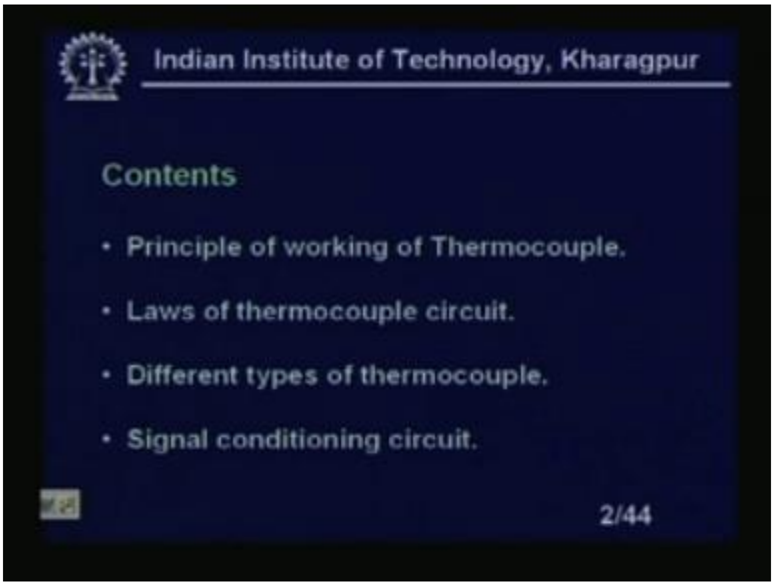
Industrial Instrumentation
Prof. Alok Barua
Department of Electrical Engineering
Indian Institute of Technology – Kharagpur

Lecture - 8
Thermocouples

Good afternoon! This is lesson 8 of Industrial Instrumentation. In this lesson, we will study the thermocouples. As you, know the thermocouple is one of the most widely used temperature sensors for the industry, because it is cheap and it is rugged as well as it is easily replaceable. So, making all those qualities, I mean actually lead to a very, I mean extensive use of this temperature sensors in almost all process industry like steel, petrochemicals, fertilizers, everywhere.

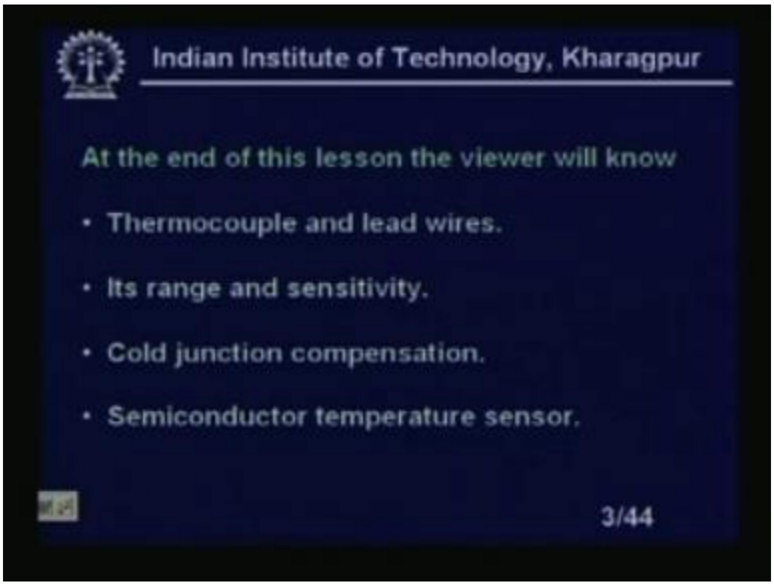
(Refer Slide Time: 1:36)



Now, the contents of this lesson will be the principle of working of thermocouple that means we will still go, go through the Seeback effect, the Peltier effect and the Thompson effect. Then, the laws of thermocouple circuit; we will, I mean explain why this law is necessary, because in many cases we will find the two, the tables for these thermocouples, not for all thermocouples, are available. Different types of thermocouples and their specifications - this is very important, because if we use any dissimilar metals, obviously we will get the output voltage, but people over the years, they have see that if we use a particular two different metals or the alloy or the alloy, you will find that the output will be large. That means sensitivity will be high as well as nonlinearity will be less. Also, the signal conditioning circuit which is to be discussed like cold junction compensation and all those things, although we will discuss, as well as we will discuss here the semiconductor temperature sensors.

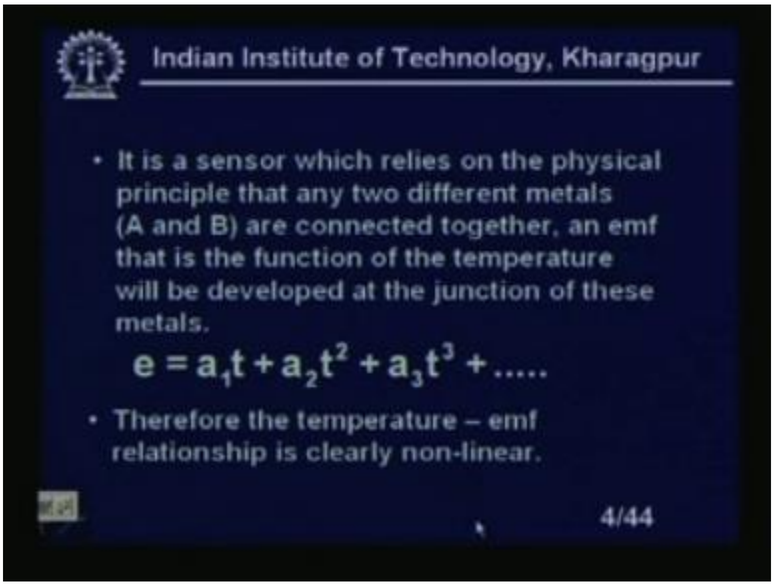
Even though it is a thermocouple circuit, but that semiconductor temperature sensor will be utilized to make the cold junction compensation. What is cold junction compensation? That will be explained after sometime.

(Refer Slide Time: 2:57)



At the end of this lesson, the viewer will know thermocouple and lead wires, its range, sensitivity, cold junction compensation as well as semiconductor temperature sensor that I told you.

(Refer Slide Time: 3:11)

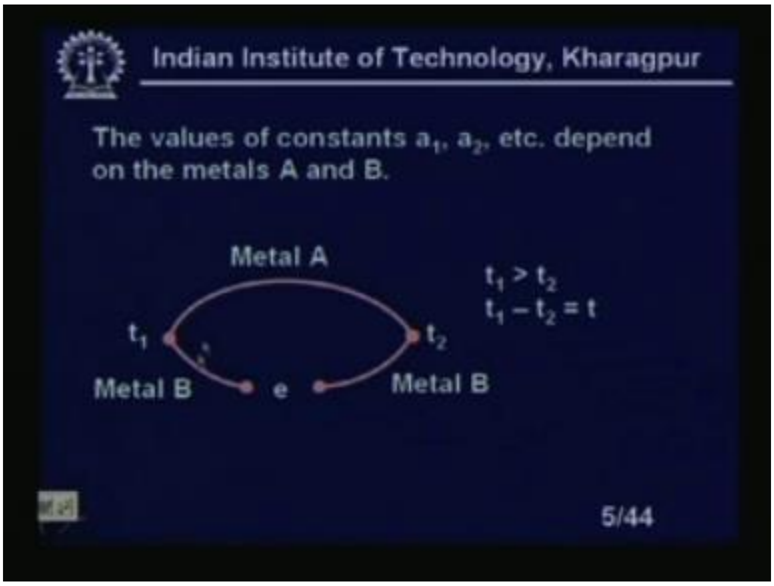


Now you see, it is a sensor which relies on the physical principle that any two different metals A and B are connected together, an emf that is the function of the temperature will be developed at the junction of these metals. In this expression, we will find e equal to a 1 t plus a 2 t square plus a 3 t cube plus so on, right? Therefore, we can see that this temperature emf relationship is clearly non-linear. We will see the, most of the thermocouples is actually represented, its voltage temperature relationship will be represented by 7 to 8 degrees, sometimes even 9 degree polynomial. That means it will go on a 1, a 2 up to a 9.

There are some thermocouples obviously, which will have, which will obviously have the second or third degree, it can be represented to second and third degree polynomial. Because you see this is a non-linear term, that is the reason the thermocouple, even though it is extensively used in industry, it is a, always that there is a thermocouple charge available. That means for each thermocouple you need to charge, so that if we get an unknown voltage, from looking at the chart you can find what is the, what is the temperature, what is the unknown temperature.

But, please note that this is not very, I mean, I mean it is very serious problem, because you see, nowadays you can have your, you can build your own ROM, where you can correlate between the temperature and the emf, so the non-linearity problem can be immediately solved.

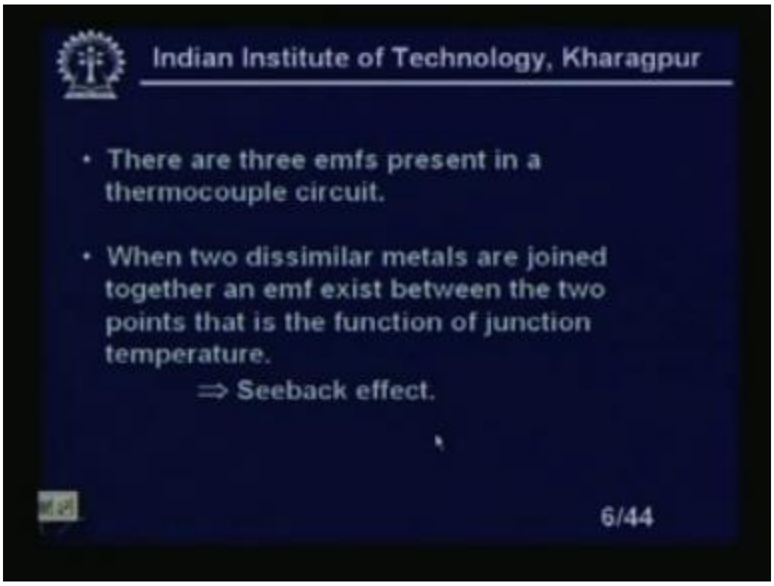
(Refer Slide Time: 4:51)



The values of the constant, this a 1, a 2, etc., depend on the metals A and B, right?
It does not depend on the temperature. It depends on the metals and it is a constant; we will find this is a constant. So far the metal is pure and the metal is the same type of metal you will use, you will get the same value of a and b, same value of a 1, a 2, a 3 and so on. I have, you see here we have metal A, we have metal B.

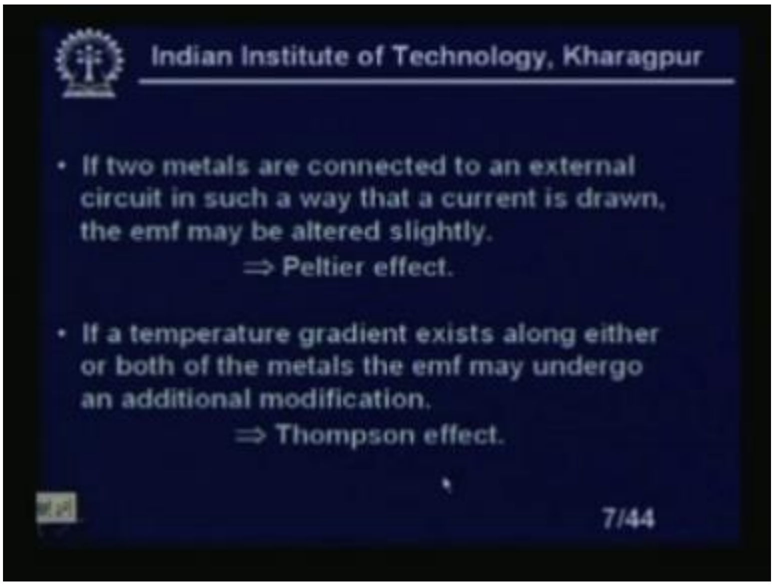
Now, t 1 is one junction temperature, t 2; these two junctions, two different junctions, metal A and metal B has a junction here, metal A and metal B junction here. t 1 is one temperature, t 2 is another temperature. t 1 is greater than t 2 and we are writing t 1 minus t 2 is equal to t, temperature difference, right? So, I will get a voltage e, right?

