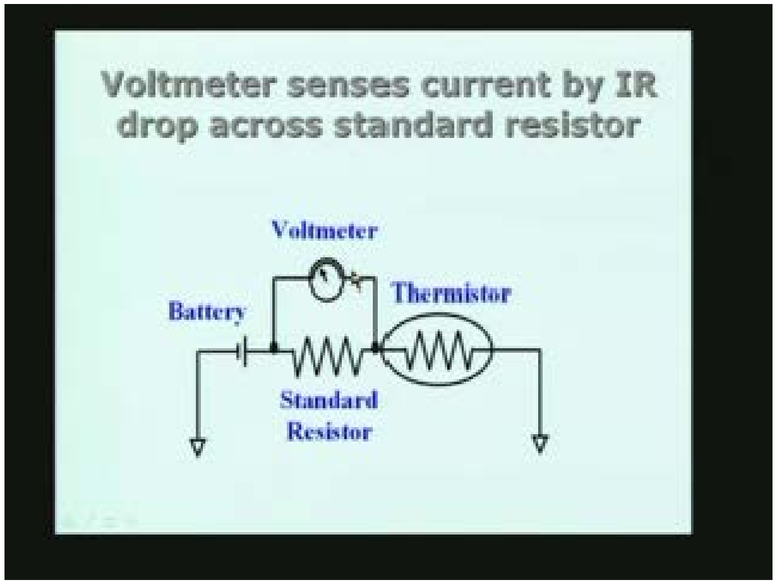

And another circuit I am showing which is a slightly different way of using it. So I have a battery, for example, this may be used for measuring the temperature of the radiator water in a car and the car battery. This is the car battery from which I take the potential, and then I have a standard resistance which is in series with the Thermistor, and when the Thermistor is of course exposed to water in the radiator and the standard resistance the current passes through both the standard resistance as well as the PRT or the Thermistor, and if the Thermistor resistance changes because of the temperature, actually you see what is going to happen as the temperature of water increases the Thermistor resistance is going to decrease, the current is going to increase, and because when the current increases the voltage across the standard resistor which is a fixed value is going to increase, and this is what you see on the dashboard of the car you see the needle going up from the green, then it goes up to the red. The temperature goes up really very high. You see that this needle is going to show, indicate the temperature variation.

Of course, it will be a nonlinear scale, because the resistance of the Thermistor is nonlinear, varying therefore, the current through the, this circuit will be nonlinear function of the temperature of the Thermistor, and therefore, the scale here is nonlinear. Therefore, you need not be perturbed about that. It does not matter for our purpose whether linear or nonlinear.

We can directly calibrate this in the terms of the temperature. Usually in the case of an automobile the temperature is not indicated. Usually it gives green and red. Green is safe and red is not safe. And if it goes to the red region you stop the car and allow the radiator to cool. So it is a very useful instrument, Thermistor, is used because Thermistor is very sensitive to temperature changes. So with this, we have completed our discussion on the resistance thermometers, and therefore, we will now look at the measurement of high temperatures.

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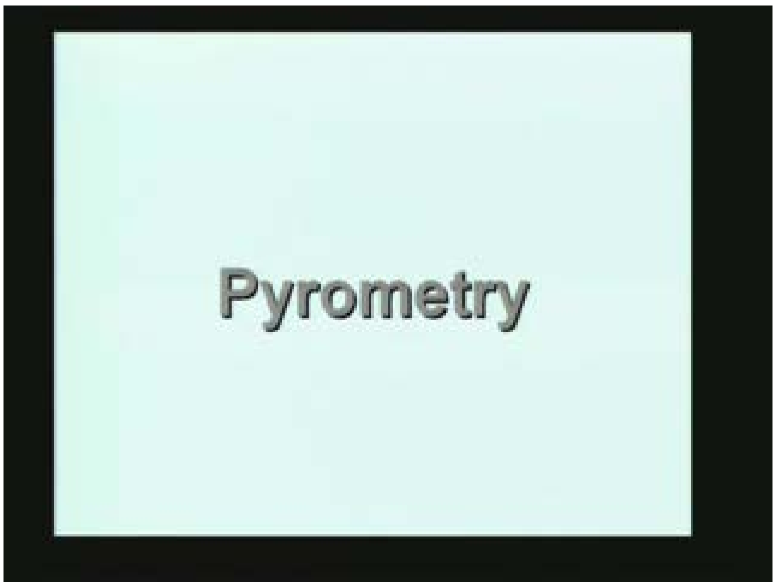

All the methods we have indicated earlier are normally for usual temperatures met with in practice and for low temperatures. When high temperatures are involved, higher than this, let us say, suppose you take the gold point or the silver point, as we indicate in the international temperature scale, for those temperatures we recommend the use of Pyrometry. Pyrometry, actually the term comes from Pyro known as fire. It comes from the measurement of temperature of fire, and fires are usually of flame. The temperatures are very high. We are talking about measurement of temperature higher than the normal.

