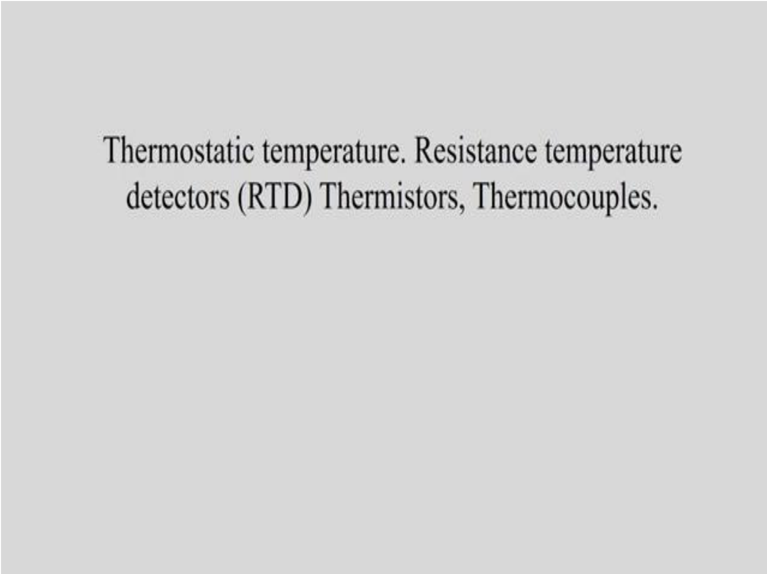
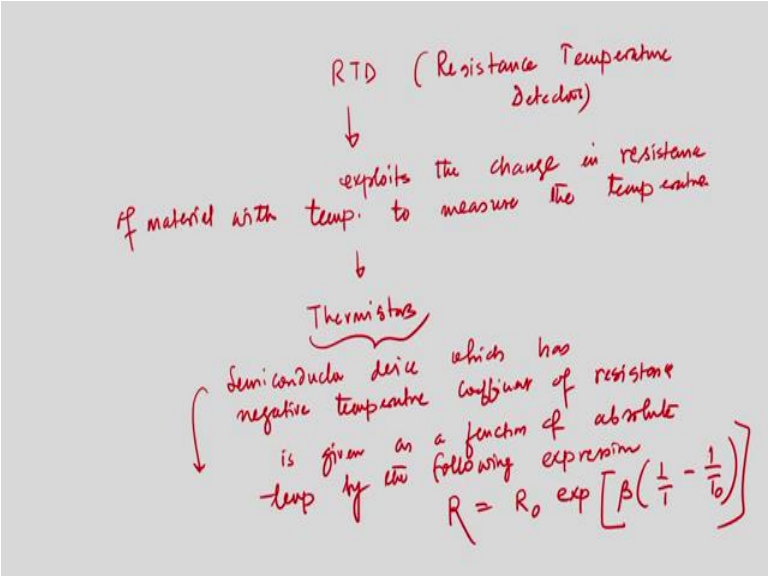
Experimental Methods in Fluid Mechanics
Dr. Pranab Kumar Mondal
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati
Lecture 25 - Thermostatic temperature, Resistance Temperature Detectors (RTD), Thermistors, Thermocouples

(Refer Time Slide: 0:38)



Good afternoon! I welcome you to the session of Experimental Methods in Fluid Mechanics and in continuation of my last lecture on the temperature measurement, today we will discuss about the thermostatic temperature measurement and for that we will discuss about the operational principle rather the mechanism of another, I can say technique and from there we will see how we can measure temperature. And if we can recall that temperature measurement, we have discussed that these are basically resistance temperature detector.

(Refer Time Slide: 1:27)



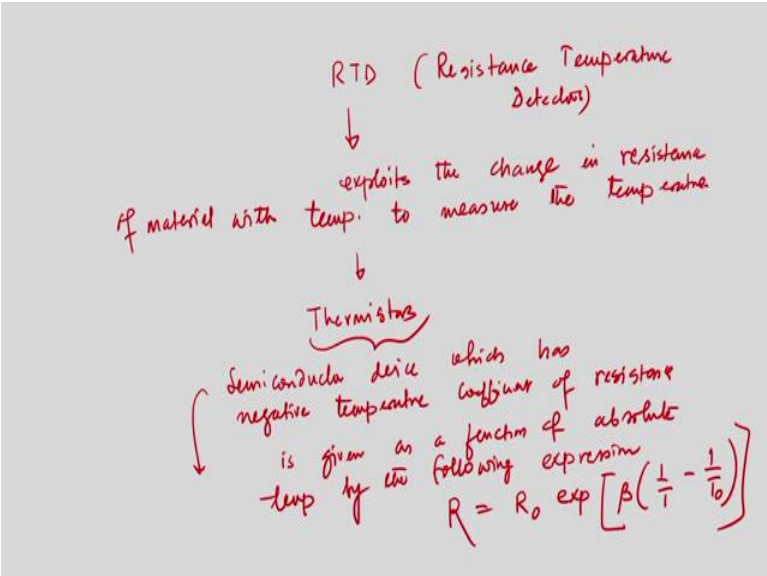
So, if I, if we try to recall that resistance temperature detectors that is RTD, resistance temperature detectors which exploits the change in resistance with temperature to measure the temperature. So, this RTD resistance temperature detectors exploits the change in temperature to change in, sorry change in resistance of material with temperature to measure the temperature. That means, how we use RTD that is resistance temperature detectors, which exploits the change in resistance and material, change in resistance with a change in temperature, essentially to know what is the temperature change.