(Refer Slide Time: 5:42)



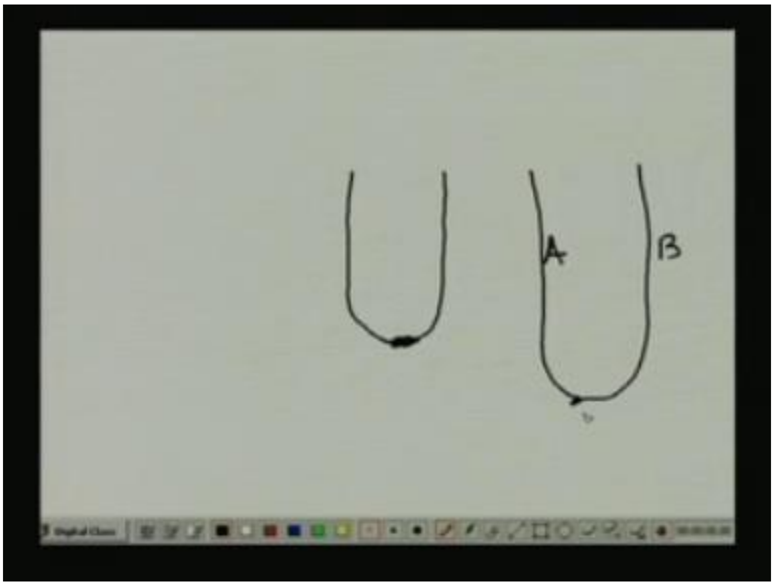
Now, there are three emf present in this thermocouple circuit, right? We have when two, Seeback effect when two dissimilar metals are joined together and emf exists between the two points that is the function of the junction temperature. This is the most prominent. Otherwise, we will find the other, like Peltier's and the Thompson of all, also will exist there, but it is not that prominent.

(Refer Slide Time: 6:08)



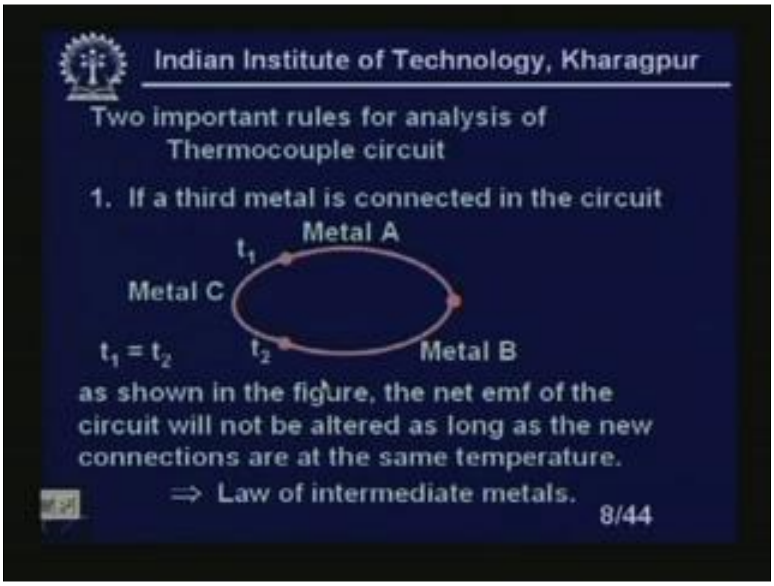
If two metals are connected to an external circuit in such a way that a current is drawn, the emf may be altered slightly, because if you can use a meter which is, has a very high input impedance, obviously it will not draw any current. But, if you try to measure the voltage, obviously it will draw some current. So, this will affect, it will, it will make a Peltier effect, so because the emf will be altered and if a temperature gradient exists along either or both of the thermocouple wires or metals. Every time we are saying metals, so ultimately you see these are the two different wires, right which is actually used to make the thermocouple.

(Refer Slide Time: 7:02)



It looks like, I mean you see that if I take a blank page two different wires, so there is a junction here, right? So, this will give you, I can draw it nicely, right, so this will make the thermocouples. Suppose this is your metal A, metal B, so this is our junction; please note, this is our junction. So, it is two different wires actually. Even though we are repeatedly telling it is metal, but these are two different wires. If I go back, so this is our Thompson effect, right.

(Refer Slide Time: 7:52)

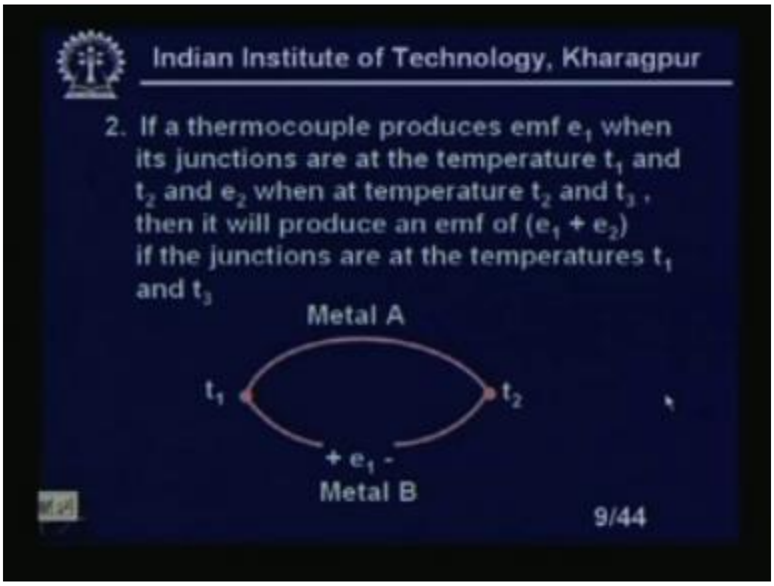


Now, two important rules for analysis of thermocouple circuit. There are two different laws, because you see that there are infinite number of, I mean combinations of the metals you can make. But obviously, you won't get the, I mean you can, you cannot make the thermocouple charge for each and every, I mean combinations of the two different metals. So, you have to use some laws of intermediate metals or laws of intermediate temperature also. These two laws are very important for solving the problems on thermocouples, which we will see later on, not obviously in this lesson, but in some other lesson.

At the end of this course, we will solve some problems. Then you will find that this type of, I mean laws of intermediate metals and intermediate temperatures is very important. If a third metal is connected in the circuit, metal C, you see the metal C is connected here, right? Metal C, this is the metal C which is connected. This is metal A, this is metal B, right? Whatever the temperature, it does not matter, so it has some different temperature, obviously. Here, I have some temperature. Here, you see that what you are able to see that this is the temperature t 1 and this is the temperature t 2. Now, we are taking the t 1 equal to t 2. If t 1 equal to t 2, it does not matter, our emf will remain same as before, right? Because it is two dissimilar metals, we have connected like this; two dissimilar metals, so these are junctions.

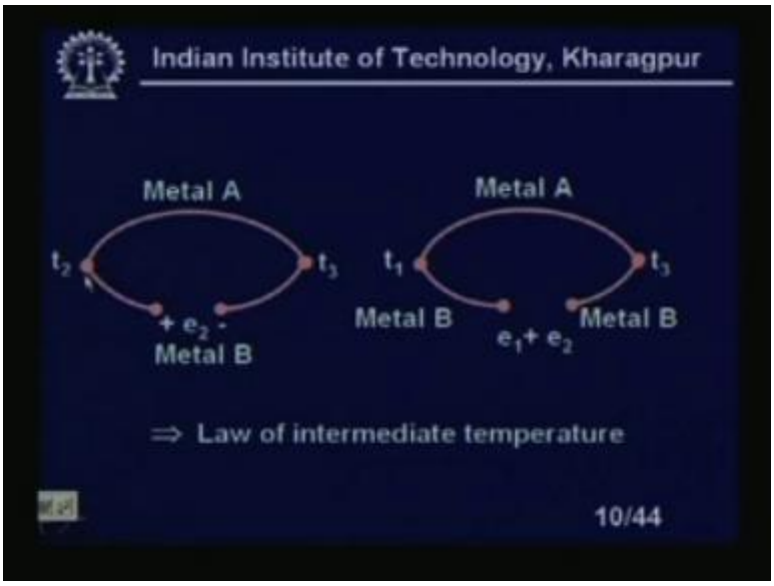
So, this is metal A, this is metal B, so I will get a current, right or you can show like this one. I will get a current, I will get a current and this is the, this junction will be … If it is, if I connect some other metal inside, so far this temperature remains same or emf also will remain the same. It won't be altered. As shown in the figure the, the net emf of the circuit will not be altered as long as the new connections are at the same temperature. These are law of intermediate metals, right?

(Refer Slide Time: 9:48)



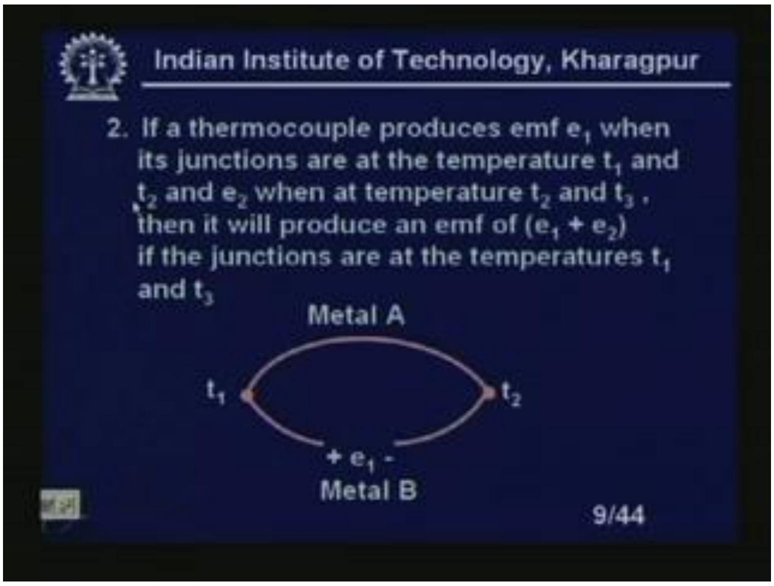
Now, if a thermocouple produces emf e 1, when its junctions are at the temperature t 1, you can see here, if a thermocouple produces emf e 1, when its junction at the temperature t 1 and t 2, these are the temperature at t 1 and t 2, so with two different temperature, this is a metal A, this is a metal B, this is a whole ……. I got a voltage e 1, right and e 2, let that, for that we have to go for next slide.

(Refer Slide Time: 10:18)



Metal e 2, sorry, temperature t 2 and t 3 will be there; same metal, metal A and metal B, I got a voltage e 2. Now, if I have the temperature of t 1 and t 3, two different, because previously it was two metals and two different junctions are t 1 and t 2. This t 1 and t 2, like this one, like that this one, so this is t 1, this is t 2, right and now we have connected another one, where this is t 2, this is t 3. Now, if now the temperature is t 1 and t 3, then the net voltage will be e 1 plus e 2, right? That is, I am, actually that is the intermediate temperature.

(Refer Slide Time: 11:08)



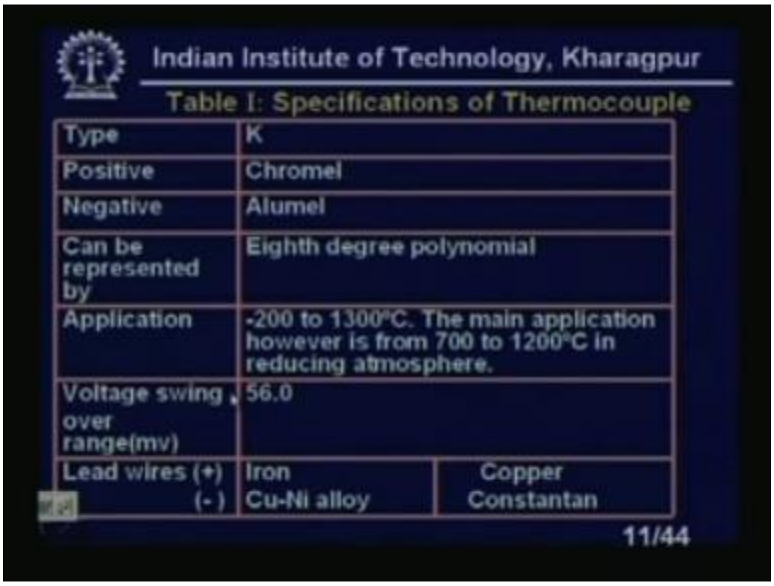
So, it is, if I go back to the previous slide, you can see, see here if a thermocouple produces emf e 1 and when its junctions are at the temperature t 1 and t 2 and e 2, when at the temperature t 2 and t 3, then it will produce an emf of e 1 plus e 2, if the junctions are at the temperature of t 1 and t 3. This is the law of intermediate temperature. These two laws, there are many laws, but these two laws will be very important for solving problems.

