**Mechanical Measurements and Metrology**
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**Module - 2**
**Lecture - 12**
**Thermoelectric Thermometry (Continued)**

This will be lecture number 12, Mechanical Measurements. What we will be doing in this lecture is to continue our discussion on thermoelectric thermometry, or the use of thermocouples, for the measurement of temperature.

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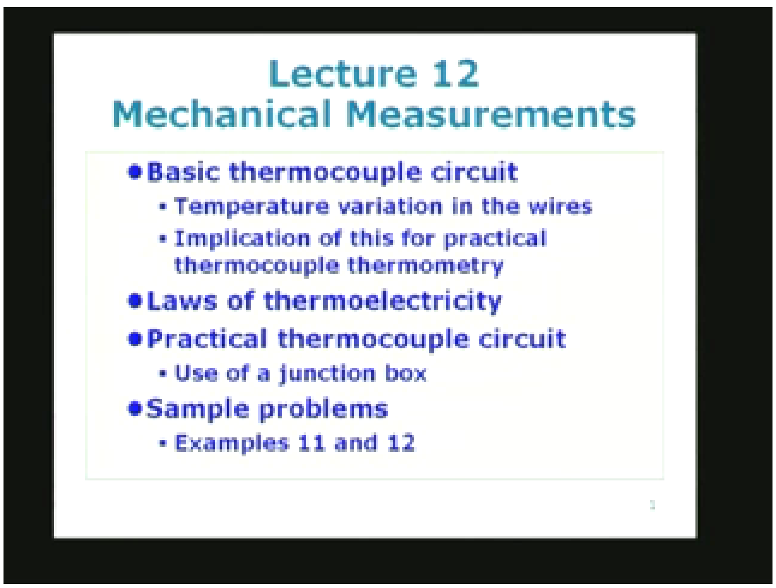


Towards the end of the last lecture we were talking about some practical aspects and before we get back to these aspects let us just recapitulate. To some extent what we did there, we in fact described the basic thermocouple circuit. We also looked at the temperature variation in the wires. We will again do the same thing here, and because there are some practical implications. And having done that, we will look at some more laws of thermoelectricity. There are three of them. These are very useful in the practice of thermoelectric thermometry. Then we will look at what is called the practical thermocouple circuit and will discuss briefly the use of a junction box, and we round off the lecture with probably two problems depending on the time available.

So in the next slide I am showing the simple thermocouple circuit which was in fact also looked at in the last lecture.

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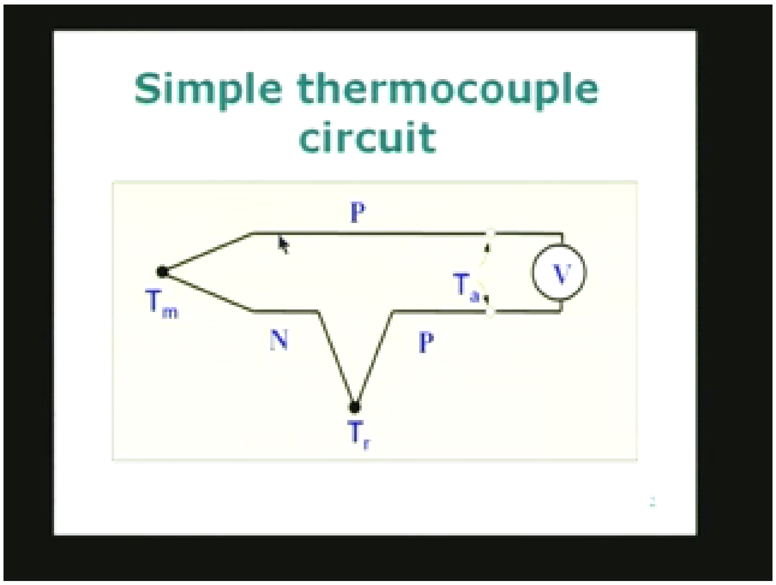


It consists of two wires, the positive wire is shown as P and the negative wire as N. And there is a junction between the positive and the negative wire which is maintained at the temperature $T_m$. This is the measuring junction. And if you remember what we have said earlier, there should be a reference junction. In this case, it is the junction between the N wire and the P wire. So the measuring junction which is between P the wire and the N wire, and if you go in the same direction between the negative and the positive wire, there is a junction which is maintained at the reference temperature.

In practice, the reference temperature is usually going to be the ice point, and we will come back to this ice point, and how to maintain the ice point later on. Invariably, when you have a thermocouple circuit, you have to make a connection to a voltmeter or potentiometer, and that requires, as you see here, two junctions are formed immediately. There are two extra junctions, one between the P material and maybe the wire which goes to the voltmeter is the copper wire, this one, and similarly, for the P material, here, I will have another wire which probably is a copper wire. So you see that as soon as we have a connection to the voltmeter we have two extra junctions.

In fact, we wanted only the junction at temperature $T_m$, and junction at temperature $T_r$, but because of the connection to the voltage measuring instrument you have two more junctions. In case these two junctions are at the same temperature, you see that this is the positive wire, this also is a positive wire, and there is the connection between the positive and copper. There is the junction between positive and copper, and similarly, another between positive and copper, and we will see a little later that these two junctions are not going to affect the measurement. How and why, we will come to it a little later on. So, this is the simple thermocouple circuit which one can think of to make the measurement of the temperature, $T_m$ with the reference temperature being given at the ice point or 0 degree Celsius. So, in the next slide, I am showing the nature of the temperature variations in the wires.

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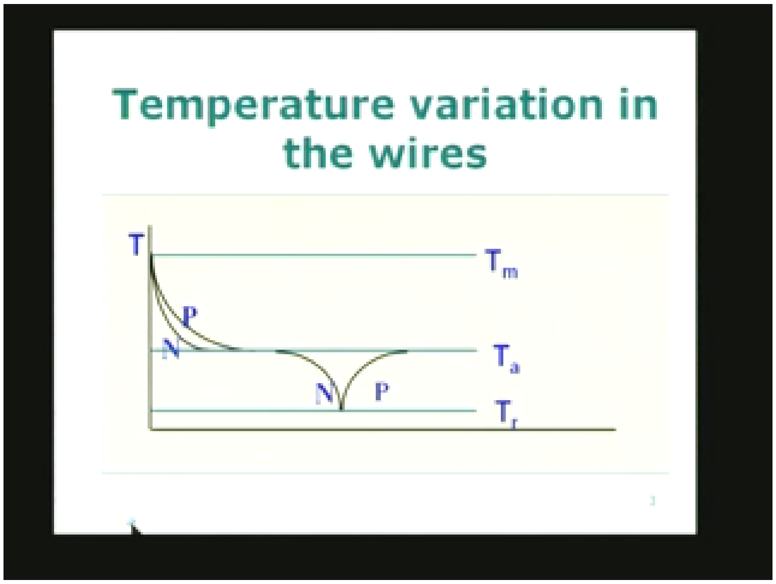


In this particular problem, you remember there was the measuring junction at $T_m$, the reference junction at $T_r$, and there was also the junction, the two junctions which were formed by connecting it to the voltmeter. We had a junction temperature of $T_a$, so I have shown these T temperatures levels, $T_m$ is this, the temperature axis, I got $T_m$, this line corresponds to $T_m$, the intermediate line corresponds to the temperature $T_a$, and the reference temperature corresponds to $T_r$. There are three temperature levels in this particular circuit, and if you look at what is going to happen in the wire connecting the various junctions, the length of the wire may be quite large.

If I use the very thin wire and a very long wire it is likely that the wire will cool off in a short length from the measuring junction. It is $T_m$ here at this measuring junction. Within a short distance it is going to cool down to the temperature $T_a$, which is, we can take it as the ambient temperature. This is so, for both the positive wire as well as the negative wire. So both of them have become more or less cool to the temperature equal to $T_a$.