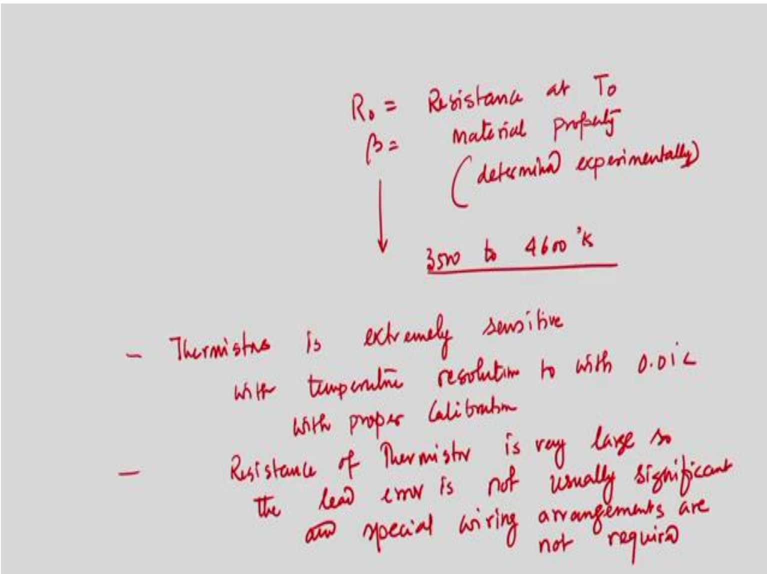
That is if we put this RTD in place where we are, where our objective is to measure temperature, then we need to know what will be the change in resistance of the material which will be in contact with the plus or, where we need to measure temperature and the change in resistance of the material will be the rather I can say that the resistance of the material will be changed as the material is now in contact to that body or a material is placed in a place where temperature is now higher than the material temperature, I mean temperature of the measuring device where you have RTD.

So, RTD we are placing in place. RTD is in contact with other material, where temperature of the material or temperature of the working substance of in that, you know I can say in that place where RTD is kept will be higher than the temperature of the RTD material. Now, since the temperature of the material or temperature of the places, where you are interested in to measure the temperature, I mean where we are interested in measuring the temperature will be definitely higher than the RTD temperature. So, by receiving temperature, by sensing the high temperature RTD resistance will be changed and that is what this mechanism is exploited to obtain the temperature measurement.

So, we have discussed a few, today we will discuss about the thermistors. So, these thermistors is basically, I can say is semiconductor device, I am writing this is a semiconductor device which has negative temperature, coefficient of resistance. And the resistance of the thermistor is given as a function of absolute temperature by the following expression that is R equal to R naught exponential beta into 1 upon T minus 1 upon T naught. So, this is the expression, approximate function of the resistance of the terms, thermistors as a function of temperature and from there we can, we will be using this to measure the temperature.

(Refer Time Slide: 6:51)





Now, in this expression if I write in the next slide, in this expression R naught is the resistance at T naught and beta is a material property, which is determined experimentally. And so, the resistance R which is given in the previous slide, which is the function of the absolute temperature, through this relationship R naught is the resistance at T naught, I know, so, and beta is the material constant. So, by now changing the resistance of the material we can calculate, we can measure the temperature of any object of any fluidic environment, and the temperature of the object or the fluidic environment is definitely higher than the temperature of the RTD.

So, this is the concept and the concept is similar, and which we have discussed in our last classes, that is the resistance temperature detectors exploits a change in resistance of the material in order to measure the temperature. That means, when we are placing these, I can say measuring instrument just to need to know the change in resistance and of course, this expression which we have written today, these are basically, these expressions are not, I can say, these are approximate expression, but these expressions are calibrated of course, and R naught which is the resistance at T naught that is known value, beta is the material property and typically this beta is 3500 to 4600 degree Kelvin.

So, beta, unit should be definitely temperature because data is multiplied by, that is or if I go back to my previous slide, R is equal to R naught. So, R is the unit of resistance, R naught is a unit of resistance. So, beta should be, beta should have unit of temperature and that is why the beta material property, which typically varies between these two, I mean between this range.

So, knowing the value of this quantity which is obtained experimentally, we can calculate what will be the change in resistance and that change in resistance is essentially because of the change in temperature. So, the temperature change which you would like to measure will be obtained if we can measure the change in resistance. The thermistors is extremely sensitive with temperature evolution to within 0.01 degree Celsius. Of course, with proper calibration that means, what is the meaning of the sentence? That means we can measure temperature if the change in temperature which is of the order of 10 power minus 2 degree Celsius, if we properly calibrate this device instrument, we can measure temperature.