Now, now we will discuss some of the important, most important thermocouples which are used in industries. So, I call the specifications result, I mean retaining table 1, so this is important, because you know, you must know that you will, as I told you, there are, you can make any combinations of two different metals or alloy. It will give an output obviously, but that will not give you our desired purpose, because I need large sensitivity, I need good stability, I need inertness, I need easy replaceability.

These, all these materials, I mean so depending on that we will find there are several thermocouples and some of the thermocouples are very widely used in industry depending on the temperature range, depending on the, whether the atmosphere is oxidation, oxidizing atmosphere or the reducing atmosphere, so depending on the output voltage, you will get from the thermocouple. Please don't; thermocouple sensitivity is very poor. So, per degree centigrade change of temperature, you will get very small amount of voltage, right? So, you need signal processing for that.

So, it is not very that you will get a large voltage. Even though the voltage in the, are of the order of millivolt, but the sensitivity is very poor. These are all microvolt per degree centigrade, right? So, all these things are …, so large emf is always a desired property of a choosing thermocouple. At the same time, you will find that the linearity, stability, is all this very important. It should be inert like platinum-platinum rhodium; platinum-platinum rhodium you will find it has a lower sensitivity. It is around 10 to 12 microvolt per degree centigrade, but however you will find its advantage is its inertness, it does not react with any other, because it can work very nice in the, I mean in hostile environments also, right?

(Refer Slide Time: 13:21)

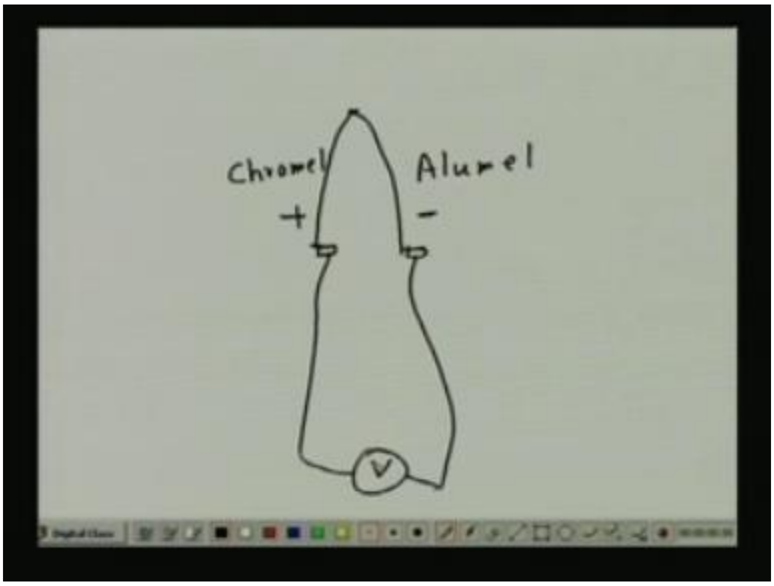


Type	K	
Positive	Chromel	
Negative	Alumel	
Can be represented by	Eighth degree polynomial	
Application	-200 to 1300°C. The main application however is from 700 to 1200°C in reducing atmosphere.	
Voltage swing over range(mv)	56.0	
Lead wires (+) (-)	Iron Cu-Ni alloy	Copper Constantan

So you see this is the and mostly, another important thing is in the industry they do not mention the thermocouple by name. They do not say chromel constantan, copper constantan and iron constantan, platinum- platinum rhodium, they do not call. Usually they give a type name. So, it is accepted for the, in the, in the any processing industry over the years. So, we also give the typical name or type, I will say of this particular thermocouple.

So, when you say that the type K that means you must know this is a chromel alumel thermocouple. You see here this is the type K. So, this means it is chromel alumel thermocouple. What is chromel? Chromel will be positive, Alumel will be negative. That means what does it mean? That means if I, if I take a blank page it will be more easy.

(Refer Slide Time: 14:07)



You see it is a, if I take like this one, this is our thermocouple, right? So, suppose this is chromel and this is alumel, so this will give you positive voltage, the positive side of the voltage. You see, thermocouple output is a pure DC voltage, right, so there should be, some probability will be there, so which is positive, this is negative. This is very important, while you will see in the lead wires, connections and all those things.

Now, please note another thing, while I will discuss the specifications, in the thermocouples you need the lead wires. The lead wires means that you see that this, how the thermocouples are very expensive, like platinum - platinum rhodium and you cannot, I mean you cannot install your instrument or voltmeter very near to the point of measurements. It might be far away, it might be 2 meters, might be 3 meters, even sometimes more, right?

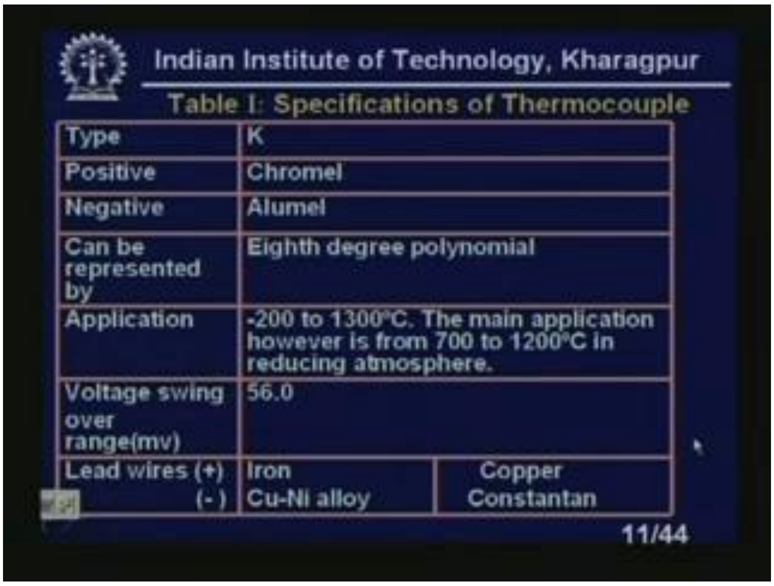
In that type of, say suppose I have a boiler which has temperatures of suppose 400 degree centigrade, I cannot install a meter very close to that, it is not possible also.
You have to transmit that signal over a long distance or even just if you have a monitoring instrument, it must be, you must measure the voltage. Suppose it is a ….., it is a, in the case of transmissionthat is different, but if it is simple monitoring instrument, it might measure the voltage. If I want to measure the voltage, I cannot install this meter, voltmeter very close to the wire or else the meter will be out of

order, meter will be damaged. So, there should be some wire, some distance of wire, suppose 2 meter, 3 meter.

Now, the problem is that we will find that if you have a, if you have a, I mean a thermocouple or platinum-platinum rhodium type, you cannot install a platinum-platinum rhodium lead wires, because it will, it will cost, it will increase the cost of the entire system, because the thermocouple is available like this one. So it is a, is a terminal will be available here, right, so you connect the lead wires there. Now, it will come to the, your voltmeter, so you will get a voltmeter, isn't it? So, you will connect a voltmeter there. So, this is certain distance here, this is certain distance we will find around, suppose like some few meters. So I need, so people has suggested some, a particular class of, for each thermocouple, thermocouple wires there is a particular type of lead wires also have been recommended.

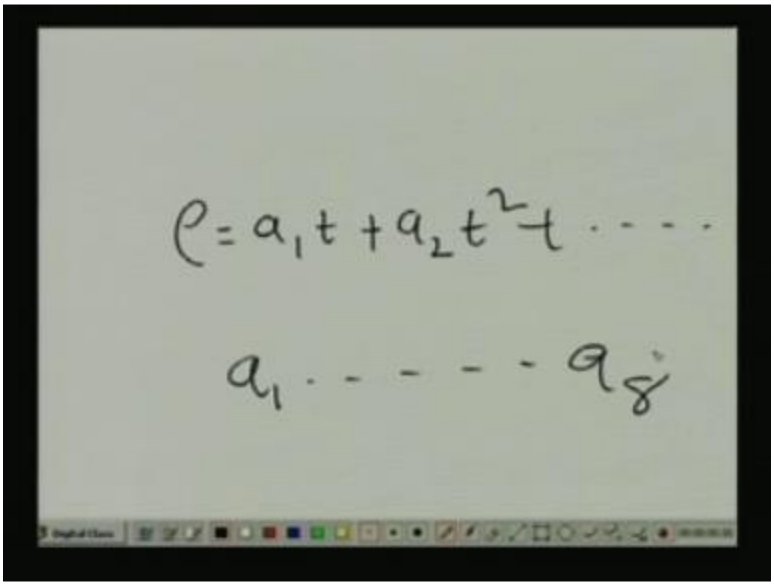
Now, you cannot change the lead wires. If you change the lead wires, you will find your calibration also will go wrong. You cannot the flip also the lead wires. I will show you what is that?

(Refer Slide Time: 17:06)



Now, you see here this is chromel alumel thermocouple and it can be represented by eighth degree polynomial. What is that?

(Refer Slide Time: 17:16)



We have already told thermocouples e equal to a 1 t plus a 2 t square, so on. So, in the case of these type of thermocouples, so a 1, 8, after that it will be insignificant the coefficients, so I can ignore that thing. So, it can be represented by the eighth degree polynomial, right?

(Refer Slide Time: 17:38)

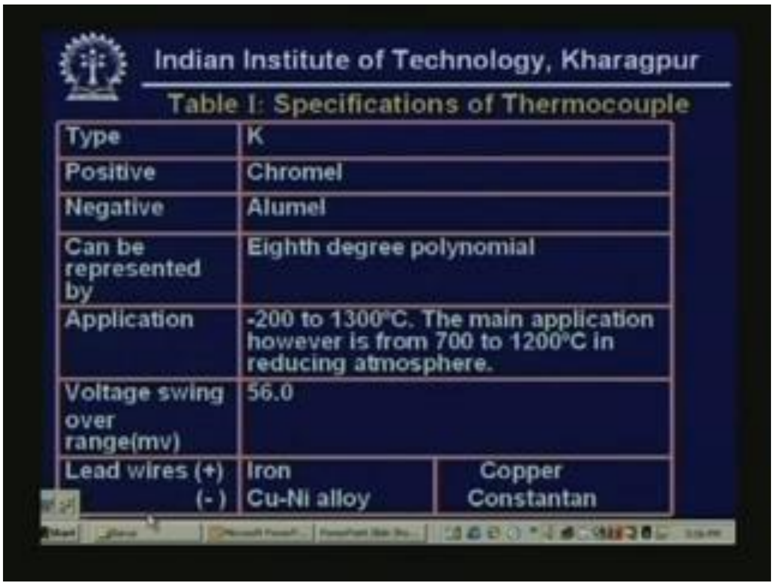


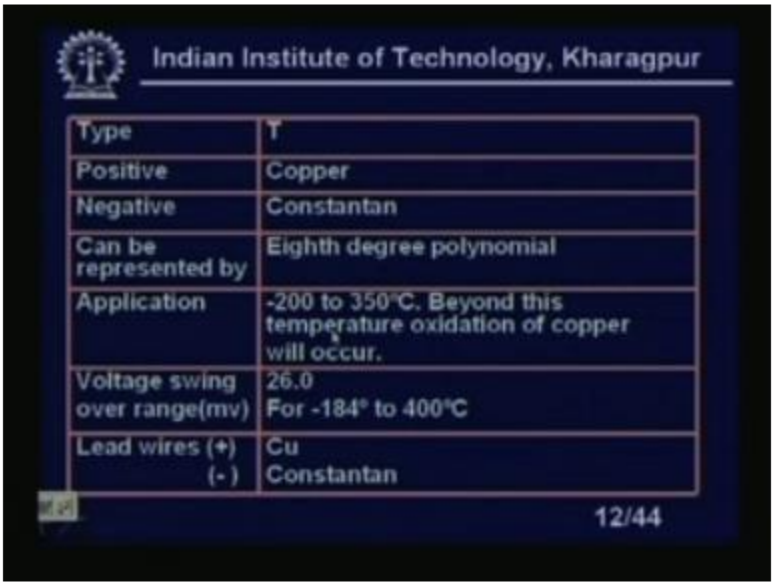
Table I: Specifications of Thermocouple

Type	K	
Positive	Chromel	
Negative	Alumel	
Can be represented by	Eighth degree polynomial	
Application	-200 to 1300°C. The main application however is from 700 to 1200°C in reducing atmosphere.	
Voltage swing over range(mv)	56.0	
Lead wires (+)	Iron	Copper
(-)	Cu-Ni alloy	Constantan

Its application is basically minus 200 degree centigrade to 1300 degree centigrade and the main application however is from 700 to 1200 degree centigrade in the reducing atmosphere. That is I told that it should be a, you must mention whether it is reducing or the oxidizing atmosphere. Total voltage swing that means for this change of temperature that means from minus 200 to 1300 degree centigrade, I will get a voltage swing of 56 millivolt. Now, typically you will see that the thermocouple, this sensitivity of the thermocouple, you will find it varies. That means per degree centigrade change of temperature how much the voltage change I will get at the output of thermocouple that is called the …. sensitivity of the thermocouple.