Therefore, the region which is subject to temperature variations along it's length, along the length of the wires, is confined to a short region close to the junction as you have seen here. This is the junction very close to where there is a variation in the temperature along the wires. Therefore, if you remember the discussion we had earlier regarding thermoelectricity, thermoelectricity manifests whenever there is a temperature variation along the wire. And in this case, the temperature variation on the wire is limited to a region close to the junction, and therefore, the active thermoelectric material is very close to the junction. So, that is what I am trying to get.

And similarly, near the junction at the reference temperature $T_r$, again there is a warming up from the junction to the ambient. You can see, here is the warming up to the junction from the junction temperature to the ambient temperature, and similarly, the positive wire. So, both of them, in other words, much of the bulk of the wire away from the junction is at a uniform temperature equal to $T_a$. And if you remember what we had said earlier, if a thermoelectric material is at a uniform temperature, there is no thermoelectric phenomenon which is taking place. Therefore, we can see that the thermoelectric phenomena which is taking place is limited to a small region close to the reference junction, another small region close to the hot junction. This is very important, because we are going to now propose using a different way of connection.

If you see here, bulk of the wire is at a uniform temperature, and therefore, there is no need to connect by using the same wires as the thermocouple wires. We can, in fact, use some other wire. We can use extension wires, so-called extension wires, which are usually made of the same material as the thermocouple wires but of lower quality, or, we can even use copper wires uniformly away from the junction. So, you have a junction, and a very short distance away from the junction you have a wire connected to it which is either copper wire or an extension wire, so that we save on the cost of the thermocouple wire.

Otherwise, if the thermocouple is, let us say wires of 10 or 20 meters long, depending on the application, we will have to use 20 meters of highly expensive thermocouple material. It is a waste, because it costs a lot of money and there is no point in doing that, because bulk of the length of the wire is actually at a uniform temperature. So this is very important to understand.

Now, apart from this, we have some three thermoelectric circuit laws which are going to be useful in the practice of thermometry, thermoelectric thermometry.

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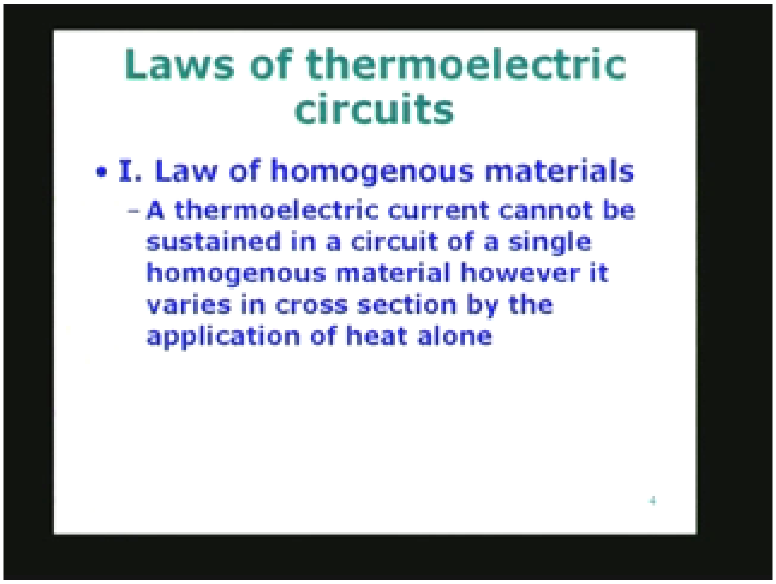


One is, of course, the law of homogenous materials, which simply says that a thermoelectric current cannot be sustained in a circuit of a single material, homogenous material, however, it varies in cross-section by the application of heat alone. Very important. If it is uniform material made of the same homogeneous material, whatever may be the shape, size of the cross-section, and so on, if we simply apply the temperature variation, nothing is going to happen.

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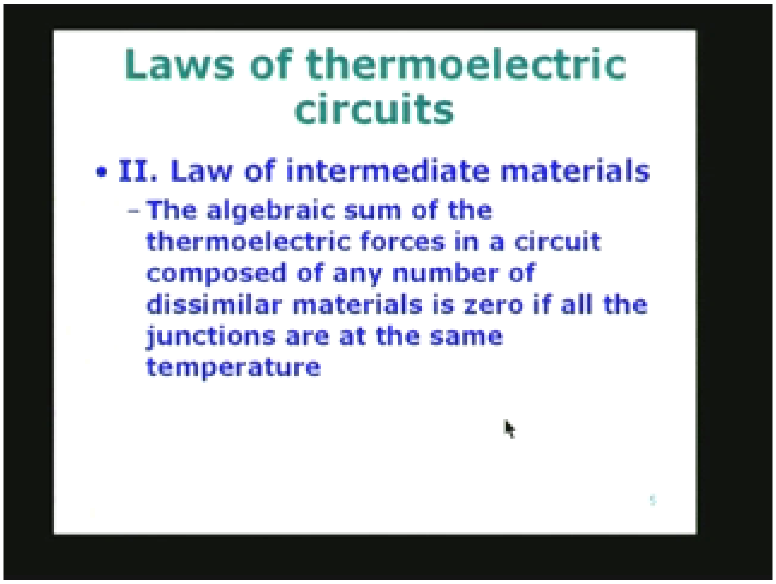


The second law is called law of intermediate materials, which plays a very significant role. As you will see a little while from now, it simply says that the algebraic sum of the thermoelectric forces in a circuit composed of any number of dissimilar materials is 0 if all the junctions are at the same temperature. This is a very important relationship, and we will go back to the thermoelectric circuit and explain it little later, but what does it mean? It means simply this:

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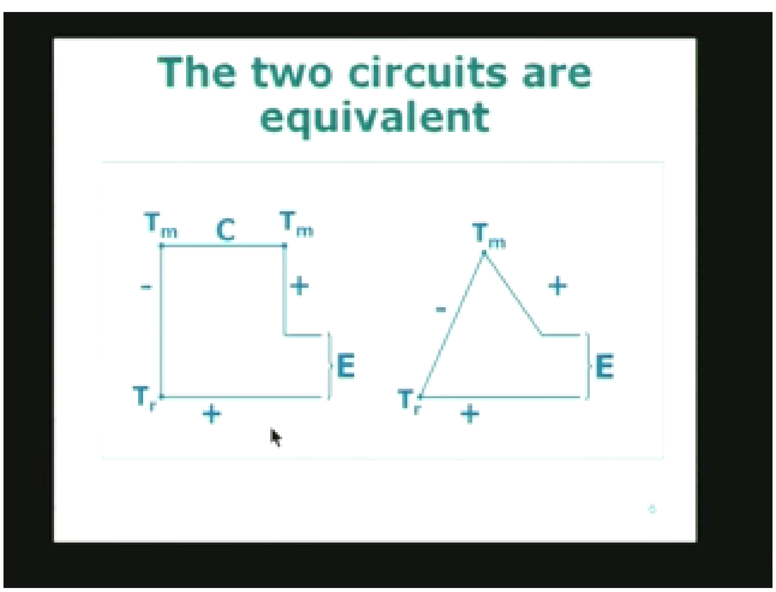

I have two circuits, the first circuit I have got the negative material. Then I have a material, C, which is connecting the junction at $T_m$ to another junction which is formed between C and the positive material, but this entire thing is at the same temperature, $T_m$. This junction, as well as junction and the entire material here, is at a uniform temperature, and now I have got the reference temperature junction here, and I am going to measure the voltage between this plus wire and this plus wire. So, you can see that there are three junctions, $T_m$ ,$T_m$, but there is a third material, C, and the relationship we just had was any number of dissimilar materials is 0 if all these junctions are at the same temperature.