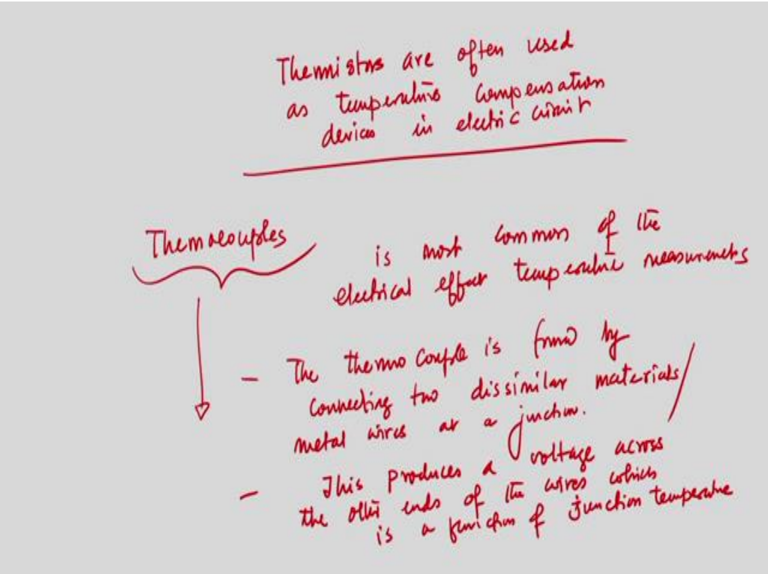
That means, the order of the change in temperature is 10 power minus 2, still we can measure using this device. So, this is extremely sensitive that I can tell.

So, this is one and another important advantage of this device is that the resistance rather I can say thermistors, resistance of the thermistors, thermistor is very large. So, the lead error is not usually significant and that means, if you try to recall our discussion which we had in my last class that resistance I mean these are placed and the resistance of the lead, which leads to significant error in the measurement. But, for the thermistors which is again we need to place in the that is what we have discussed, the circuits that is the Wheatstone bridge.

Now, the resistance of a thermistor is very large. So, the lead resistance, the error due to lead resistance is not usually significant. And since the resistance I mean our thermistor is, I can say orders higher than the lead resistance, so, resistance, lead resistance is not significant and as a result of which we do not require special wiring, that is what we have seen in the last lecture. So, this is the case that the RTD bridge connection that is what we have discussed in my last lecture, where we have seen to circumvent the problem associated with the lead resistance we have discussed different wiring connections.

But for this particular case, since the resistance of the thermistors is significantly a very large, so the lead error is not appreciable, and that is why we do not require any special wiring arrangement. And I can write this is very important that special wiring arrangements are not required.

(Refer Time Slide: 14:51)



So, this is the a few important points about this and lastly, we can say these thermistors are used rather I can say very often used, used as temperature compensation devices in electric circuit, in electric circuit, where consistent behaviour is required in variable ambient conditions. So, this is all about another RTD which is used to measure temperature and this is very sensitive, we can measure even when the change is of the order of 10 power minus 2 degree Celsius.

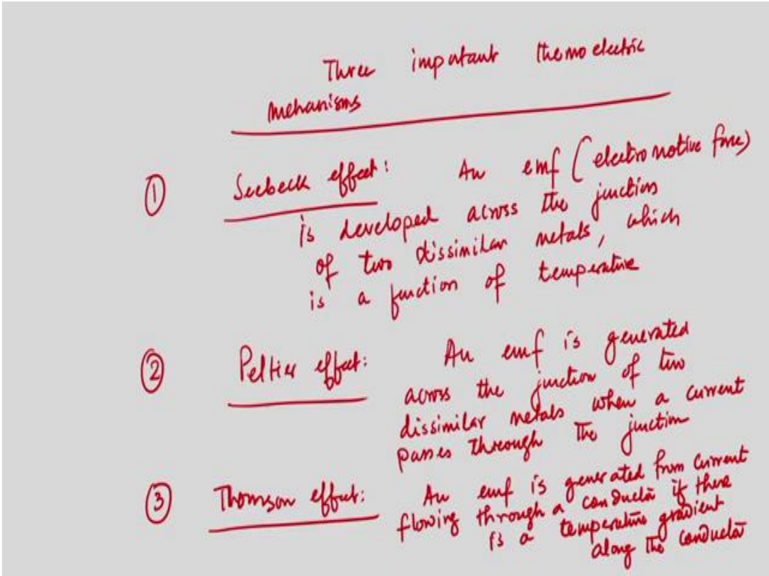
So next we will be discussing about another important resistance temperature detectors that is, is one of the important resistance temperature detectors that is thermocouples. We have read about this temperature measuring instrument in our school level, but just we will try to recapitulate what we have studied, and today we will see that again, when we will be discussing the thermocouples, we will see that thermocouples are essentially used to measure temperature. Of course, by exploiting the same effect that is change in resistance with temperature.

So, the thermocouples I am writing this is most common of the electrical effect temperature measurements. That means thermocouples RTD and in the last lecture, we have discussed about another important that is, thermocouples, RTDs and thermistors, all these instruments are using electrical effect to measure the temperature. We have discussed about measurement of temperature exploiting mechanical effects. And this module, I mean we are discussing wherein the electrical effect is electrical effects are used or I can say to measure the temperature.

Thermocouple is most common of the electrical effect temperature measurement, temperature measurements. And we know that the thermocouple is formed by connecting two dissimilar material, materials to be precise two dissimilar metal wires at a junction. And so, I am writing now the working principle, constructional feature. So, first, I will try to write the constructional features of the thermocouple. Then when the constructional feature we will try to learn the mechanism by how we can measure temperature using this thermocouple.