It varies from, suppose in the case of platinum - platinum rhodium, 10 to 12 microvolt to 60 microvolt per degree centigrade maximum, not more than that. Lead wires, see as I told you, you see it is recommended that means iron copper nickel alloy, you see here this iron copper nickel alloy that means in the lead wires iron should be connected to chromel and copper nickel alloy should be connected to the, to the alumel, right? Similarly, there are two options. You can use, instead of iron copper nickel alloy you can use copper constantan that mean copper will go to the Chromel, connected to the Chromel and constantan will be connected to the Alumel, right? So, for each thermocouple we will find this type of tables, this type of, I mean specifications on lead wires have been recommended. You see, this is t type of thermocouple, this is also quite widely used thermocouple.

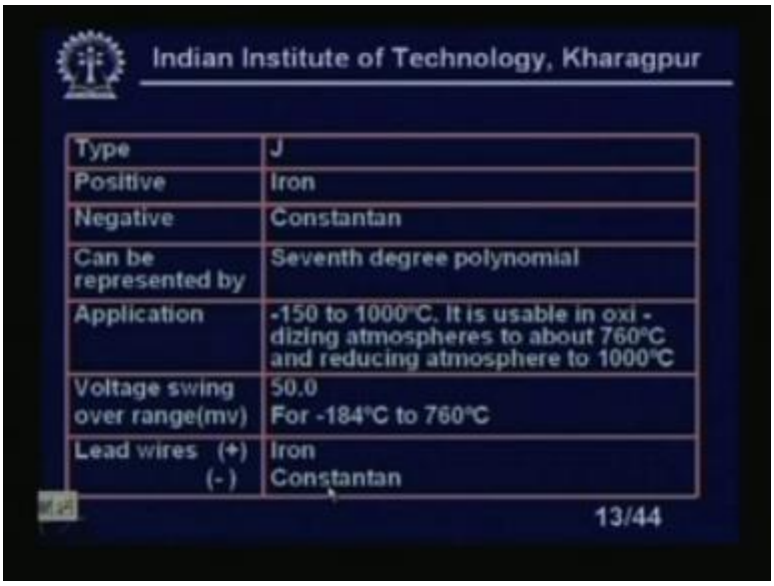
(Refer Slide Time: 19:17)



This is a copper constantan and copper is positive, constantan is negative. That means if you connect a voltmeter, positive side of the voltmeter should connect to the copper and negative side we will connect to the constantan. It can be represented by the eighth degree polynomial. Application - minus 200 to 350 degree C; beyond this temperature oxidation of the copper will occur, so we cannot use. Because, if you oxidize, the copper is oxidized, your entire calibrations will be no more valid, so you cannot use beyond 350 degree centigrade. We …., do not need to be, because there are many other thermocouples which can be used.

Now, voltage swing, you see the voltage swing we have calculated 26 millivolt for minus 184 degree centigrade to 400 degree. For these change that means around 584 degree centigrade, total change in the output voltage I will get 26 millivolt. You can see that how much is the sensitivity. Now, you see another interesting point in the case of, I mean low cost thermocouple you can use the same wire for the lead wires also, because you cannot get a cheaper wire than this one. Suppose the iron constantan, obviously we will use the iron constantan as a lead wires. Copper constantan, you cannot have a, have a cheaper than this. You have also, you should have the lead wires also of the copper constantan, right? So, copper should be connected to, copper constantan should be connected to constantan, there is no problem.

(Refer Slide Time: 20:33)

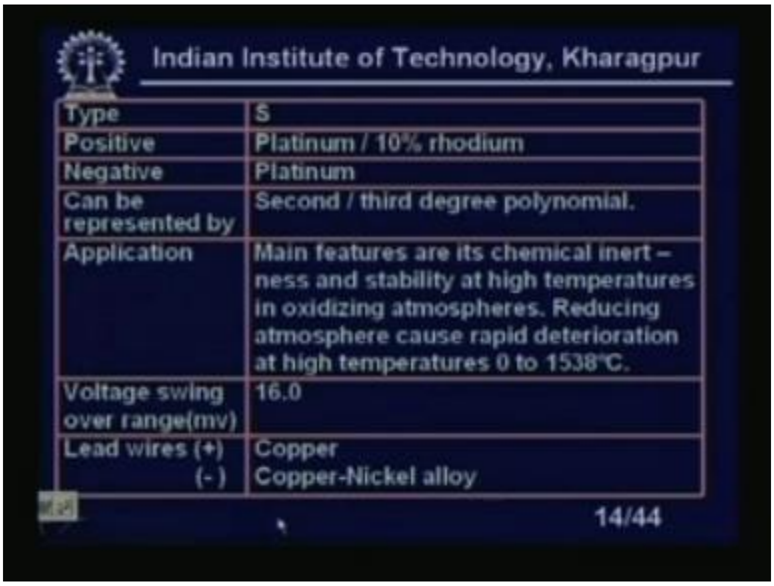


Type	J
Positive	Iron
Negative	Constantan
Can be represented by	Seventh degree polynomial
Application	-150 to 1000°C. It is usable in oxi - dizing atmospheres to about 760°C and reducing atmosphere to 1000°C
Voltage swing over range(mv)	50.0 For -184°C to 760°C
Lead wires (+) (-)	Iron Constantan

Now, J type of thermocouple, this is also quite cheap thermocouple, widely used thermocouple. The positive is iron, negative is constantan. It can be represented by the seventh degree polynomial. Application is minus 150 degree centigrade to 1000 degree. It is usable in the oxidizing atmospheres to about 760 degree centigrade and reducing atmosphere to 1000 degree centigrade. So, in which atmosphere we will use, depending on that you will choose the temperature range.

Voltage swing, you see, minus 184 degree centigrade to 760. So, you see, sensitivity is not much high, because the, here the range is quite high, I mean quite large, whereas in the previous case that copper constantan, the range is small. So, for minus 184 degree centigrade to 760 degree centigrade of voltage, temperature change of the hot junction, so I will get a change of 50 millivolt, right and lead wires, iron will be connected to iron positive and constantan will be connected to constantan.

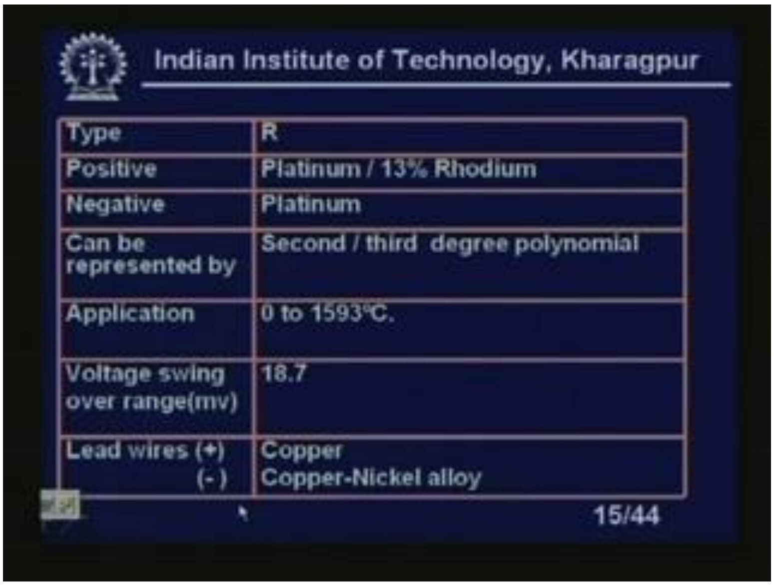
(Refer Slide Time: 21:35)



This, as I told you earlier, this is the platinum. These all are noble metals, obviously it is quite expensive. Now first one, the positive side is platinum 90% and 10% rhodium, right and negative is platinum, please note. It can be represented by a second and third degree polynomial, right? Now, main features of it is chemical inertness, stability at high temperatures and its oxidizing atmospheres, reducing atmospheres cause rapid deterioration and high temperatures and typical range is, I should, range is, should be zero to 1538 degree centigrade. Voltage swing is 16 millivolt.

Now, copper, I mean in the case of platinum-platinum rhodium, I mean thermocouple, you cannot use the same, it is expensive. We use copper and copper nickel alloy.

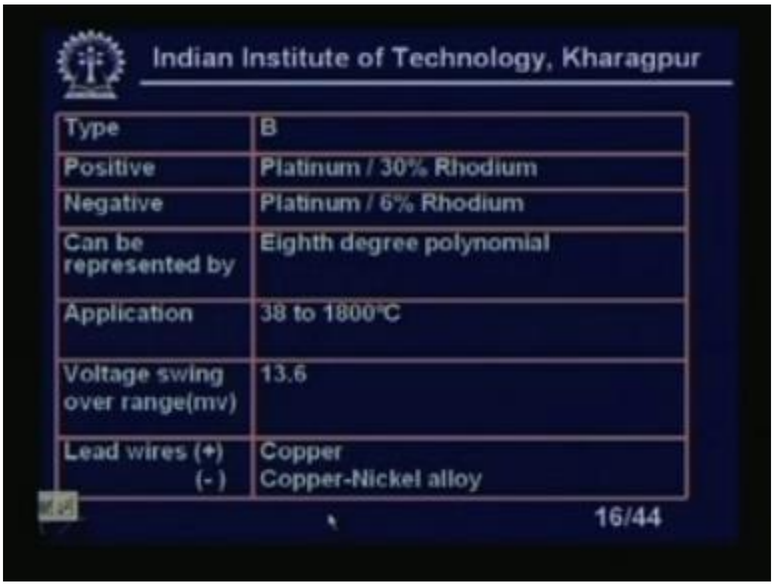
(Refer Slide Time: 22:26)



Type	R
Positive	Platinum / 13% Rhodium
Negative	Platinum
Can be represented by	Second / third degree polynomial
Application	0 to 1593°C.
Voltage swing over range(mv)	18.7
Lead wires (+) (-)	Copper Copper-Nickel alloy

This is also the platinum-platinum rhodium, but here the rhodium percentage has been increased. So, instead of 10% rhodium, because you, as you know rhodium is more expensive than the platinum. So, it is 87% platinum and 13% rhodium alloy, which will make the positive terminal and negative is the platinum; can be represented by second or third degree polynomial. Application is zero to 1593 degree centigrade. Voltage swing is 18.7 millivolt. So, copper should be connected to platinum rhodium, copper should be connected to platinum rhodium and negative copper nickel alloy should be connected to platinum. This will give …

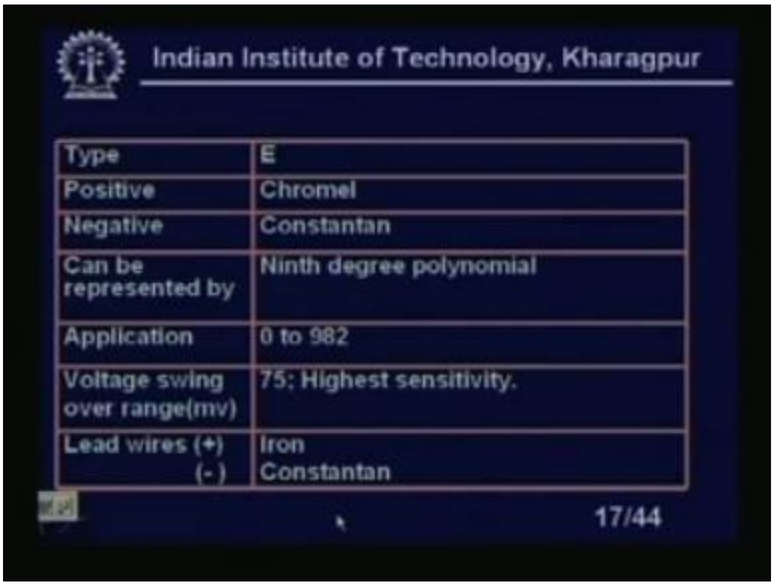
(Refer Slide Time: 23:07)



Now we have one more, two more rather. Platinum rhodium, this is one positive which is platinum 70%, 30% rhodium and platinum your 94%, 6% rhodium that will become negative. It can be represented by eighth degree polynomial. So, no, I mean advantage as we have in the case of 10% and 13% rhodium and application, 30, 38 to 1800 degree centigrade.