That means, because these two junctions are at the same temperature, this material being there is of no significance. That means, I can remove this material C and look at the circuit shown on the right. I have got a single junction at temperature at $T_m$,$T_r$, and I have got a negative wire, and the positive wire at this particular thing is missing. These two are equal. That means, that whatever potential difference I am going to measure across the terminals in the first circuit is exactly the same as the one I am going to measure in the second circuit. That means this extra wire which is at a uniform temperature equal to $T_m$ is not going to affect the measurement, and if I go back to the previous figure here, you see that this is the temperature, $T_a$. This is the temperature $T_a$. This is the third material, and you see that this is exactly what we have in the second law which we explained in the earlier slide. That means that the presence of these two extra junctions is of no significance.

It is as though the voltage indicated here is only because of $T_m$ and $T_r$, and these two junctions are absent. If it were not so, we would never be able to use the thermocouple circuit because it will be very difficult to construct the thermocouple circuit to measure the temperature. With this, let us look at another important law called as the law of successive or intermediate temperatures.

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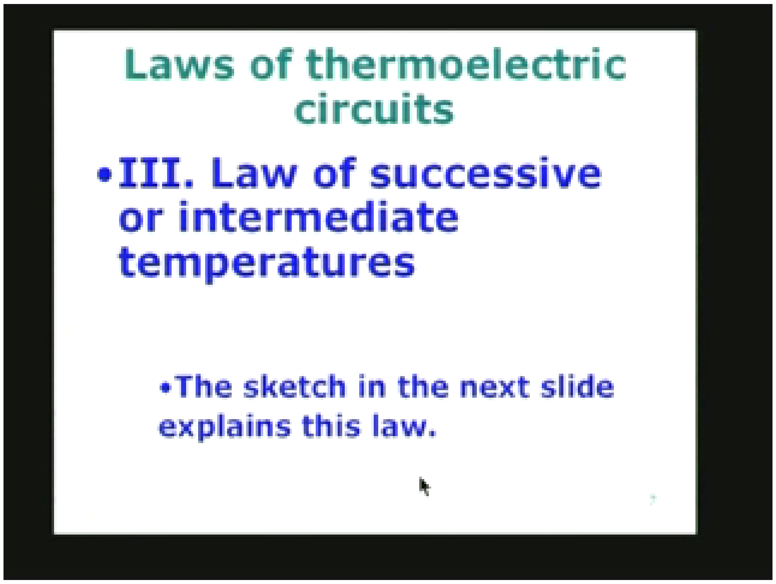


This is very useful, and I am making a small sketch in the next slide to explain this relationship of the law.

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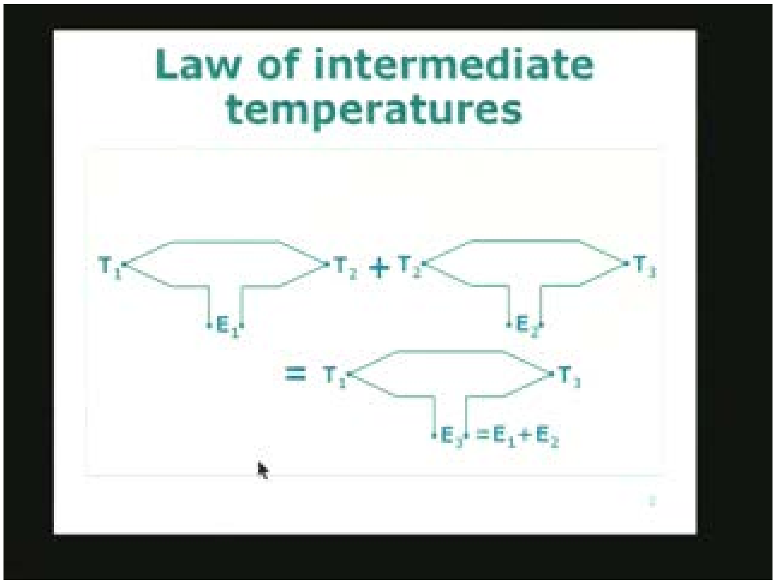


Suppose I have two junctions, $T_1$ and $T_2$, and I measure the electromotive force across the junctions. This is $E_1$. I have another arrangement in which the junctions are at temperature $T_2$ and $T_3$, and I measure the voltage for the electromotive forces $E_2$. Now, if the junctions are at $T_1$ and $T_3$, here $T_1$, $T_2$,

$T_3$, so, now I make it $T_1$, $T_3$, the electromotive force appearing across the junction, $E_3$, is the sum of these two, sum of $E_1$ and $E_2$,very important relationship.

Let me just see how it can be used. For example, suppose I don't have an ice reference point. I am not able to have an ice reference point. Suppose this is the temperature I want to measure $T_1$. $T_2$, instead of being the ice point, I have got the room temperature. Let us assume the zone temperature is measured by a third thermometer, some other thermometer which is easily accessible to us. So, I know the temperature, $T_2$, I know the temperature $T_2$.

Now, if you connect it, connect the thermocouple between $T_1$ and $T_2$, which is room temperature, it will give you some output, $E_1$ and the $T_2$ room temperature with respect to, let us say, $T_3$,I consider the ice point for example, $T_2$, with respect to ice point will give $E_2$. Actually, what I should do is I should add this $E_1$. To $E_1$ I should add $E_2$ to find out what is the output of this thermocouple. If this were at the measuring junction temperature, and this were the ice point, therefore, to find out what is the correct temperature all I have to do is to add whatever is going to be obtained by this arrangement between the room temperature and the ice point. This can be done by, of course, looking up a table.

You look up a table of a thermocouple, whatever material you are having for the thermocouple, you look up the table, put $T_2$ equal to room temperature, $T_3$ equal to ice point. This directly comes on the table. You are going to measure this $E_1$ in your experiment, then you add this $E_1$ plus $E_2$ and you will get the value $E_3$, and this $E_3$ will now be the correct value of the electromotive force which you should see.

Go back to the table, find out what is the temperature corresponding with $E_3$. That is the correct temperature of the junction $T_1$. So the law of intermediate temperatures is an important relationship which helps us in actually performing thermometry. So the three laws of thermometry, or thermoelectric materials, the first law which said something about the fact that you cannot have any thermoelectric effect in a homogeneous material whatever may be the area of cross-section, however, it varies by applying heat. You may not able to get anything out of that. The second one is we had the law of intermediate materials.

The presence or absence of the material, intermediate material, is not going to be felt as long as the junctions which are extra junctions which are formed, are at the same temperature, and the law of the intermediate temperatures helps us in finding out what will happen if I do not have the reference junction at the ice point but at some temperature. I can find out by the use of this law of intermediate temperatures, the appropriate value of $E_3$, and therefore, I can find out what is the appropriate temperature. Thus, with these three laws, I am going to propose the use of a practical thermocouple circuit because the practical thermocouple circuit actually requires the application of the three laws which I have just now proposed which we have looked at. These three laws are going to be used here.

Let us look at how it is done. We have the P and N material, positive and negative. Sometimes I have used plus and minus, sometimes P and N means the same thing. One junction is the temperature, $T_m$, and I have, at the other junction, at the reference temperature $T_r$, N and P material. These are P and N, this is N and P. This is very important. The junction must be between P and N here, and when you go around, which will be from N to P, this is very important, but what I have done is I have connected a copper wire between here and here, a copper wire between here and here, and also a copper wire between here and here.