So, next one is at a junction, next one is that this joining produces a voltage across the other ends of the wires which is a function of junction temperature. So, this is the construction with feature. Thermocouple is formed, so, if you would like to fabricate then we need to connect two dissimilar materials, to be precise two dissimilar metal wires at a junction. And when you are connecting these two dissimilar metals at a junction, this produces a voltage across the other ends of the wires, which is a function of definitely junction temperature. So, now if we need to know the operational principle, the mechanism by how thermocouple measures temperature, we need to know three basic thermoelectric mechanisms.

(Refer Time Slide: 21:35)



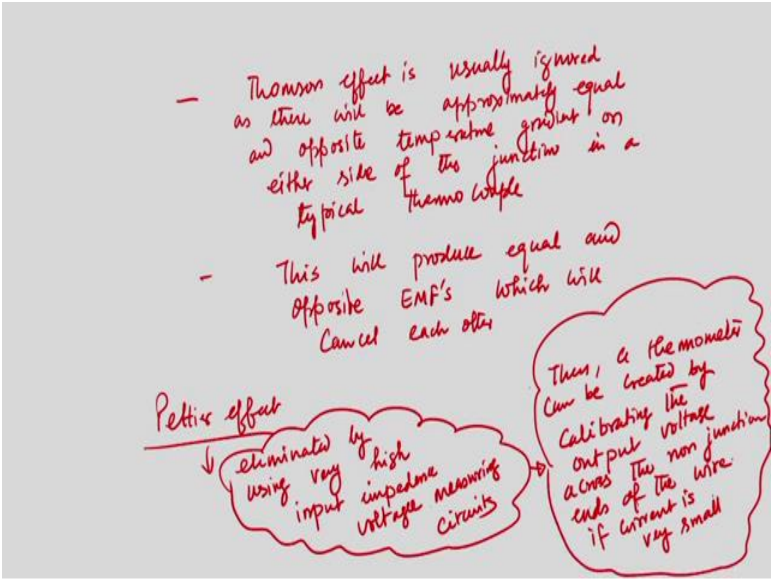
So, now you should know the three important thermoelectric mechanisms and these three important mechanisms are important to describe, to understand the operational principle of the thermocouple and of course, to know by how a thermocouple measures temperature. What are those three important effects? We have studied these effects in our 10 plus 2 level, you know, physics course, so but today just I am trying to recapitulate all those.

First is seeback, seeback effect. What is this? Although we have studied it, but again I am trying to discuss not in detail, but I am trying to write the what this seeback effect and why this effect is important to describe the mechanism of the thermocouple. So, what is a seeback effect? So that means an EMF that is electro, electromotive force is developed and EMF is developed across the junction of two dissimilar metals and this EMF is a function of temperature. That means, if we connect these two dissimilar material and electromotive force will be developed and of course, across the junction and the EMF which is being developed is a function of the temperature.

Next one is Peltier effect, what is this? An EMF is generated across the junction of two dissimilar metals when a current passes through the junction. That means, the first one seeback effect that an EMF is developed across the junction of two dissimilar metal, metals. And the EMF which is developed is a function of temperature. Peltier effect is telling that an EMF will be developed or is generate or will be generated across the junction of two dissimilar metals when a current passes through the junction.

And third one is also important to know that is Thompson effect, what is this? An EMF is generated from current flowing through a conductor if there is a temperature gradient along the conductor. So, this is the Thompson effect, we have studied many times, we know it that an EMF is generated from the current flowing through the conductor if there is a temperature gradient along the conductor. So, these three effects we have discussed and these three effects are important to know rather to understand the mechanism of the thermocouples.

(Refer Time Slide: 27:44)



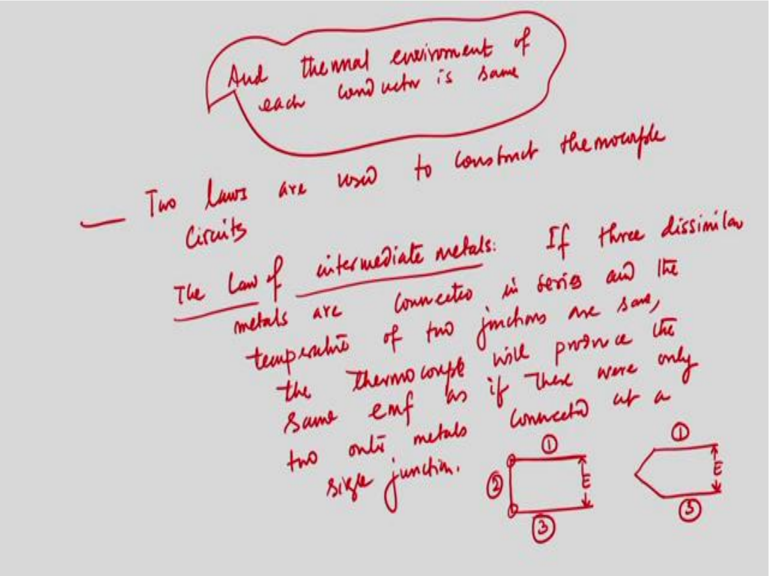
Say this, I can write this Thompson effect is not, rather I can say is easily ignored, ignored, as there will be approximately equal and opposite temperature gradient on either side of the junction in a typical thermocouple. So, this is very important that Thompson effects are easily, I mean Thompson effect is easily ignored as there will be equal as well as, opposite as long as approximately equal temperature gradient on either side of the junction in a typical thermocouple. So, this will produce equal and opposite EMF and which will cancel each other.