Now, you see application is almost same for all the, all this I mean, platinum - platinum rhodium thermo ….. That is the reason we have not represented and we have not written it, I mean repeatedly, but it is same, right? As it happened in the case of first, I mean slide of platinum-platinum rhodium thermocouple, so same the lead wires are copper-copper nickel alloy.

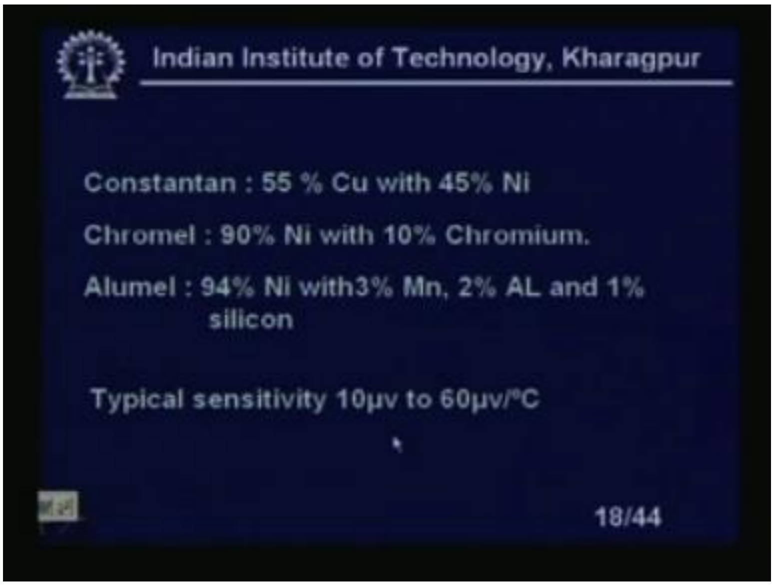
(Refer Slide Time: 23:54)



Type	E
Positive	Chromel
Negative	Constantan
Can be represented by	Ninth degree polynomial
Application	0 to 982
Voltage swing over range(mv)	75; Highest sensitivity.
Lead wires (+) (-)	Iron Constantan

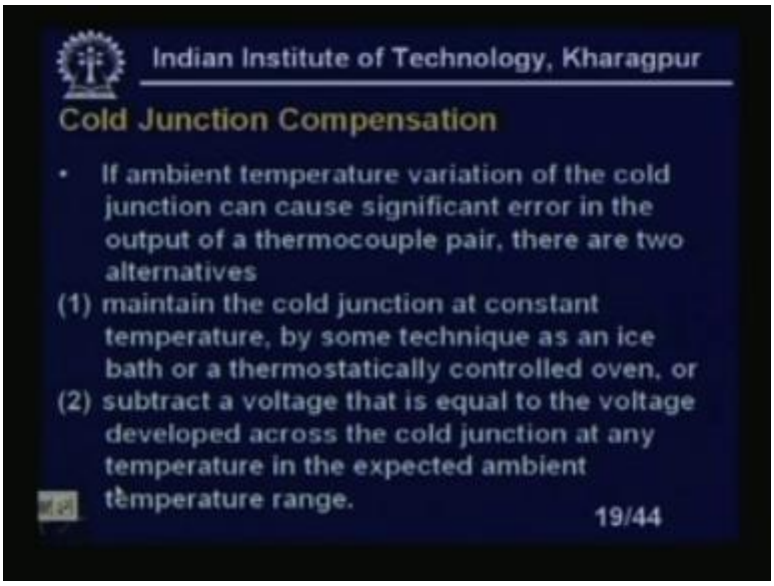
Now, E Chromel constantan; it is actually rather, I mean it is a newer thermocouple. It has a, its sensitivity is the highest, please note. It is very high, so it is zero to 980 degree, 82, but it is 9 degree polynomial and the 75 millivolt for this range, voltage swing we get will be 75 millivolt. So, it is quite high that inside it is more than around 65 microvolt per degree centigrade, highest in fact. So, iron constantan are the lead wires, so iron should be connected to the chromel and constantan should be connected to constantan, right?

(Refer slide Time: 24:32)



Now, what is constantan? Constantan is an alloy with 55% copper, 45% nickel. Chromel is 90% nickel, 10% chromium, Alumel is 94% nickel with 3% manganese, 2% aluminum and 1% silicon. Now, typical sensitivity is 10 microvolt to 60 microvolt that I told you earlier.

(Refer Slide Time: 24:51)



Now, cold junctions you see the, the thing is that in the cold junction that we see in the industry, you are, while you are, I mean making these, you, making a thermocouple, hot junction will be the measuring junctions and cold junction is supposed to be at zero degree centigrade, right? Well, I mean, if I had, suppose instead of zero degree centigrade if it is something higher, suppose 15 degree centigrade or 35 degree that is not a problem.

I can add, I am, accordingly add or subtract voltage from our actual voltage, so I can get the, I can get the voltage, actually the voltage for 35 degree centigrade of the hot junction, I mean the cold junction. But the problem is if the cold junction temperature varies it is not possible, is not it, because you, you cannot maintain the cold junction at a constant temperature. Summer will be one temperature, in the winter there will be some other temperature, in the monsoon there will be some other temperature of the cold junction. …… junction is something different, because you are measuring that particular temperature in which you are interested. So, but I am not interested to know the, there should not be any variations of the output voltage for the change of the temperature of the cold junction. So, I must have some sort of mechanism by which that I must correct the voltage output from the thermocouple, right? So, that is called the cold junction compensation of a thermocouple circuit.

If ambient temperature variation of the cold junction can cause significant errors in the output of a thermocouple pair, there are two alternatives, right? One is maintain the cold junction at a constant temperature by some technique as an ice bath or thermostatically controlled oven or subtract a voltage that is equal to the voltage developed across the cold junction at any temperature in the expected ambient temperature range, is not it? Because the and you see that the latter one, this one is much easier.

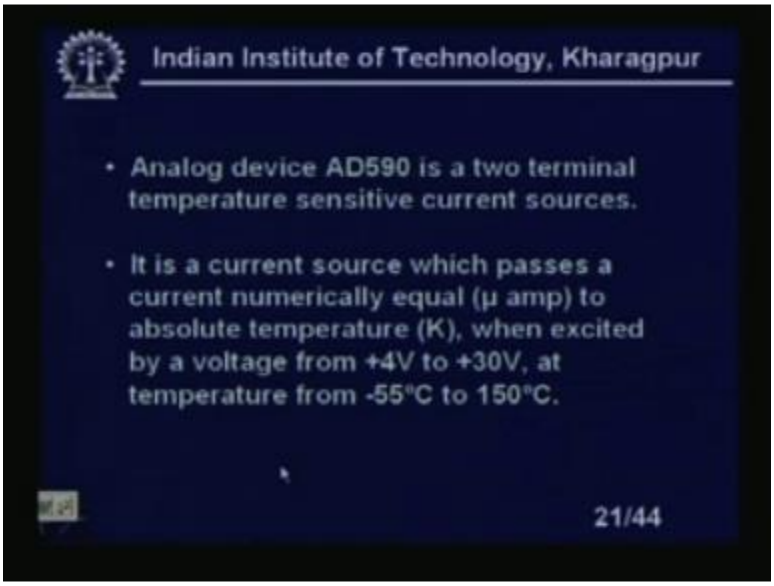
The number 2 is much more easier than the number 1, because you cannot have a industry, you cannot, if you have some 500 thermocouple you cannot have a 500 ice bath, I mean thermostatically controlled oven. So, we have to make this type of the … Some electronic circuit is necessary to make this; subtract the voltage is equal to the voltage developed across the cold junction at any temperature. So, it will automatically nullify the variations of the cold junction temperature.

Now, in this context, I must discuss one junction semiconductor sensor. Actually that is utilized, widely used for, in the industry for making the cold junction compensation. This is developed by the analog devices.

(Refer Slide Time: 27:30)

Now, you see, junction diodes are well suited for temperature measurement. The junction potential of the silicon transistor and the diodes changes at about 2.2 millivolt per degree centigrade over a wide range of temperature; 2.2 millivolt per degree centigrade. This property can be used as the basis of an inexpensive sensor having fast response. Even though it is used as a temperature sensor, but I will use this particular property of the semiconductor junction diode to make my cold junction compensation of thermocouple circuit.

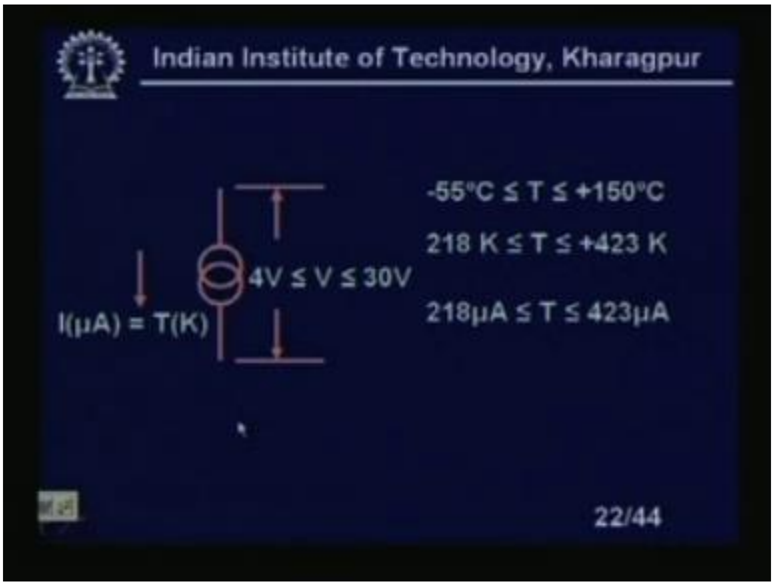
(Refer Slide Time: 28:00)



Now, analog device AD590 is a two terminal temperature sensitive current sources, right? It is a current source, which passes a current numerically equal to micro ampere to absolute temperature when excited by a voltage of 4 volt to 30 volt at temperature between minus 55 degree centigrade to 150 degree centigrade. You see, this is quite wide range and obviously I can measure a temperature suppose of 700 degree centigrade that is quite obvious, but obviously the cold junction, actually temperature does not vary between, it is a quite, it, it won't go below minus 55 degree centigrade, neither it will go above 150 degree. This is a quite wide range I should say.