So now, when I connect these extra copper wires, you see I have made, I have a new, one more junction here. If you want, you can call it junction number 1 extra, junction number two extra, there is the junction number three extra, four, and then five, and six. Six extra junctions have been formed by connecting the copper wires as lead wires. Instead of taking the same wire all along, I could have done that, that's what I did in the simple thermocouple circuit.

Here I am deliberately using copper wire, and if you look at the temperature variation, the temperature $T_m$ here, $T_a$ here, most probably all this material from somewhere very close to the junction is all at the same temperature, $T_a$. That is the ambient temperature. Similarly, here therefore the P and N materials have variation of temperature along their length close to the junction here, and therefore, why waste the material P far away from here? Similarly, it is for the junction at the reference temperature. Therefore, I am saving a lot of high quality thermocouple wire by substituting it with copper wire.

Copper wire is available in good purity and also uniform quality, and it is much much cheaper compared to the thermocouple wires, maybe a fact of 25 or 50, that is the cost ratio. So, the advantage of using a practical thermocouple circuit is that I am going to substitute the P wire by copper wire, N wire by copper wire. Sometimes, what is done is instead of copper wire I use what is a so-called extension wire P.

Same P wire extension wire which is not necessarily of high quality means that the purity and other requirements of the junction, the extension wire will be less than that for the thermocouple. So instead of this copper wire, I will even have a P wire made of less quality wire, and similarly here, I may have N wire which is an extension wire, same composition as the wire here, but not of equal purity of manufacture, with the same care, and so on. So I can use less expensive extension wires instead of the copper wire. That's also possible.

The advantage of using less expensive junction wires is that most probably the performance of that material will be similar to the P material, or the N material, as the case may be, and because the temperature variation is very little in that wire any inhomogeneity in that is not going to materially affect the temperature in the wire, and you can see I have got again a voltmeter connected using two junctions, and if these two junctions are at the same temperature as these are, all these extra junctions which are formed, 6 of them if they are at the same temperature, or at least these two are in the same temperature, these two at the same temperature and so on.

We can guarantee that there will be no extra voltage developed due to thermoelectricity, and therefore, the voltage measured here is purely due to the temperature, $T_m$ and $T_r$. That means, I am equating the practical thermocouple circuit is exactly the same as the simple thermocouple circuit we had only one junction, another junction, all wires of the same P and N material, this is exactly equivalent to that, electrically equivalent to that. That is very important because of the temperature variation along the lead wires is confined to regions close to the junctions, and that is in fact the important region.

Sometimes, what we do is in order to make sure that these extra junctions which are formed are at the same temperature these are going to be connected to a large block of material which is a highly conducting material in terms of thermal conductivity, and all these terminals are going to be connected on to lugs on that material, of course properly electrically insulated, but they are all tied on to the same material which can, in fact, be kept at a constant temperature by, for example, circulating cooled water, and so on. A junction box is made by; in fact I will just a make simple sketch of a junction box so that we understand what we are talking about.

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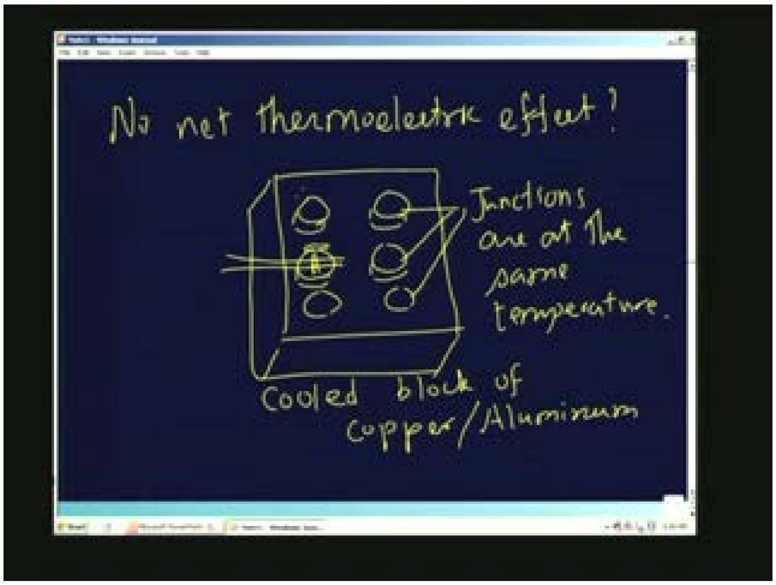


So what we have is a large piece of material like this, and you might even have, it may be connected, or it may be cooled, cooled block, for example, of copper or aluminum, and we have  all the junctions here, something like this, and you connect the wire at the base, and possibly with a screw. It is something like that. So, the advantage of this is that all these junctions, all these, they are after all going to form junctions, are at the same temperature. So they are all at the same temperature.  The advantage is that we are now making certain that all the wires which are connected to the blocks here, terminal blocks here, are at the same temperature, and therefore, no net thermoelectric effect. That is the important thing. So we don't have any net thermoelectric effect because of the lugs which are now all at the same temperature.

Now to continue with the discussion, let's look at, if you remember, the simple thermocouple circuit. We have a measuring junction, you can see here we have a measuring junction, we have a reference junction, and the reference junction has to be maintained at the constant temperature equal to the ice point, so we require an ice point apparatus or something which will provide the ice point, and it can be done by a simple arrangement like this.

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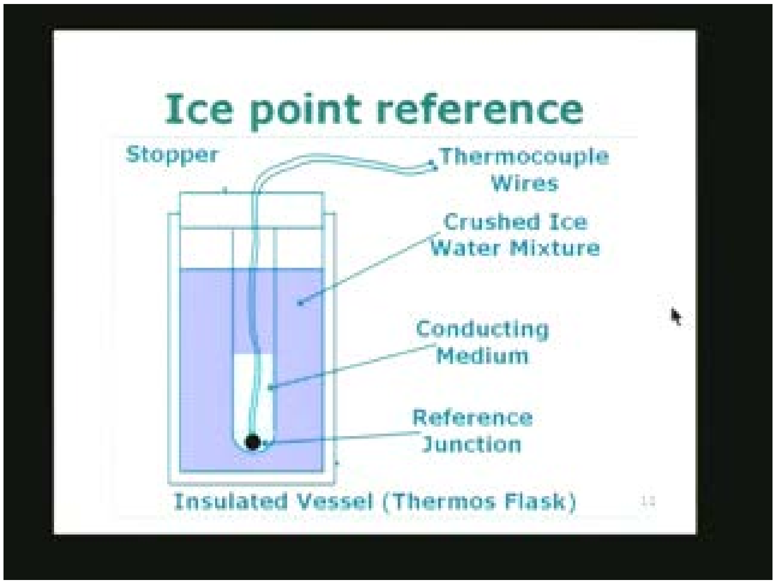


What I have got here is a large vessel. Normally, we use a thermos flask, double walled thermos flask. Inside that I have got a long tube. You can see the long tube here, into which I have put the thermocouple wires, and there is a junction which has formed right here. This black thing is the reference junction and it is immersed in a liquid which is a conducting medium.

For example, I can use mercury, or I can use some oil, something which is going to have a good contact between the thermocouple and the medium, and the medium is now in the tube which is completely immersed in this blue colored thing here, is the crushed ice water mixture. As long as ice and water coexist together, that means the ice and the water mixture, crushed ice and water, water is formed, and as long as the ice and water mixture is present inside this vessel the temperature is going to be the phase change temperature corresponding to 0 degree Celsius. Therefore, the temperature of the entire mass here is 0 degrees and if this tube is immersed totally into it and the reference junction is kept at the bottom the chances are that the entire thing is going to be at the ice point. So this ice point cell or ice point reference here is going to provide one reference junction for use with our thermocouple circuit.