So, and I can write this will produce equal and opposite EMFs and rather I can say which will cancel each other, which will cancel each other. So, this is, that is why Thomson effect is easily ignored. Now, the Peltier effect can be eliminated by using very high input impedance voltage measuring circuits. That means we have only Peltier effect, Peltier effect, and of course seeback effect, seeback effect, but this Peltier effect can be eliminated. So, if we connect two dissimilar metals at a junction, there will be these three effects.

But the Thompson effects we ignore, we have written, rather we have discussed why it is ignored easily. Peltier effect also can be eliminated, why it can be eliminated? So, the Peltier effect can be eliminated by using very high input impedance voltage measuring circuits. So, this Peltier effect can be eliminated using very high input impedance voltage measuring circuits. I am writing here thus, a thermometer can be created by calibrating the output voltage across the non-junctions end of the wire, non-junction ends of the wire, if current is very small.

So, what we have discussed now? We have discussed systematically that the Peltier effect can be eliminated using very high input impedance voltage measuring circuit. That means, a thermometer can be created by calibrating the output voltage across the non-junction ends of the wire, if current is very small, not only that thermal environment is same, thermal environment of each conductor is same, is very small and so, this is one problem.

(Refer Time Slide: 33:51)

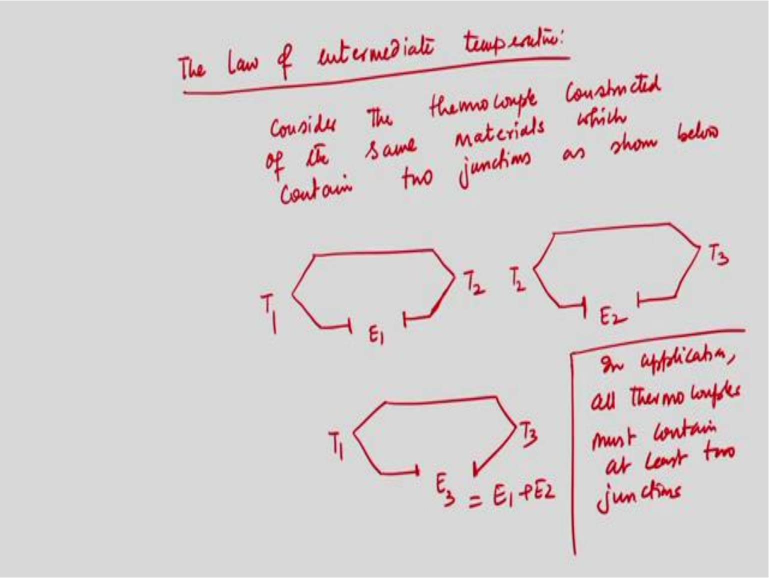


And thermal environment of each conductor is same. So, these two is satisfied then we can create a thermometer. So that means two laws are used to construct thermocouple circuits, that means two laws are used to construct a thermocouple circuit that is first one is known as the law of intermediate metals, what is that? If three dissimilar metals are connected in series and temperature of the two junctions are the same, temperature of two junctions are same, the thermocouple will produce the same EMF as if there were only two outer metals connected at a single junction.

So, this is the law of intermediate metals, if three dissimilar metals are connected in series and temperature of two junctions are same, the thermocouple will produce the same EMF as if there were only two outer metals connected at a single junction.

So, if we try to schematically describe this law then I can, so, over here, say this is material one, this material two and this is material three and this is E. So, this is material one, this is material two, this is material three. Then what I can do, this is material one and this is material three, this will be the connection. So, that means, the temperature of two junctions are same. So, if the temperature over here and temperature over here is same, then the thermocouple will produce same EMF as if they are only two outer metals corrected at a single junction. So, this is the case. So, this is the law of intermediate metals.

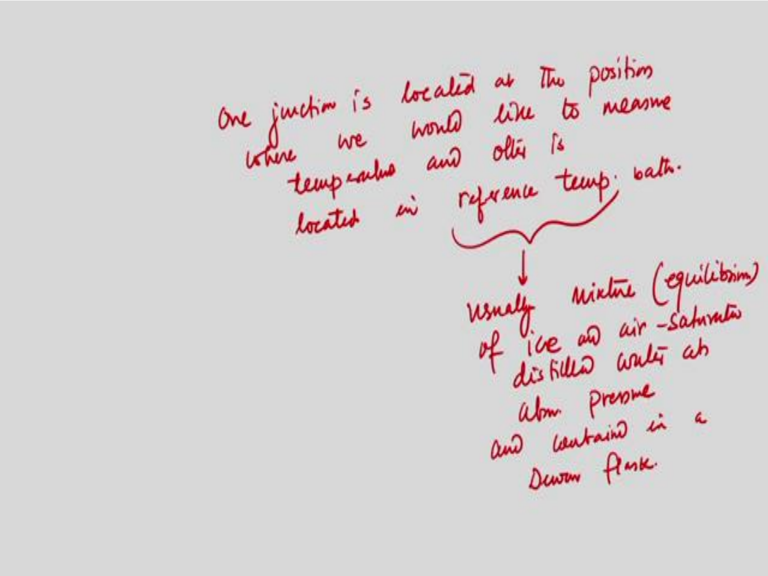
(Refer Time Slide: 38:04)