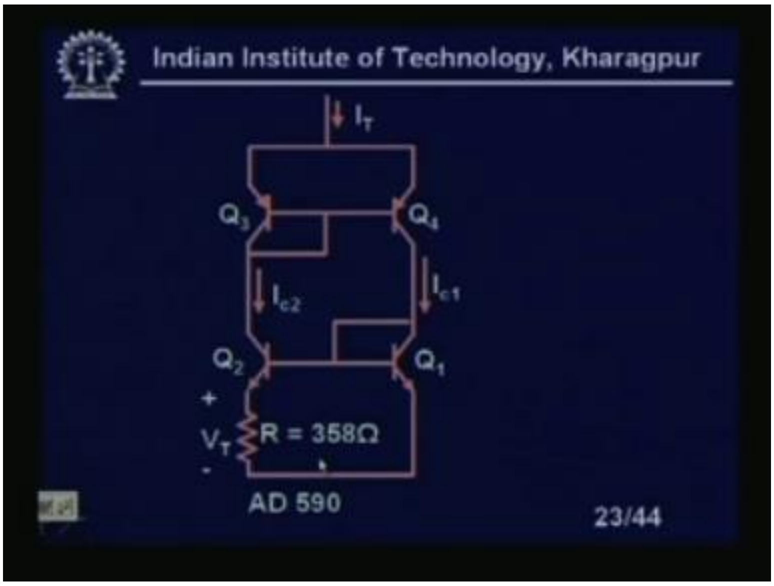
Usually what it happen in a tropical country that temperature will vary, suppose 7 to 8 degree centigrade which is very cold to suppose 40 degree centigrade, so with this temperature range, I can make very nice cold junction compensation by these devices.

(Refer Slide Time: 28:58)



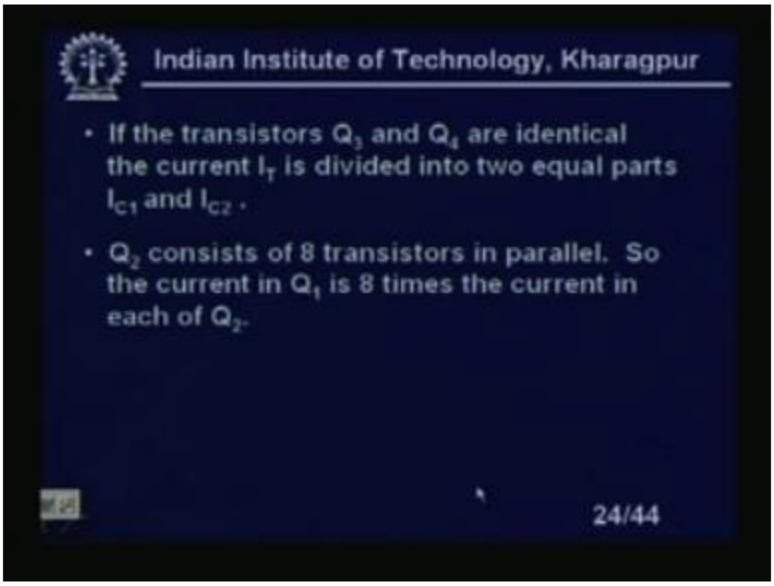
Now, this is the symbol of the constant current source. You see, its range is minus 55 degree centigrade to 150 degree centigrade, which is equivalent to 218 Kelvin to 423 Kelvin and it will give you, for this Kelvin temperature 218 micro ampere to 423 micro ampere. So, that means for 1 micro ampere, 1 Kelvin change, I will get 1 micro ampere change in the current.

(Refer Slide Time: 29:25)



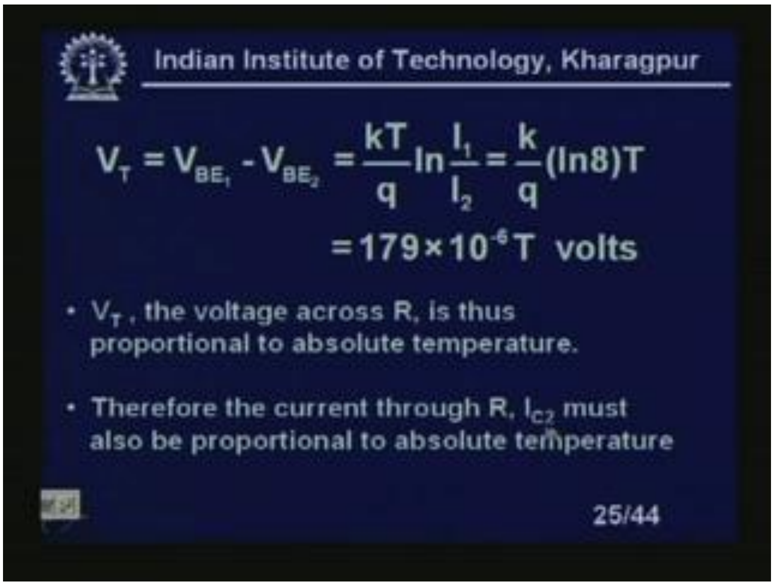
This is the simplified circuit of the cold … AD590. You see, the two transistors. Its, I T is divided in two half Q 3 Q 4 and Q 2 Q 1 and there is a resistance R. The details is coming next.

(Refer Slide Time: 29:36)



If the transistors Q 3 and Q 4 are identical, the current I T is divided into two equal parts I C1 and I C2. Let us go back, so we can go, so I C1 and I C2, it is going in the I C1 and I C2 dividing two equal parts I C1 and I C2. Now, Q 2 consists of 8 transistors in parallel, so the current in Q 1 is 8 times the current in each of Q 2, quite obvious. Again, the different between, difference between the VBE's that means the voltage emitted based emitted drop of the transistors, two transistors, of two identical transistors with different collector current is proportional to the absolute temperature.

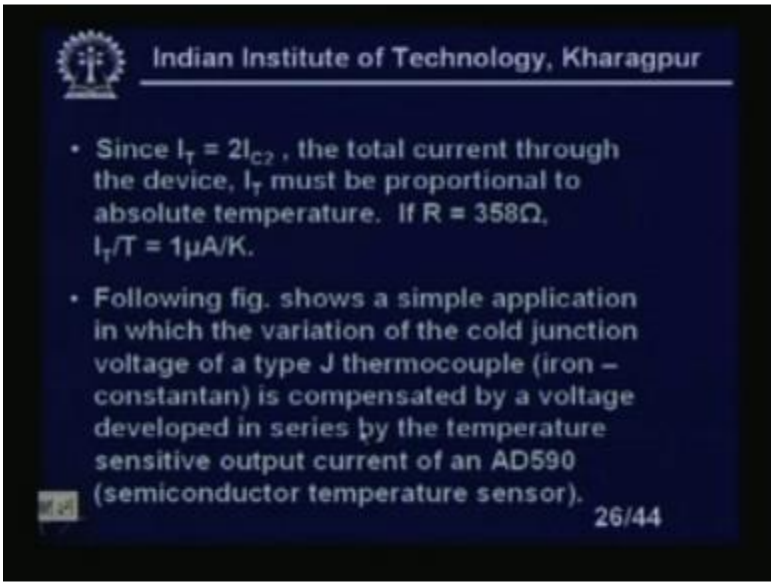
(Refer Slide Time: 30:26)



Now, I can write that V T equal to V BE1 minus V BE2 equal to that is base emitted drop of the two transistors that is kT by q natural log I 1 by I 2 equal to k by q. If you put all these, k, q, Boltzmann constants, then electronic charge, all, all the values, you can put natural log, because I 1 and I 2 its ratio is 8, so natural log 8 kT, so putting all the values of the Boltzmann constant and the electronic charge, I will ger 179 into 10 to the power minus 6 into T, T is the temperature into volts, right?

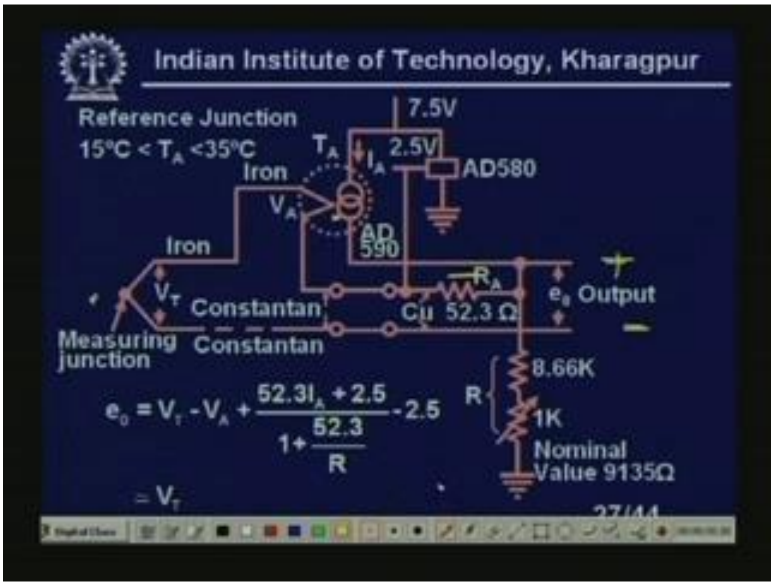
Now, the V T is the voltage across R and is thus proportional to the absolute temperature. Therefore, the current through R that means that resistance I C2 must also be proportional to the absolute temperature.

(Refer Slide Time: 31:11)



Since I T equal to 2I C2, the total current through the device I T must be proportional to the absolute temperature and if R equal to 358 ohms, then obviously what will happen? You will find the I T by T current for, by temperature if you want, micro ampere per Kelvin, right? So, using this property, so people are making, so following figure will show that a simple application in which the variation of the cold junction voltage of the type J thermocouple, iron constantan, is compensated by a voltage developed in series by the temperature sensitive output current AD590.

(Refer Slide Time: 31:48)



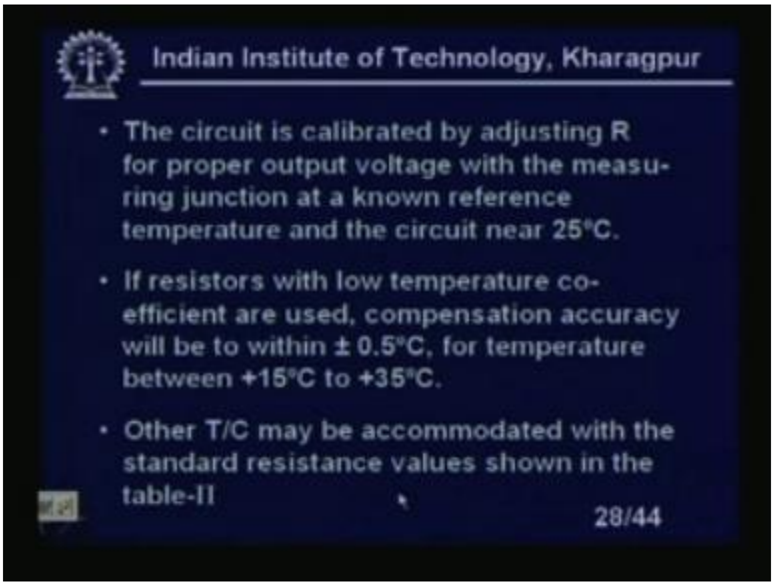
You see, this is our circuit. It is a very common circuit used in all laboratories, all industries. The temperature range is minus, I mean sorry, 15 degree centigrade to 350 degree centigrade. That means you see, this cold junction is very close to the AD590, right? This cold junction temperature may vary and this is the measuring junctions, this is my measuring junctions and this is my cold junctions. Let me take that means you see, this is our measuring junction and this is our cold junction. This is AD590 and it has a supply voltage seven point ….

These are just not, it is AD50. So, ….. analog device, but it will give us, I mean stabilized power supply of 2.5 volt. It is necessary and this is by the voltage. This iron, this is constantan, this is also constantan. This is iron constantan; this is, this is, actually the scheme is for the iron constantan thermocouple. This is true for any thermocouple. Only we will find, the value of R A will change. As the thermocouple changes, this value of R A will change, right? Otherwise, it is the same circuit for everywhere that means this 52.3 will be different for different thermocouples.

I will show you the different charts that means this AD590, so this will give you current. So, obviously this will be my output voltage. So, this voltage will be, even we can show you experimentally, if I change this cold junction compensation temperature, cold junction temperature, this is the cold junction, because this is our cold junction, this is AD590, even though, I mean if the measuring junction, if measuring junction does not change, temperature does not change, we will see, we will see that the output voltage will not change, right? Fine.