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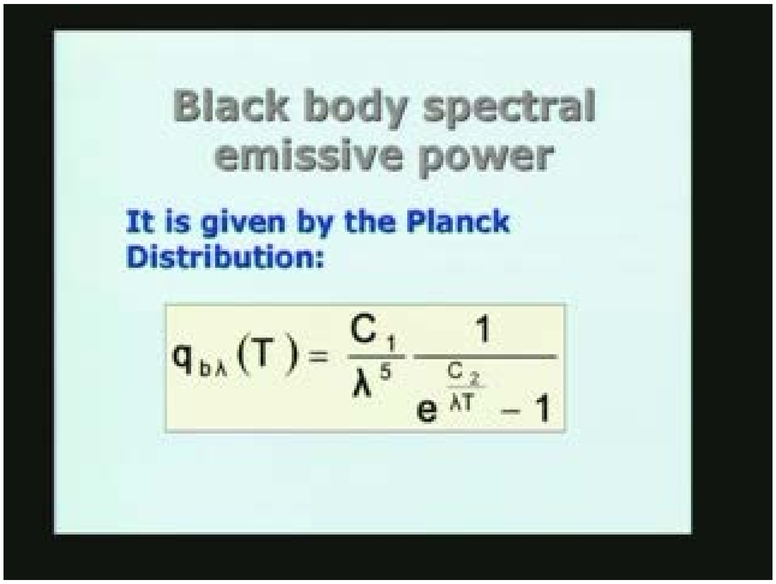

And what is the basis for the thermometry at high temperatures? We use the black body spectral emissive power as the basis for thermometry. It is well known that any substance, or anybody, any surface which is maintained at a temperature higher than the absolute zero of temperature will start losing heat by radiation. This is because of thermal motion of the molecules inside the, within the surface. And because of this, heat is radiated and it is dissipated continuously to the background even in the absence of a fluid or a substance in contact with the surface. There will be heat loss which is given by the black body emissive power which is the function purely of temperature, and the wavelength at which the heat is radiated, it is given by the Planck distribution function which is the fundamental relationship which can be derived from fundamental considerations, and it is given by $q_{b\lambda}$ (T), which is the black body spectral emissive power, which is given by watts per square meter, micro meter.

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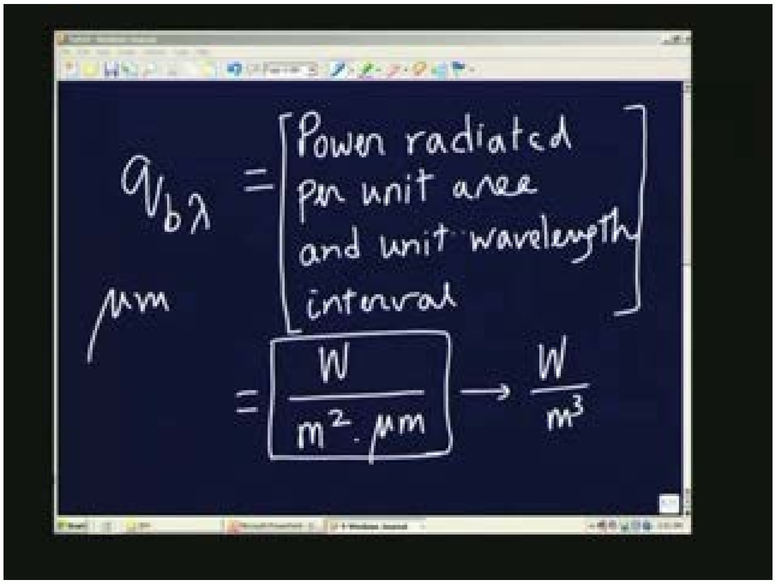

Micro meter is lambda, so, per unit wavelength. Let me just describe that slightly in more detail on the board so we understand what we are talking about. It is $q_{b\lambda}$,is nothing but the power radiated per unit area and unit wavelength interval. And the power radiated will be in watts, unit area, means meter squared, unit wavelength. Wavelength, we usually measure in micrometers, and therefore, this will become micrometer. And if you were to represent it in the SI units I would have had watts per cubic meter, but this is what we will use because the wavelength is measured in micrometers. And let me just digress a little bit and indicate the different regions of the wavelength which we are going to meet with the wavelength.