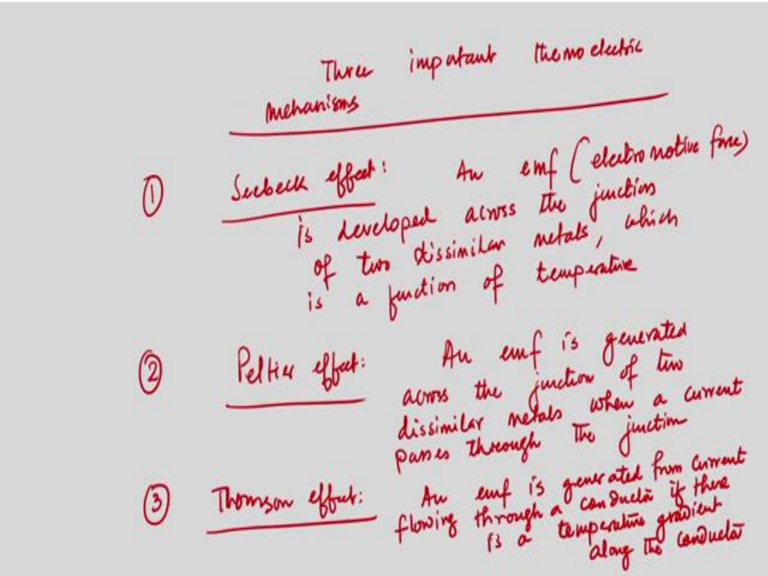


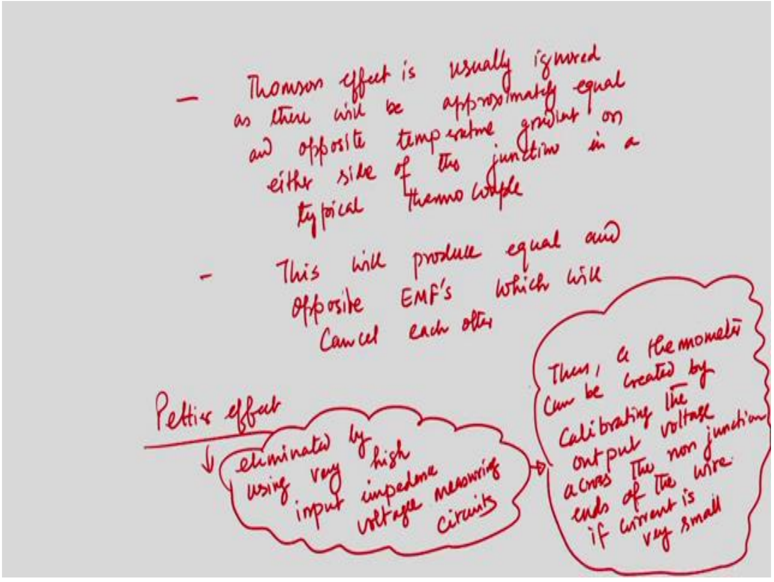
Another one is the law of intermediate temperatures, the law of intermediate temperature. What is this? So, I write now, if say consider the thermocouple constructed of the same material, which contain two junctions as shown below. So, we are considering the thermocouple which is constructed of the same materials, which contain two junctions as shown below. So, if I try to draw the schematic then we will find like this. So, this is T2, this is T1 and this is E1. So, the thermocouple is constructed of same materials, and other is, so, this is T2 and this is T3 and this is E2. Then if we T1 and T3, then this would be E3 that is nothing but E1 plus E2.

So, the thermocouples constructed of same materials, which contains two junctions as shown below. So, we have shown here three junction. So, this is guess, so, in application I am writing, in application what is found that all thermocouples. So, laws of intermediate temperature that means we have thermocouple constructed of same materials which contains junction as shown below. Then E3 if we now T1 and T2 same material, T2 and T3 and then if we thermocouple had T1 and T3, then the EMF that will be developed that will be equal to E1 plus E2. So, now in application all thermocouples must contain at least two junctions.

(Refer Time Slide: 41:54)







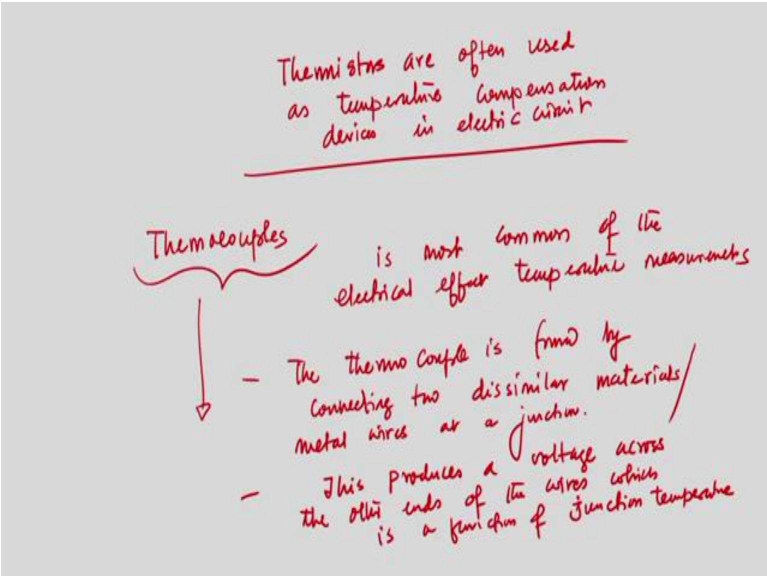
So, one junction is located at the position where we would like to measure temperature and other is located in reference temperature bath. And this reference temperature bath is usually a mixture, rather I can say equilibrium mixture, mixture of ice and air saturated distilled water at atmospheric pressure and contained in a flask, and contained in a Dewar flask. The mixture, so, what is done? One junction is located, of course that is what I was telling that should be located in a position, at the position where we would like to measure the temperature, while the other end will be located in the reference temperature bath and the reference temperature bath usually is the mixture of ice and air saturated distilled water and the temperature which will be produced is 0 degree Celsius.