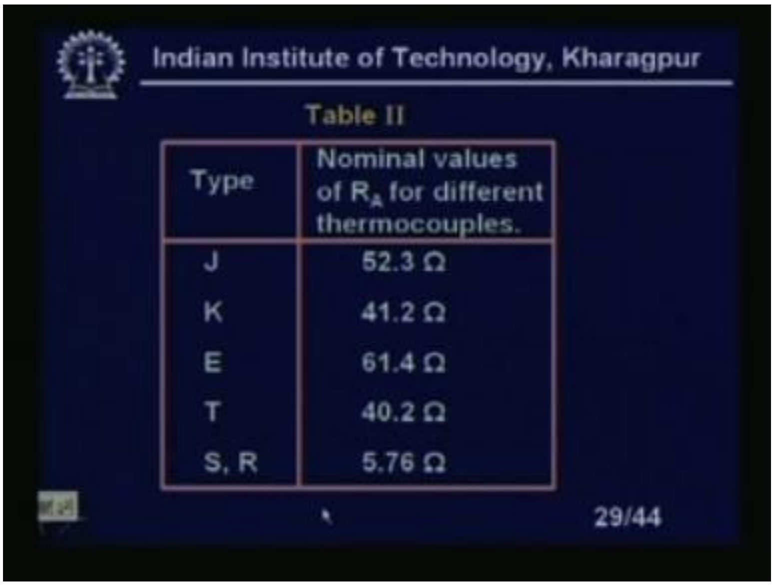
So, this is our, now we will see that it is, output voltage is equal to V T. You see, it is independent of the temperature of the variations here. If the variation, it will, I A will take care of that, because if the temperature increases I will increase, automatically the voltage will be subtracted, so the V T will be there. So the, that is I want, actually my output voltage should be equal to V T.

(Refer Slide Time: 34:09)



The circuit is calibrated by adjusting R for proper output voltage with the measuring junction at a known reference, because you see that you have a resistance R. You can see here, so this is our resistance R. So, for a known resistance with temperature the ….. is calibrated by calibrating this R value. Now, once it is calibrated, so we can go ahead; so, voltage with the measuring junctions at a known reference temperature and the circuit near 25 degree centigrade. If the resistors with low temperature coefficient is used, the compensation accuracy will be within 0.5 degree centigrade for temperature between plus 15 degree centigrade to 35 degree centigrade. Other thermocouple may be accommodated with the standard resistance values shown in the table II. You see this is the table II.

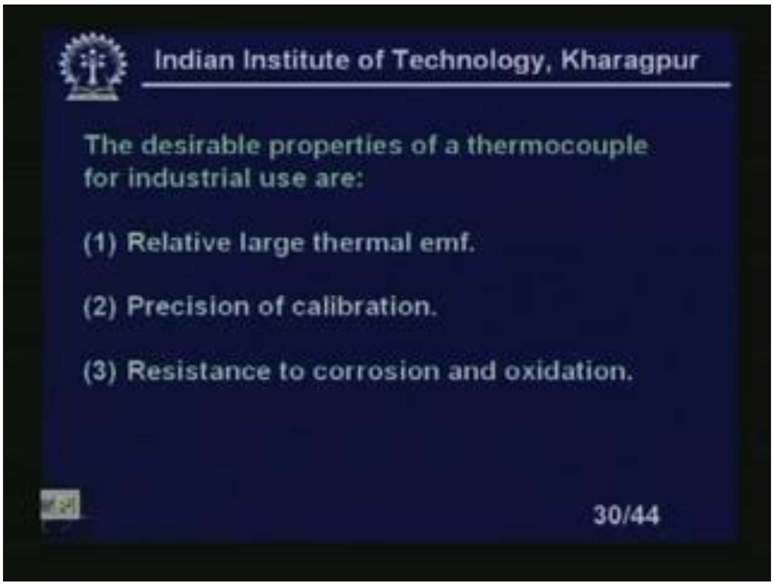
(Refer Slide Time: 35:01)



We will find that, as I said that the resistance R A, so in the case of J type of thermocouple it is 52.3 ohm. For K, it is 41.2 ohm and E, 61.4. Every time it is, obviously you have to calibrate it by, by, with the known temperature using that particular, the resistance R. But, this is the fixed resistance or whenever we will change the thermocouples, you, this resistance R A, R subscript A must be changed also.

Already we have shown in the circuits of the, for J type of thermocouple with 52.3 ohm, we have given the chart here, right? So, S, R it is same 5.6 ohm.

(Refer Slide Time: 35:38)



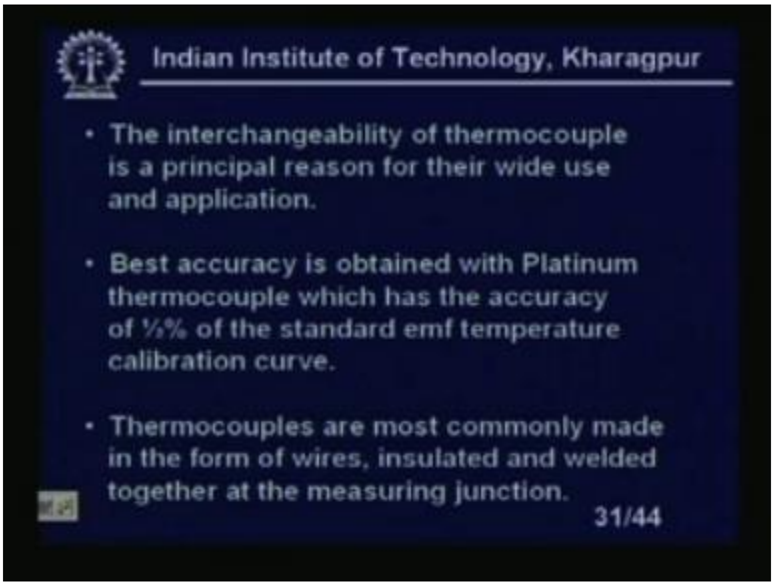
Now, desirable properties of a thermocouple, please note it is for industrial uses. They are relative large, the emf; everybody wants the large thermal emf. Especially the change is more important, because you can amplify the signal. That is not a very problem, you can amplify the signal the dc signal, but the change, sensitivity should be high. Precision of calibration - you see, in the industry it is not possible, I mean usually what you will, you see, the calibration you cannot afford to have the calibrations every time.

What you will do? That you will take a large length of wire, suppose copper constantan, Chromel Alumel or platinum-platinum rhodium, what the harm can happen? Your, suppose for some, due to some contamination the junction thermocouple has been, calibration has gone wrong or suppose due to the, I mean welding I mean due to the problem in the welding, this thermocouples has ….., so you just, what will you do? You will replace this thermocouple. So far you take from the same pieces of wire, you do not have to recalibrate the instrument. That is the great advantage of this type of thermocouple.

If I take a wire, large length of, suppose if I take two wires of the platinum-platinum rhodium 10 meter, another platinum of 10 meter, we calibrate it, fine. Once you calibrate, we make our calibration chart, right? What we will do? We will use a small portion of this, suppose 30 centimeter portions of we will cut from each of the, each of the wire, then we will make our own thermocouple. If it is damaged, then we will just take the same wire, again from the, that the same largely, that that 10 meter wire, again we will make up our own thermocouple, is not it? So, I do not have to recalibrate the instrument; it is a great advantage.

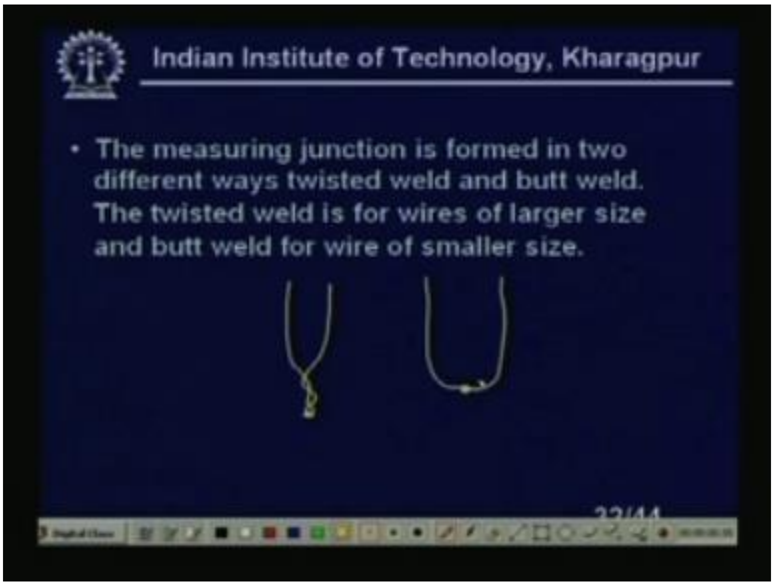
Resistance to corrosion and oxidation, this is very difficult, because it is not, mostly we will find this resistance to corrosion and oxidation is not available. You will have to use the thermocouple in a covering material, which is called an industry sheath.

(Refer Slide Time: 37:43)



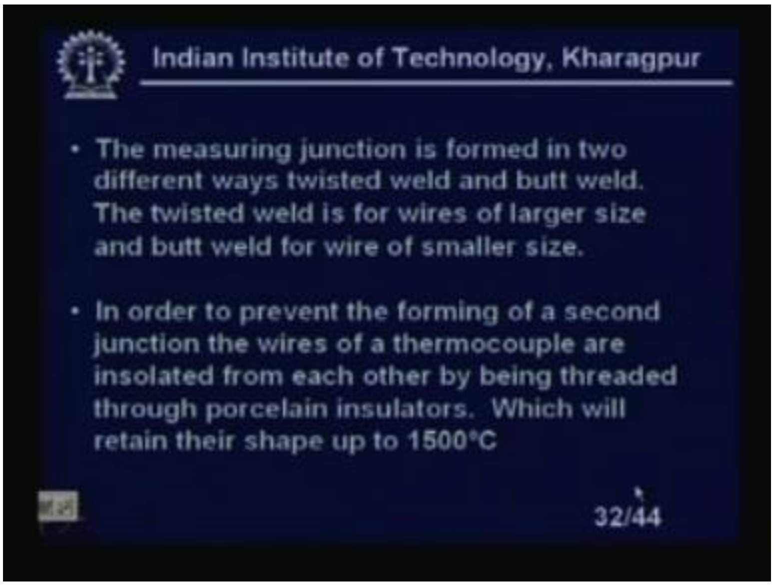
The interchangeability of the thermocouple is a principle reason for their wide use and application. Best accuracy is obtained with the platinum thermocouple, which has the accuracy of half percent of the temperature emf calibration curve. Thermocouples are most commonly made in the form of wires insulated and welded together at the measuring junction. As I told you, there are two types of weld. A twisted weld and a butt weld. What is that?

(Refer Slide Time: 38:14)



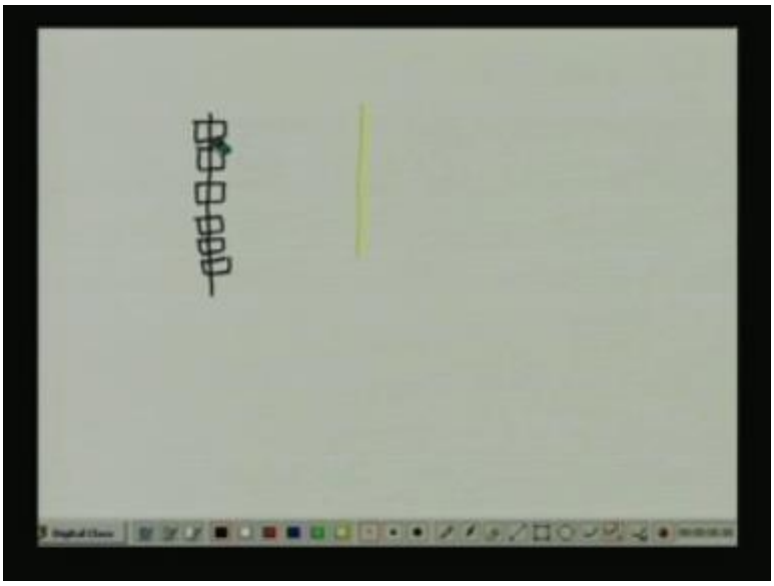
You see here that your twisted weld means you will get a wire, you will get a wire, you will get a wire. Now, this portion is welded or you can have a butt weld. This is a twisted weld. You can have a butt weld, which will look like this. This is a butt weld. So, there are two types of weld available. If the short the twisted weld is for wire, so larger size and butt weld is for the smaller size. If the wire is small, so you can have a butt weld, even they have a twist. Obviously, twisted weld will have more strength, anyway.