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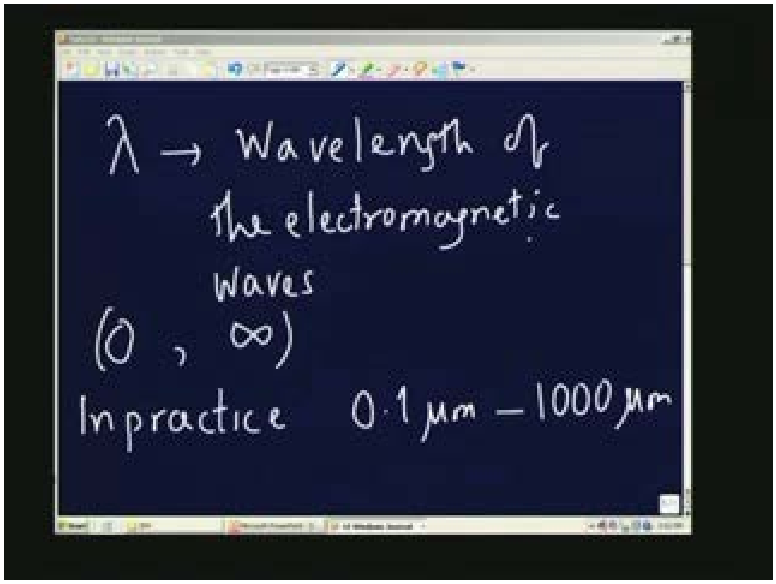

Actually, lambda is the wavelength of what, of the electromagnetic radiation. The power radiated is in the form of electromagnetic waves, the wavelength of the electromagnetic waves, and in principle, it can be from 0 to infinity. This is the interval, but in practice, for the kind of temperatures we are interested in, it will be somewhere between, that is point 1 micrometer to about 1000 micrometers.

We can in fact divide this range further into ultra violet, less than about point 3, then we have the visible point 3 to point 4 to point 7 micrometer. Then we have the infrared, IR, actually greater than point 7 micrometer, but we also sometime divide into near IR, middle IR, and the far IR. IR stands for Infra Red, so these are sub-regions. So the entire thing is from about point 1 to 1000 micrometers. This is the electromagnetic spectrum which will be of some importance in the case of Pyrometry.

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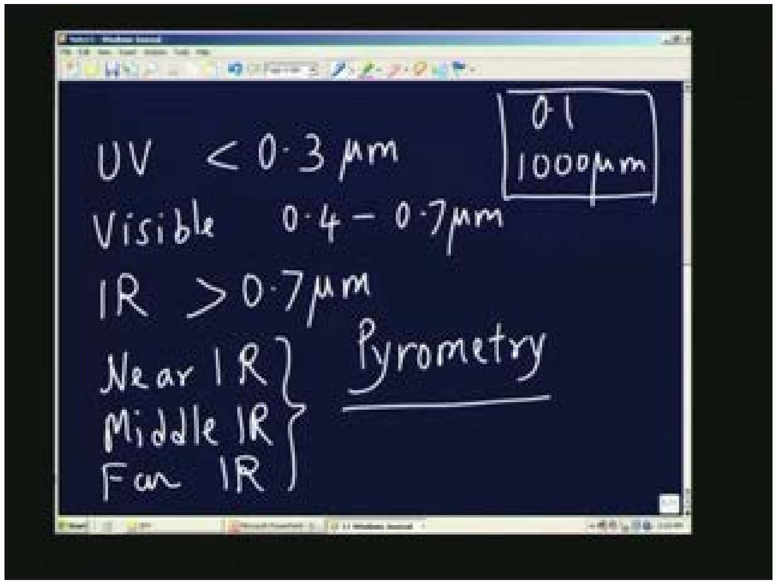

What is this Pyrometry?
If you remember the definition we gave earlier when we were talking about temperature measurement in a general way, we said that any systematic change in some quantity, any systematic change in some quantity with respect to temperature becomes a thermometer. So here we have radiation given out by a surface or by a black body which is a definite function of temperature. Therefore, what will happen is if the temperature changes, the amount of radiation which is leaving the surface is going to change in a systematic fashion with respect to temperature.