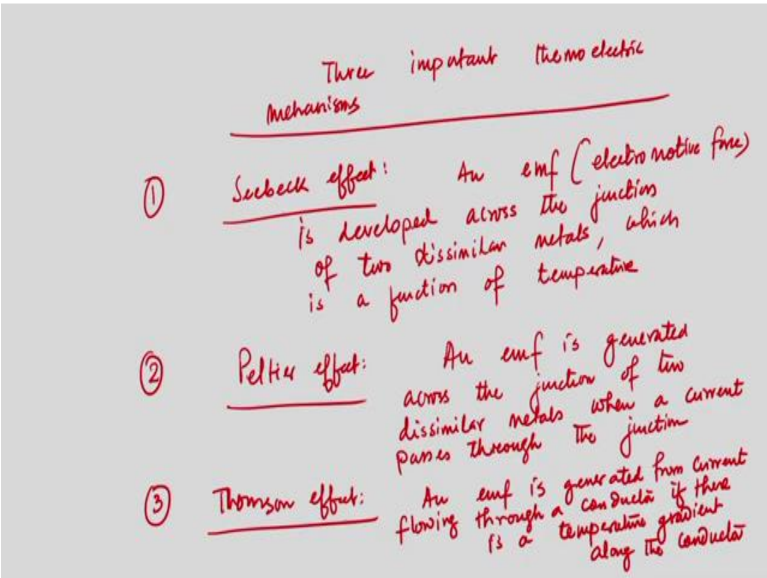
So, that means what we can say that this if we now go to the this constructional feature, that is the, this effect will produce equal and opposite I mean the, sorry, this is the important effect that an EMF will be developed across the junction of two dissimilar metals and the EMF which is developed that will be a function of temperature. If we now place the one end at the reference temperature bath, where we know the temperature is 0 degree Celsius temperature, while the other end is placed or connected in place where temperature we would like to measure.

So, now, the temperature I mean because of this temperature difference, we will have an EMF which is produced. If we can measure that EMF, that is what the electrical effect that is used, we can measure the temperature. As I said, Thompson effects is easily ignored and we have discussed why this effect is ignored, because this, the there will be approximately equal and opposite temperature gradient on either side of the junction. So, in a typical thermometer, so, this will produce equal and opposite EMFs and which will cancel each other.

Peltier effects are eliminated by using very high input impedance voltage measuring circuit. And also, we have written that we can have a thermometer which can be created by calibrating the output voltage across the non-junction ends of the wire and that is the working principle of the thermocouple to measure the temperature.

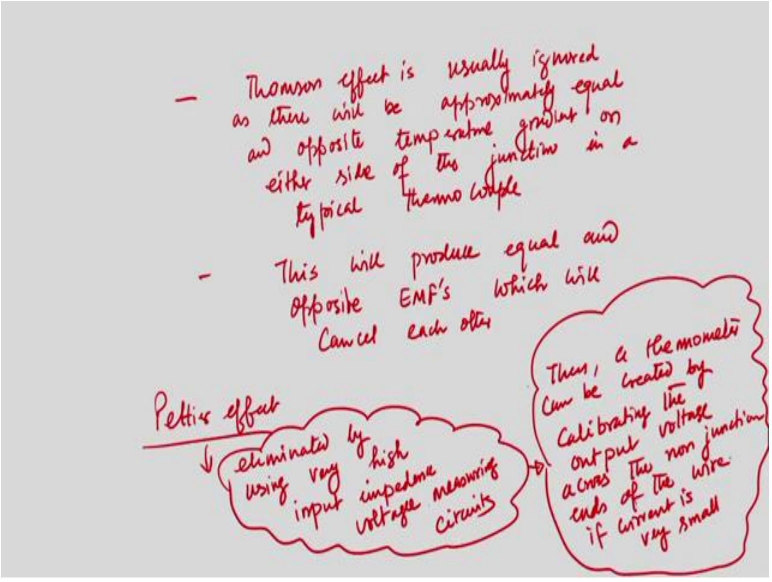
(Refer Time Slide: 46:19)