Of course, the question now is, if you have a large number of thermocouple temperatures to be measured, which is $T_1, T_2, T_3, T_4$ etc, each one of them will require a reference temperature which is given by the ice point. So do we provide one ice point for each one of them or can we provide a single ice point reference?

That question is answered by looking at an arrangement which is possible, and here I have shown many hot junctions with a single reference junction, and also I have shown a junction box. You can see here I have got measuring junction 1, 2, 3, and 4. I have just taken 4 here.

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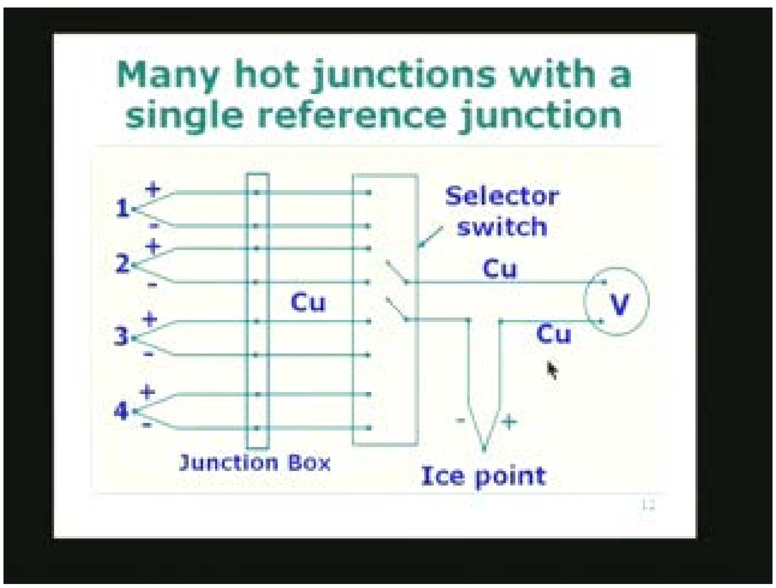


You could have any number, sometimes, even hundreds of them can be used, and I have got the positive and negative wires coming from the junction connected to a junction box, this long thing is the junction box kept at a uniform temperature by the arrangement which I indicated earlier, and from the junction box I have taken copper wires, all these extension wires are copper wires, and then they go to another junction box-cum-switch. So these are the junction box points, and there is a switch which will connect any two of these terminals to the rest of the circuit.

Let us look at, for example, if I were to connect this wire through the switch to this wire, and this wire through the switch to this wire, what will happen is, there is a copper wire, there is another copper wire, these are two. All these four points are on the selector switch which can be kept at the same temperature. Therefore, all these junctions are at the same temperature and these two junctions also. Then, this is connected to one ice point reference, the minus plus here, again a copper wire and copper connected to the voltmeter.

Thus, by using the selector switch,usually the selector switch is very expensive equipment; it consists of a rotary switch. Even though it is shown here as a long vertical thing here, actually, it is usually a rotary switch with 16, or 32, or 64 terminals available for us, and by rotating the thing I can select these two or these two or these two and so on. Therefore, what I do is when I want to take the readings of $T_1$,$T_2$,$T_3$,$T_4$, I will go through 1, 2, 3 all the different positions and note down what are the corresponding electromotive force which is going to be indicated by the voltmeter, oky. One cycle will mean I go from 1 to 2, 2 to 3, 3 to 4, note down four readings and again I am ready to do this, if the temperature is varying with respect to time.Therefore, here, by using a selector switch which is a rotary switch most of the time made with gold contact so that the contact is very very good. So we are able to use a single ice point cell with several hot junctions to measure the voltages one by one. By selecting each one in turn and then putting them together we are able to get the measurements of several junction temperatures using a single ice point as well as the single voltmeter. Very important.

The advantage of using a single voltmeter is that the error in measurement of various quantities is the same because we are using a single instrument. If we use different instruments, the calibration between the different instruments will also come into the picture, whereas, here there is only one instrument I am using, and the error is limited to the error of one instrument. Hence, several interesting points will come out of that if you look carefully. I don’t want to give all the information. The student should learn some of these things by looking through and understanding what are the principles involved.

In fact, if you look at this sketch all the three different laws of thermoelectric circuits which we talked about earlier are all applicable here. They are all applicable here and in fact we have several junctions which have been formed. We are seeing to that all the junctions are at the same temperature. By using the junction box concept we are using a good selector switch which is also a usually very bulky item whose temperature will remain more or less uniform throughout. So these are all some of the things involved in this particular measurement.

So, to cut short the discussion, or to summarize what we have done till now; we started with thermoelectric phenomena, we discussed the Kelvin relationship, and then we talked about the relationship between the temperature and the output of a thermocouple circuit. We talked about either a table, look up table, or you could think in terms of fitting a polynomial, and then we looked at both the simple thermocouple circuit and the practical thermocouple circuit using the three laws of thermoelectric circuits, and we also used the information that the temperature variation in the materials is confined to regions close to the junctions.

Actually the main point here is that the thermoelectric phenomena is not a junction phenomena. You will see that when we talked about the thermoelectric effects, the Seebeck, the Peltier, and the Thomson effect, you see that the Thomson effect actually continues all along the material of the wire. The Seebeck effect is simply a combination of the other two, so that the relationship between the three of them, the Seebeck, and the Thomson, and the Peltier. The Peltier is something which happens near the junction, whereas the Thomson effect is taking place all along the length of the wire. Therefore, it is not correct to think in terms of the thermoelectric phenomena happening at these two junctions. No, it is happening all over the place.

The question is, can we confine it to a region close to the junctions?
What is going to happen in practice, because the wires are very thin, and usually they are very long, and because they are very long they are going to move. They are going to be in the laboratory space, and the laboratory space is in uniform temperature, therefore, it will cool to that temperature, and therefore, confining the temperature to temperature variation to closed junction is an automatic phenomena which takes place, and therefore we are able to practice thermoelectric thermometry by using an arrangement which is shown in the figure. So let us look at what are the other possibilities.

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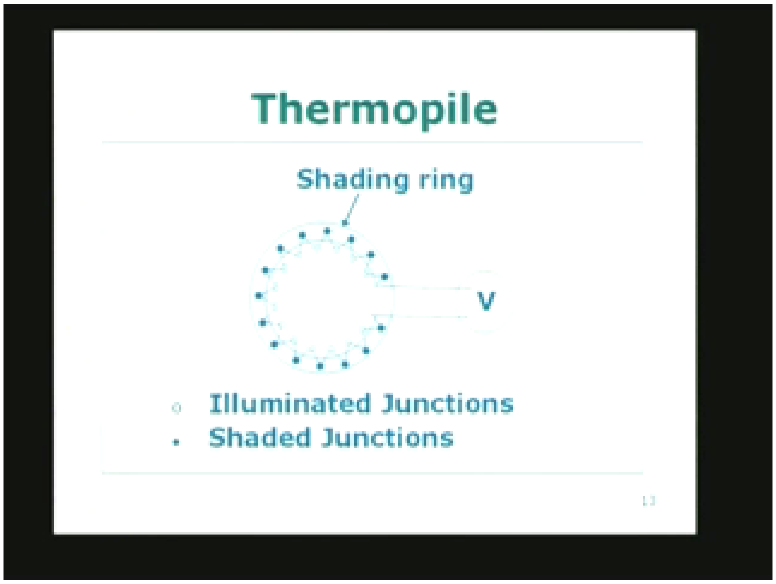


We have several things which we can do, and let me explain. Before I come to the thermopile arrangement here, let me just briefly explain using the blackboard. Let's look at the possibilities.