Therefore, I am invoking this as the thermometric property. The thermometric variable, or thermometric property, is the black body radiation, and the systematic variation of the black body radiation with respect to the temperature is the one which gives me a handle on the situation. It can be used for measuring the temperature. So let us see what is going to happen if I change the temperature of a black body.

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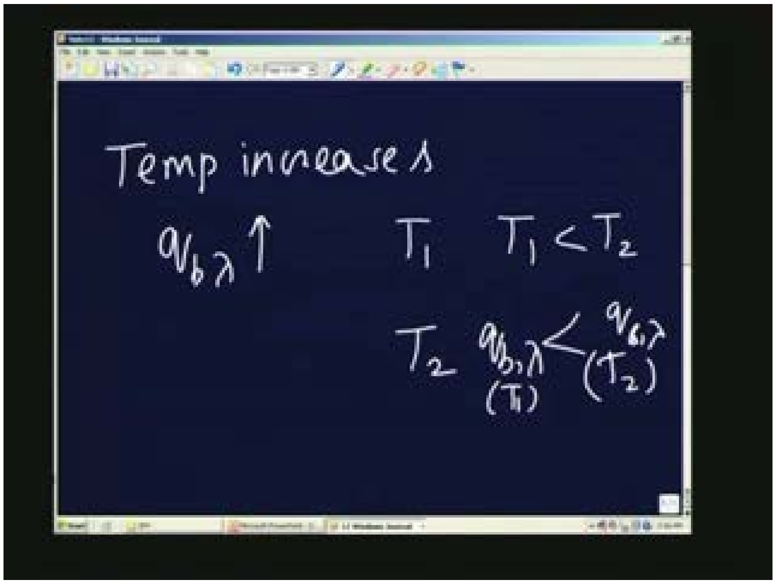

Therefore, if you increase the temperature, increases, this can all be explained using the Planck function. I will go back to that in a moment. If temperature increases, $q_{b\lambda}$ (T), increases. That means that if you have two temperatures, T_1 and T_2, if T_1 is less than T_2, then, $q_{b\lambda}$ (T), is less than T_1, is less than $q_{b\lambda}$ (T), at T_2 for any lambda. For all lambda this should hold. So, if the temperature is higher, immediately that will radiate more at any wavelength. Any wavelength you fix, if you fix the wavelength it's a monotonic increase with respect to temperature. It's very important to remember.

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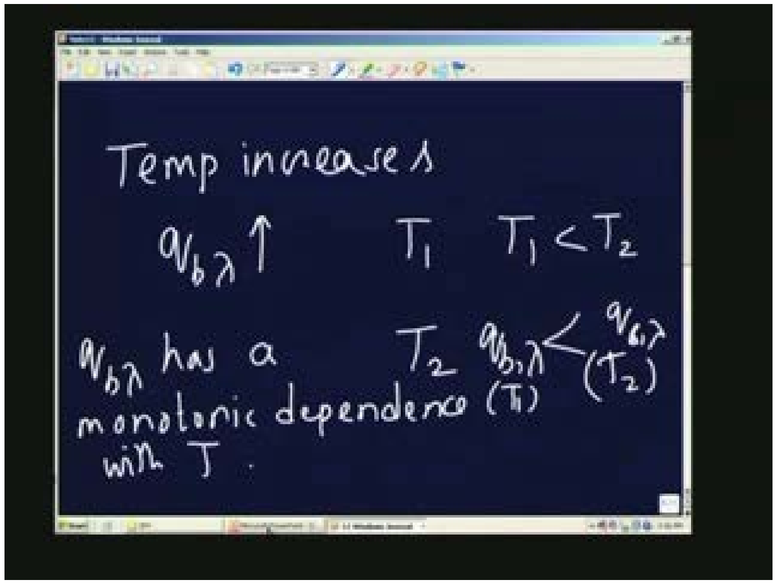

So $q_{b\lambda}$ (T), has a monotonic dependence. Monotonic means one-sided, or one way dependence. Monotonic dependence with T. It increases if the temperature increases. $q_{b\lambda}$ (T), also will increase. So with this, let us look at the Plancks function again.