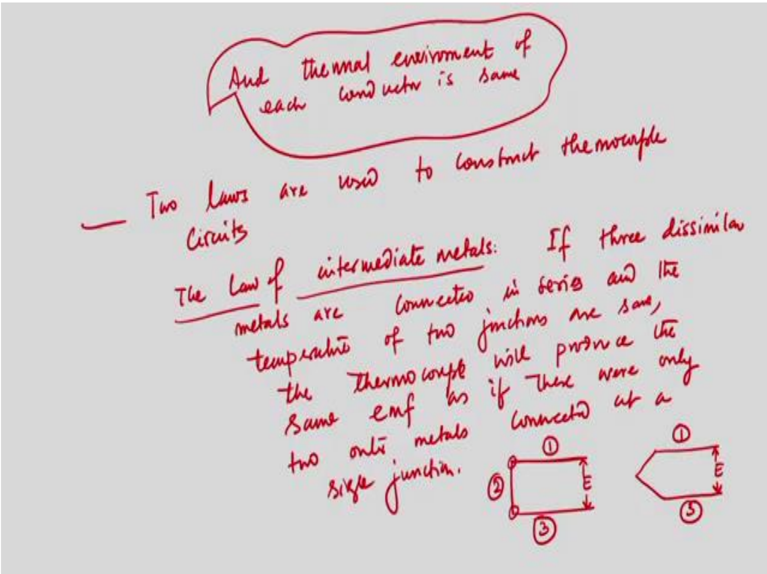


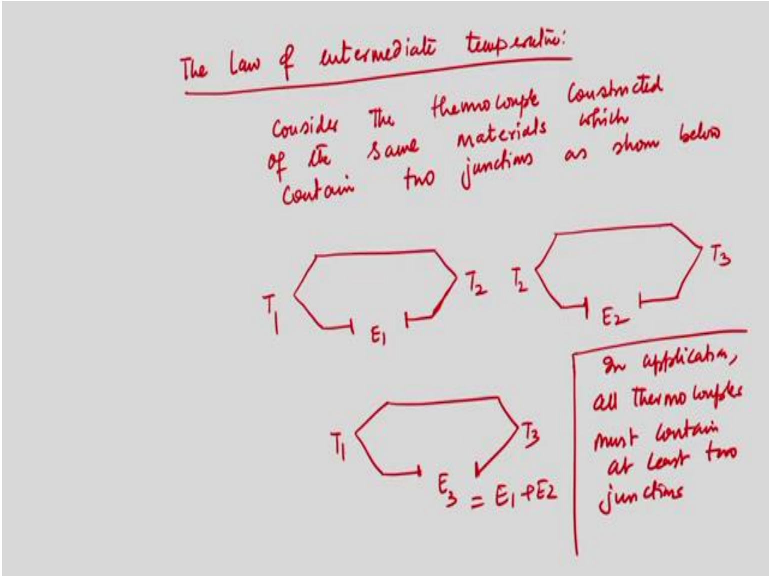


So, we have discussed about the thermocouples, constructional feature we have discussed that thermocouple is formed by connecting two dissimilar metals at a junction and this produce a voltage across the other ends of the wire, which is function nothing but the function of junction temperature. So, that means the voltage, so if we other ends of the wire and which is a function junction temperature. So, this is the effect we are using to measure the temperature. And to understand that, we need to know three important effects that is Seeback effect, Peltier effect and the Thompson effect. These three effects we have studied in our 10 plus 2 level, but today just I have recapitulated, we have tried to recapitulate all these three effects.

(Refer Time Slide: 47:12)







And we have discussed the Thompson effects is usually ignored, because the, I mean the EMF which is produced which will be equal and opposite and they will cancel each other. Peltier effects can be eliminated by considering high input impedance voltage measuring circuits. So, from these three effects we can say that as if a thermometer can be calibrated, thermometer can be created by calibrating the output voltage across the non-junction ends of the wire, if current is very small.

So, current is not very small, current is not very high and of course, the thermal environment is of each conductor is same. So, and from there, we have seen two laws which are used to construct the thermocouple circuit, the laws of intermediate methods and the laws of intermediate temperature. And we have seen that when we are placing any thermometer, a thermocouple which were involved, I can say in all the application.

Rather in most of the applications, thermocouples must, rather in all applications thermocouple used to measure temperature, I mean, we will have at least two junctions. That is obvious that all the thermocouples will have at least two junctions, rather in applications where it is used to measure the temperature. One junction is located at the position where you would like to measure the temperature, other junction is placed, is kept in a reference temperature bath where temperature is maintained at 0 degree Celsius temperature.

Now, if the other end temperature will be definitely higher than the temperature of the reference temperature, now, as I said this thermometer, so, as if other end is placed in a place where temperature is higher than the temperature of the reference, but of course and temperature of the measuring instrument. So, we can now have output voltage across the non-junctions ends and that voltage if we using these, by calibrating this voltage, we can measure the temperature.

So, to summarize today's discussion, we have discussed about another two important RTDs, I mean, measuring instrument, temperature measuring instrument which exploit the electrical effect. One is thermistors, we have discussed that again exploit the change in resistance of a material with a change in temperature in order to measure the temperature. And in the second one, we have discussed the thermocouples which is largely used in most of the applications and in most of the applications the thermocouples used we have two junctions.

And to understand, we have discussed about the constructional feature and then from the constructional feature, how we can measure temperature that is also we have discussed. And to know that, to understand that we need to know three important effects that we have discussed.

And finally, we have seen that essentially a thermometer can be created by calibrating the output voltage across the non-junction ends of the wire, if current is very small and also the thermometer environment of each conductor is same. And from there we have seen that two laws are used to construct the thermocouple circuits. One is the laws of intermediate metals and laws of intermediate temperature. So, with this, I stop my discussion today and we will continue our discussion in the next class. Thank you.