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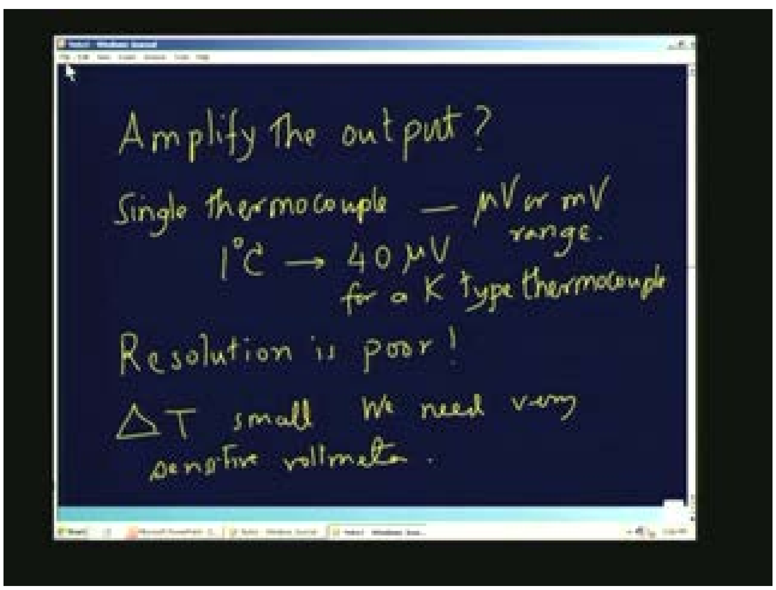


Can we amplify the output? If so, how do we do that?
If you remember, a single thermocouple, the output is in the microvolt or millivolt range. This is well known. We have already seen this earlier

because 1 degree Celsius gives about 40 microvolts for a K-type thermocouple. In fact, K-type thermocouple is one of the most sensitive. Even that provides only about 40 microvolts. Other thermocouples will provide less than this. So, if you use a single thermocouple, resolution is going to suffer. Resolution is poor. Or another way of saying that is that I must have a very sensitive voltmeter to measure small temperature differences. So if delta T is small, we need a very sensitive voltmeter. That is the problem. Now, can we improve this situation?
For that, let us look at what are the possibilities.

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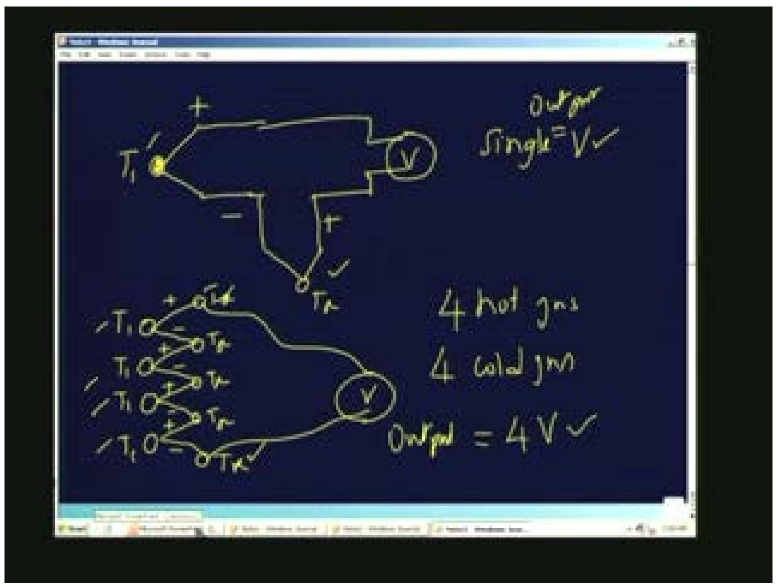


Suppose I put two thermocouples in series, this is junction $T_1$. This is positive, this is negative, so I want to increase the output by, of course you have to have this, what you have, this is one single thermocouple. We have already seen this. This is single. Suppose I do the following. Suppose I take several junctions. So I am going to connect like this. So these are all at $T_1$, and let us assume that these are all $T_r$. So I am going to have a plus wire here, a minus wire here, a plus wire here, a minus wire here, and so on, and of course, I am going to take the connection from here, and I will connect it to a voltmeter. So I have got here four junctions, T, at the same temperature, and three junctions, plus these two junctions, because these two entire thing is at uniform temperature and because this is made up of thermal material, if you use the law of intermediate materials you can see that this junction and this junction together is like one junction.

So, I have here four hot junctions and four cold junctions, all in series. That means that I am going to get the output. If this is V, this will be four times V in the output. This output is equal to V single hot junction, single reference junction. I am going to get voltage equal to V. I have got four here and four cold junctions. As I explained just a while ago, these two together form one cold junction. So there are four cold junctions. I get four times the output. That means I am able to get a bigger output. For example, instead of 40 microvolts per degree I will get here 160 microvolts per degree. This is an advantage. So, with this background, let us look at one of the applications, and it is called the thermopile.

What is the thermopile?
Thermopile consists of a large number of hot junctions and a large number of cold junctions. In this case, I have shown it in the form of a circular arrangement. So I have got the hot junctions are all open circles, and the cold junctions are all the blocked circles, and there is a shading ring.

What the shading ring is doing is to prevent the heat from being communicated to the junctions which are in the shadow. One of the uses for the particular thermopile arrangement would be, you have, let us say solar energy falling on these junctions. Because of the solar heat which is falling on them these junctions will get heated compared to the other junctions which are in the shade because of the ring which is surrounding it. These are at a lower temperature. All the black dots are at a lower temperature and they are all in series.

In this case, I think I have got fifteen or so junctions. So 15 times voltage will be developed and what this measures is a large output. If the output for each thermocouple pair is only 40 microvolts, as I just said, you will get about fifteen times 15 times 40, about 600 microvolts, which will be a sizeable amount. So, the junctions which are shown in the open circles are illuminated junctions, and the others are shaded junctions.

In fact, we have also indicated here another use for thermometry. If you remember, we were talking about measurement of temperature and suddenly we have shifted our emphasis. Here I am talking about measurement of solar energy. So actually, the heat flux or the flux from the sun can be directly converted to increase the temperature of the junction, and this is proportional to the amount of heat which is falling on it, and therefore, I am able to measure the solar flux using essentially a thermocouple, or a thermopile, in this case. Thermopile, because a large number of thermocouples are in series. What we did earlier was to increase the output.

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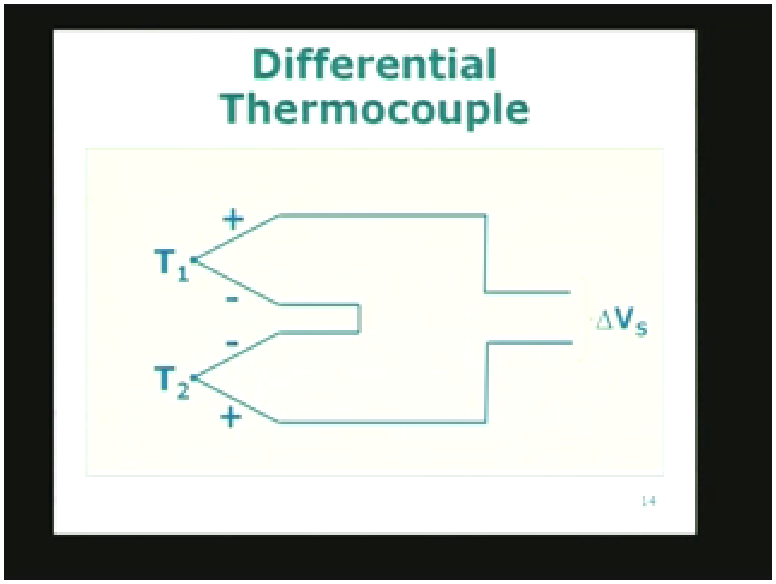


We can also do the following. We can have a differential thermocouple. What is the differential thermocouple? It measures directly the temperature difference between two junctions. Where do we use it? Why do we use it? We will just look at it.