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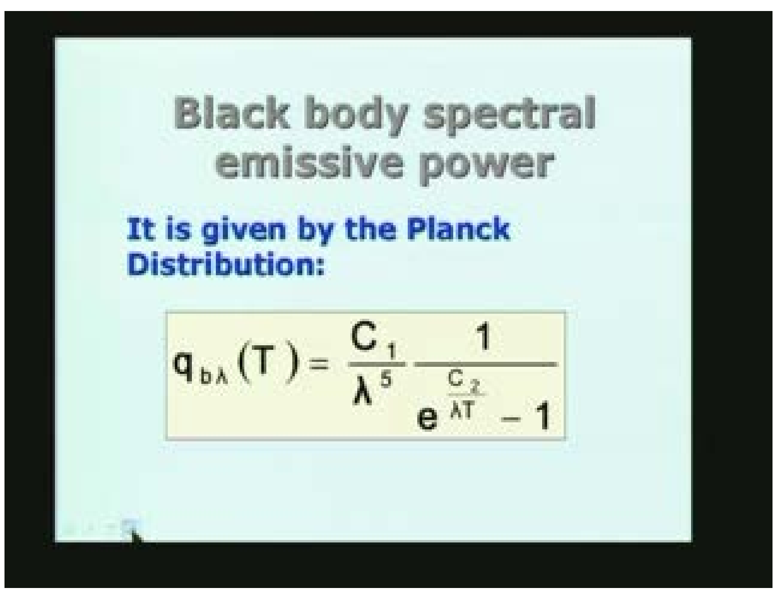

You see that the Plancks function tells me that $q_{b\lambda}$ (T), at any temperature T is given by C_1 by lambda to the power of 5. C_1 is called the first radiation constant multiplied by, there is another factor here, 1 over e to the power of C_2 by lambdaT here. C_2 is the second radiation constant minus 1. This particular relationship is the basis for pyrometry which we are going to talk about.

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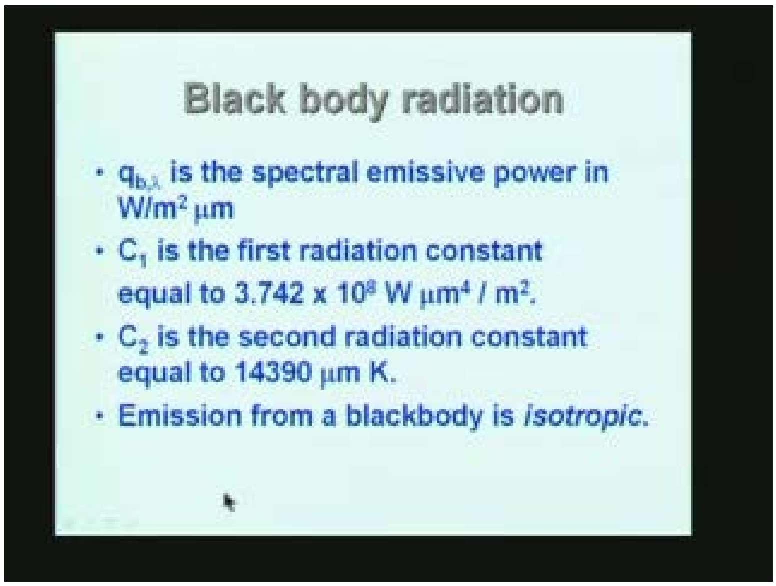

So here, $q_{b\lambda}$ (T), is in the units I have already talked about earlier, watts per square meter micrometer, C_1 is the first radiation constant whose value is given by 3.742 into 10 to the power of 8 watts micrometer, to the power of 4 divided by square meter. C_2 is called the second radiation constant which is equal to 14,390 micrometers Kelvin, and one of the important things about emission from a black body is that it is isotropic. That means that radiation leaving a black surface has no directional preference. At all directions it will propagate with the same intensity.

Of course, I am not defining all the terms. That will take too much time, and for the purpose of understanding pyrometry we need not go into great details of radiative, the knowledge of radiation is not necessary. Whatever is required only I am trying to give because the time available for us in this course is limited to may be one or two hours. Already, next lecture also it will be more or less commutation of what we are going to do.

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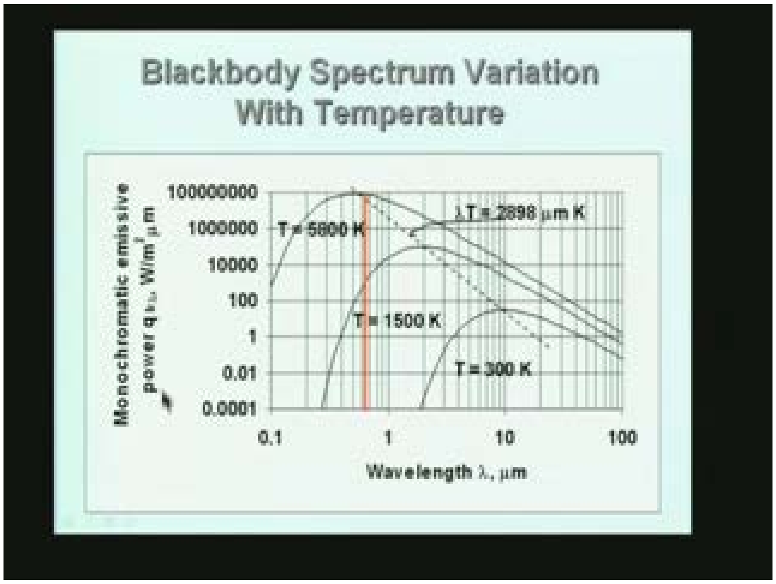

Let us look at the black body spectrum. What I have done is I have taken the black body function, $q_{b\lambda}$ (T), as a function of lambda, and plotted for three different temperatures. These temperatures are normally met with practice T equal to 300 Kelvin, corresponds to the room temperature, or the radiation leaving the surface of earth is more or less at this particular temperature. So this is called terrestrial radiation. Then we have T equal to 5800 Kelvin, which corresponds to the solar temperature, the temperature of the sun. And I have taken one value T equal to 1500 K.

Somewhere in between, this can be a molten material, or the temperature inside a furnace, so I have taken three temperatures, and you notice that this curve is within this curve, and it is within this curve. That means that the monotonic property which I talked about is important, is satisfied. This curve will always be below this curve, whatever. Whether you go this way or this way it is going to happen like this, and you will also will notice one more thing that the scale here and the scale here is logarithmic, and you see that the variation is from 0.0001 here to 100000000. The variation is about a factor of 10 to the power of, I think, 12 in this particular scale.

It's a very large scale I have combined in a very small graph, and I have deliberately put a red line here which corresponds to between 0.6 and 0.7 micrometers here. This red line corresponds to a particular lambda, and you will see, notice, the following. This red line cuts the curves, of course, it doesn’t cut the 300 Kelvin line at all because it is much lower, somewhere below this axis. So the value of the $q_{b\lambda}$ (T),is about 404 here, at 1500 Kelvin. But when it goes to 5800 Kelvin, it becomes, you see it becomes 10 to the power of 8. It becomes almost 10 to the power of 8. So the variation from here to here is very severe. And suppose you look at an object at 1500 Kelvin.

With our eye we are able to see because 1500 Kelvin, the object will be visible, and you see that point 6 micrometer I have chosen is in the visible part of the spectrum between 0.4 and 0.7 the visible part of the spectrum. So I can actually see the object from the light coming out, or the radiation coming out from the surface, and you will notice that at this temperature, 1500 Kelvin, I will get the amount of light coming out will be such that I will feel that it has got some brightness.

And If I compare it with a surface at a higher temperature that surface at a higher temperature will certainly appear brighter. That means how do I distinguish what happens at a lower temperature and high temperature? It is by looking at the brightness of the object at that particular wavelength. The brightness is related to the magnitude of the curve here, the value on the y axis. The larger the value the larger the brightness, the smaller the value smaller the brightness. So immediately, see that thermometry will determine, will be based on how bright is the object. Suppose I am going to measure the temperature of a, an object. The temperature is not known. If I compare it with an object which is a, let us say, black body. At a certain temperature I can find out when the two are going to be equally bright, and that will be the basis for Pyrometry.

In the next lecture I will describe more fully this concept of brightness and the associated terminology called the brightness temperature, and we will see how this brightness temperature can be compared. And based on that how we can measure the temperature of an object. That is what going to be done in the next lecture. We will also introduce another concept which is going to be related to the, what is called the color temperature, or the ratio temperature which is determined by, instead of drawing a single line here, I will draw another line next to it somewhere here, for example.

I will choose two different wavelengths, and I will define the color temperature based on the ratio of the $q_{b\lambda1}$(T), to $q_{b\lambda2}$(T). At a given temperature of the object there will a certain ratio. By comparing this ratio with that for a black body, I can also define what is called the color temperature. Color temperature, or ratio temperature, it is also called two-color temperature because two colors are used. So Pyrometry can be either by measuring the brightness temperature or by measuring the color temperature as the case may be. So what we will do is to look at all these aspects in the next slide. Thank you.