I have two junctions, one at temperature $T_1$, the other junction at temperature $T_2$ instead of the reference temperatures. I am not using a reference temperature here. I am using two junctions, one at the higher temperature, and the other one is at lower temperature. So, plus minus, and this minus, is coming here, and then plus. So between the two plus wires I am going to measure the output, and this will be the output due to the temperature difference between the junctions $T_1$ and $T_2$.

If you remember the third law which I proposed, in the third law I had $T_1$ and $T_2$. It is like $T_1$ and T reference minus $T_2$ minus T reference. So what you get here is nothing but $T_1$ minus $T_2$. You can work it out in your mind. This arrangement is going to give you directly the temperature difference.

What is the advantage of this?
Suppose I have a fluid flowing through a tube, and it is losing heat, let us say, it is entering a temperature $T_1$, and after going through a certain length

of the pipe it is going to come out with a temperature $T_2$ which is very close to $T_1$. That means that may be 2 or 3 degrees variation is there. I can measure it in two different ways. One is I can measure $T_1$ separately by using the thermocouple and a reference junction. I can similarly measure $T_2$ separately using a reference junction and trace the ice point and this measuring junction.

Now, I get two values from the table, one corresponding to this temperature the other corresponding to this temperature. Then I have to take the difference between these two points. That means that the error in the first measurement and the error in the second measurement, if you remember the propagation errors in this case, there are two measured quantities and the error of each measured quantity, $T_1$ separately, $T_2$ separately, is going to affect the temperature difference because of the propagation of the error. If you measure directly, $T_1$ and $T_2$, you are not going to have that problem.

Therefore, whenever we are measuring very small temperature differences as in the case of a fluid which is flowing through a tube and getting heated and losing heat or getting heated if the temperature rise or temperature drop is a small quantity like 2 or 3 degrees, or even 5 degrees, you can measure the difference directly instead of measuring the two separately and taking the result. There is another advantage.

If you are measuring the temperature difference between the two quantities which are very close to each other, the thermocouple is almost a linear device. That's a great advantage. Suppose $T_1$ is 35, and $T_2$ is 38, three degrees 3 into 40 microvolts is what you are going to get. So, directly you can convert the temperature difference, the potential difference, directly temperature difference, by simply multiplying by using the Seebeck coefficient at around 30 degrees, 35 degrees, whatever value it is you can obtain that, so the advantage of differential thermocouple is, there are many. One is it reduces the error in a quantity when you want only the temperature difference, not each temperature separately as in a flow where temperature difference is to be measured.

Also, the advantage is that the thermocouple is more or less linear in a small range, and therefore, I can use a constant value for the Seebeck coefficient and without looking up into a table I can directly measure the temperature very accurately. In fact, the different thermocouple can be used with an amplifier also. Suppose I take the difference between these two signals, put it in amplifier, I can amplify it by a constant factor. Maybe I can use an amplifier with 100 amplification, 40 microvolts will become 40 into 100, 4000 microvolts, and it becomes a very large value. So I can measure it very easily without much difficulty, and there is no reference junction. There are only two junctions, the difference directly being measured, is the great advantage. So with this background, I will try to see if I can give one or two examples.

In fact, I had two examples in mind, maybe it will possible, maybe not. Just before we go to the example, I just want to make something known to you.

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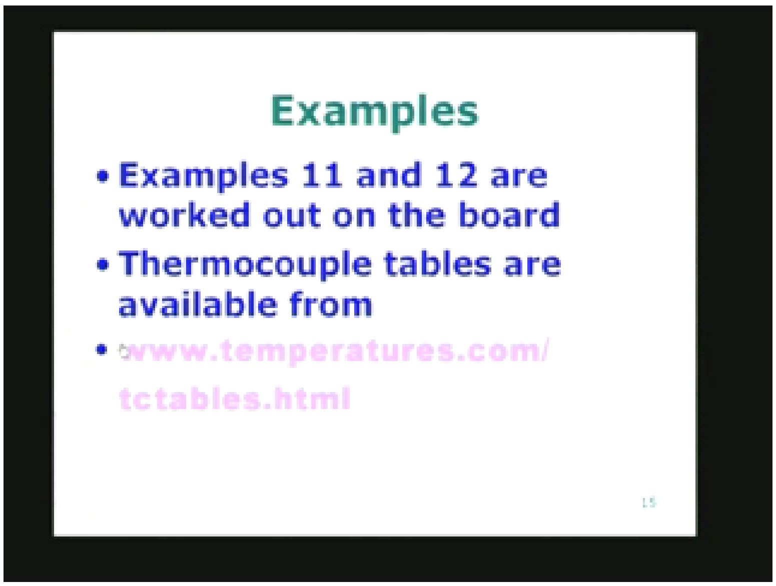


The thermocouple tables are available from the following website. It is <<www.temperatures.com>> and you go there and put <<tc tables.html>>. I think I will show a different way.

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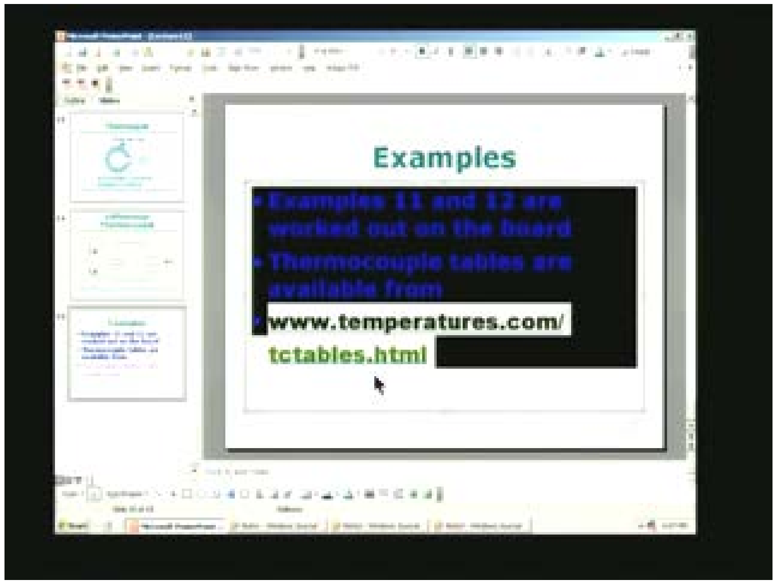


You can see better; <<www.temperatures.com/tctables.html>>. This is the useful link. If you go into that, you will be able to download all the tables, you may require for calculating temperatures based on the measurement of the voltages. So with this background let us take a look at the example, so the example I am going to take is the following.I will call it example number 11, no numeric here. I am going to use a differential thermocouple arrangement differential thermocouple as a calibration device.

Suppose I have a standard calibrated standard reference thermocouple which has been obtained from commercially available source and I have what I will call as individual thermocouple then this is supposed to guarantee some performance index.

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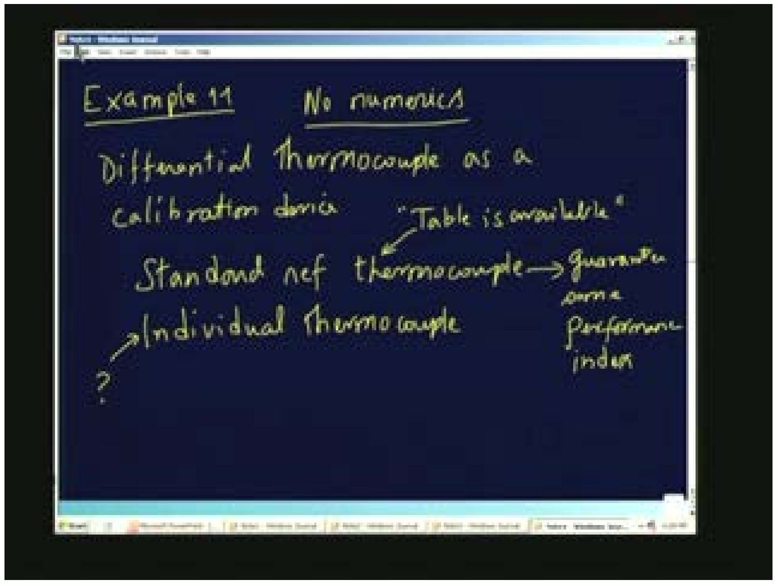


For example; what we will be doing is; for this thermocouple a table is available. The manufacturer has guaranteed that a table is available and you can use the table for this purpose. For this I don't know what it is. Now how do we go about calibrating this individual thermocouple with the help of the standard reference thermocouple. For that what I am going to do is I am going to make a circuit like the following: it is exactly like what we had, the differential thermocouple. This is standard.

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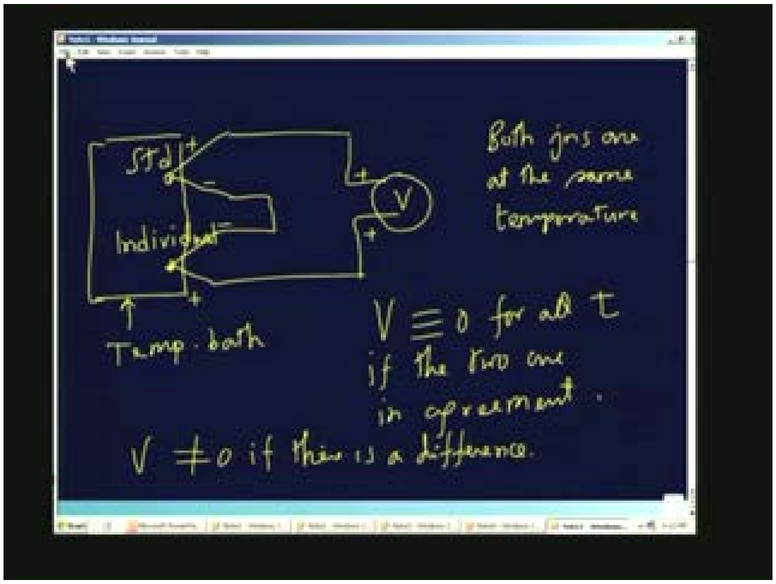


These terminologies are normally used by people working in instrumentation. This is the standard reference thermocouple and this is individual. Now I am going to measure the potential difference across these two junctions. That means this is plus minus minus plus, this is plus, this is plus. So at these two I am going to put constant temperature bath, whose temperature can vary but both of them are at the same temperature, both junctions are at the same temperature and I can in fact also measure what is known as the common temperature by using the standard reference itself directly.

I can make the measurement of the common temperature to which the two junctions are exposed by using the standard reference thermocouple and I can also make the temperature reading of the difference between the two thermocouples.

If the standard reference of individual are exactly alike V will be equal to zero for all t if the two are in agreement. Because at any time I am making the measurement, both are at the same temperature that means, I don't expect any voltage difference. But if the individual thermocouple is not behaving exactly like the standard ,the V is non zero if there is a difference in the thermocouple. Therefore, I am going to make a small plot like what I am going to show in the next slide.

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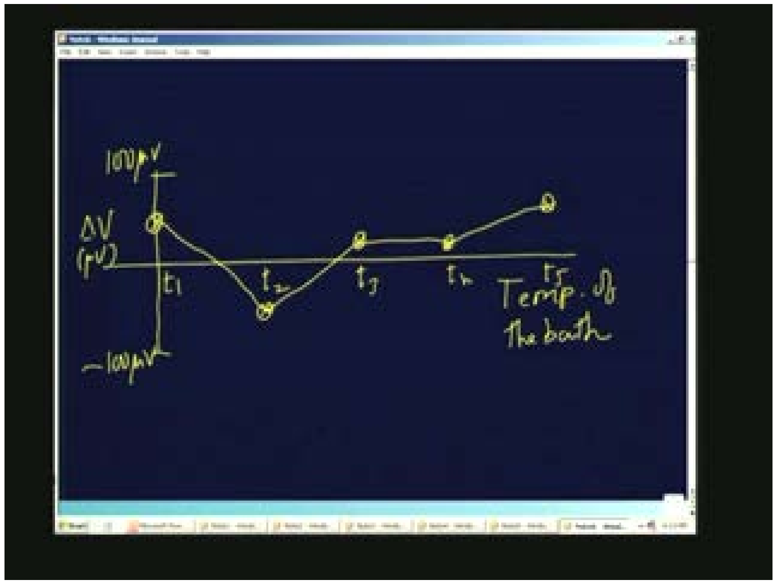


Therefore, I am going to make a plot like this; this is the temperature of the bath, I can start with some value $t_1$, $t_2$, $t_3$, $t_4$, etc. On this I am going to plot delta V which may be in micro volts because the two are made of the same thermocouple material. I am expecting a very small departure; I am not expecting a very large departure. Therefore you may have hundred micro volts here and may be minus hundred micro volts here, the difference is only very small.

Of course in terms of the K-type thermocouples this will be something like two and a half degrees. If you remember that forty micro volts is per degree so at $t_1$ the two may not agree so I may get a point like this. At $t_2$ the error is actually like this, here the error may be like this and so on and so forth. So I can roughly say that the difference between the two thermocouples is such that the error distribution or the error variation with respect to temperature is given by a curve like this. So this can be used as a calibration device because I can add or subtract as the case may be the voltage indicated here as a correction. So the values may be used as a correction.

What do you mean by correction?
I am going to use the standard reference table that is there already. That table gives us some value. In that whatever value you get you add or subtract the value shown here and go back the table and find out what the temperature is. So I am going to use the individual thermocouple in the measurement, I am

going to find out what the output is of this individual thermocouple, and corresponding to each then I can find out what is the error between the individual thermocouple and the reference by having a calibration chart like this and I am going to use this as a correction to make a correction in that and therefore to improve the accuracy of the measurement of the temperature using the individual thermocouple.

If I have got let us say hundreds of thermocouples which I am going to use in the laboratory I may not be able to calibrate each one of them like this. I will take probably a few of them at random may be five or ten thermocouples at random find out how each one of them performs with respect to the calibration like this and then may be average error because normally what we do in practice, is to make thermocouples in the laboratory using the wire obtained from the same manufacturer from the same batch. That means most of the thermocouples are similarly behaving and therefore if I take a few of them from this slot and I calibrate some of them and then try to find out the average error and so on that may be a good idea.

Therefore, the calibration need not be that you calibrate each individual thermocouple of course for highest accuracy you have to do that but in the case of ordinary laboratory practice, I may take a few of them and calibrate them and then assume that this is an average of the behavior of all the thermocouples and use it. So, a differential thermocouple has become useful in another way now.

First I said it is useful when you want to measure a small temperature difference and also said that the thermocouple is more or less linear in this small temperature range and therefore I can easily measure the output. Third one is, I can use it for the calibration purpose. So the simple differential thermocouple has at least three different uses which you can think of.

In the next lecture, lecture number 13 I am going to continue and give the next example and then once having done that I will try to look at what are the sources of error in thermocouple thermometry. Thank you.