(Refer Slide Time: 39:11)



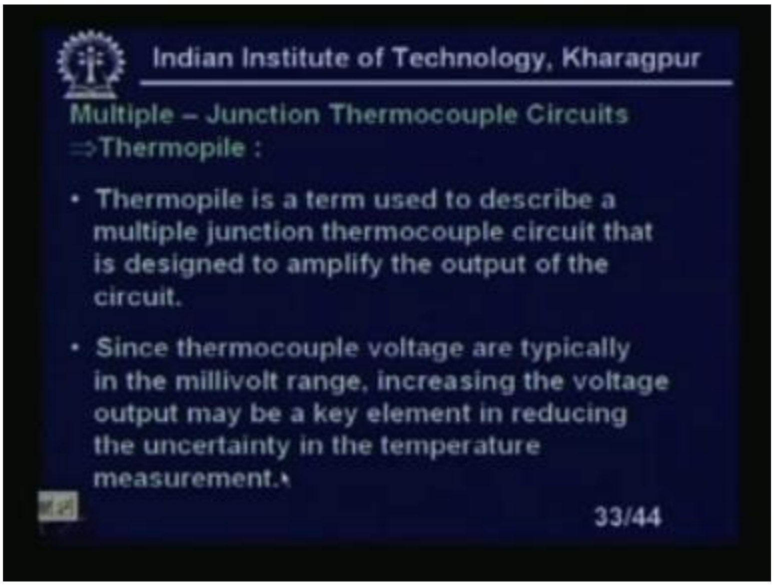
In order to prevent the forming of a second junction, the wires of a thermocouple are insulated from each other by being threaded through the porcelain insulator, which will retain their shape up to 1500 degree centigrade, because the two wires might get connected. If it is connected, you will get a second junction that is undesirable, so what we will do? We will pass through the insulator and it can retain a shape of 1000, up to temperature of 1500 degree centigrade. It looks like this.

(Refer Slide Time: 39:38)



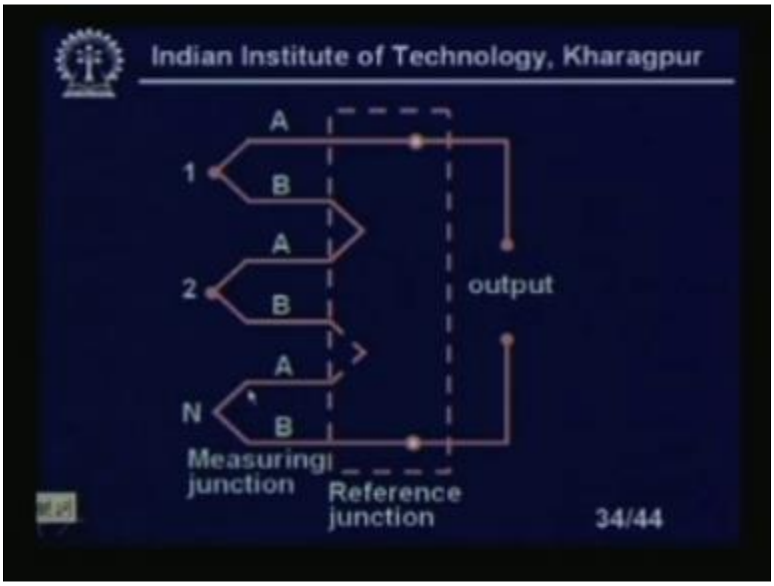
That means you see that it will, what it will happen? You will find that wires are there, sorry, see you will get a wire and a porcelain will be, it is passed through the porcelain. That means it looks like, it looks like, sorry, here it will be there; now it looks like this, right? So, you will get two different wires and a porcelain separator will be there. So, you can make your own thermocouple like this one.

(Refer Slide Time: 40:46)



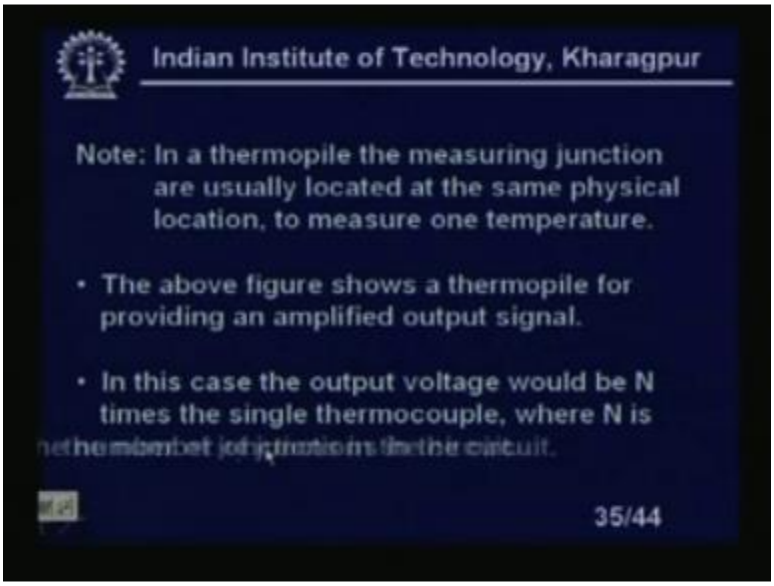
Now, multiple junction thermo, thermocouple output is very small, as I told you. You will find sometimes it is necessary to make the multiple junction circuit, right? So, multiple junction thermocouple is called thermopile. Thermopile is a term used to describe multiple junction thermocouple that is designed to amplify the output of the circuit. It is used in the, to measure the radiations, optical radiations; it very easily can be measured. See, the thermocouple voltages are typically in the millivolt range. Increasing the voltage output may be a key element in reducing the uncertainty in the temperature measurement.

(Refer Slide Time: 41:18)



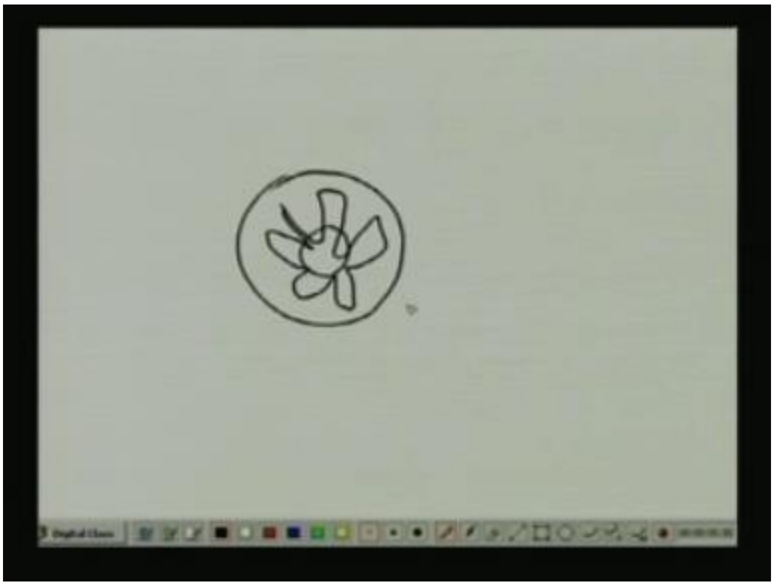
You see, this is actually a thermopile or a multiple thermocouple. There is a measuring junction, several measuring junction, it can be ‘N’ such measuring junction. Cold junction will be at one temperature, measuring junctions at one temperature. So, this is the reference junction. So, what will be the output? Output will be the ‘N’ times the voltage of the single thermocouple. This is because, they all are in series, right? So, I will get obviously large output, right?

(Refer Slide Time: 41:52)



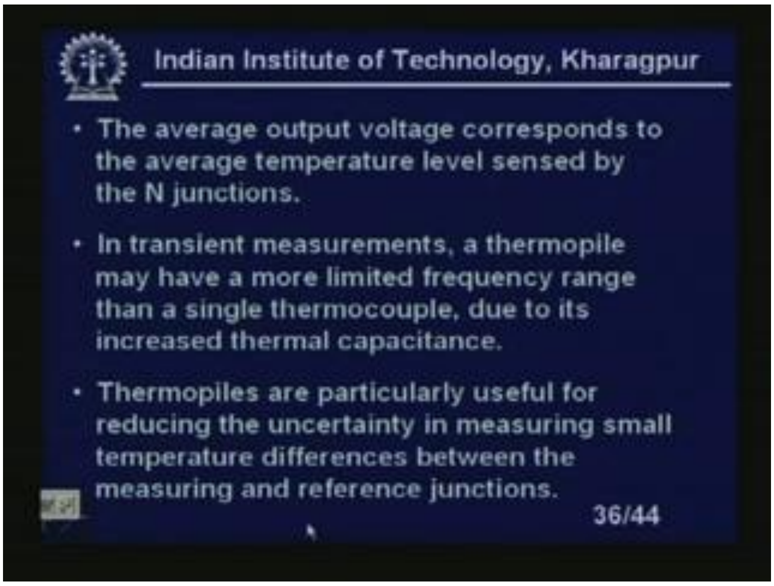
So, that is actually the thermopile or in a thermopile the measuring junctions are usually located at the same physical location to measure one temperature. Above figure shows the thermopile for providing amplified output. In this case, the output voltage would be N times the single thermocouple, where N is the number of junctions in the circuit.

(Refer Slide Time: 42:19)



It looks like this that means if I take a, we will find the thermopile, actually what they do? They make a, like this one, so the, so that this, this centers they make the hot junctions and these are all, the outside are called cold junctions and they put a collimator lens over this one. So, when the sunlight falls what will happen? So, it will get a, collimated here and all the measuring junctions will have the same temperature, right? So, this type of photometer is available for optical radiation measurements and the sun rays measurements and all these things.

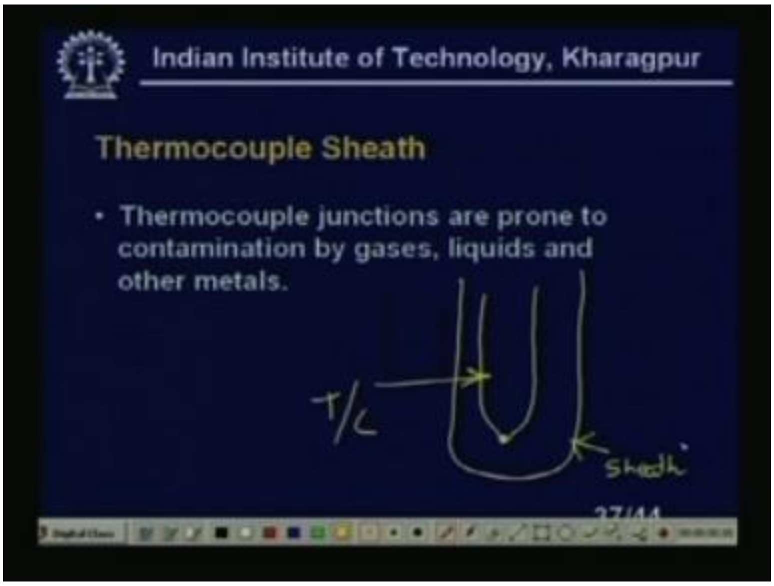
(Refer Slide Time: 42:54)



In transient measurements, the thermopile may have a more limited frequency range, because obviously you can see that that the, it will increase thermal capacitance. The time constant of the thermocouple will usually increase. Now you see, thermocouple is, it can be used for very fast measurements, because for dynamic temperature measurement if you look at the time constant, the time constant of the thermistor is very small. The thermocouple is obviously high, but the, but the, but the, it is obviously, I mean higher than the thermistor, but you can utilize it for making the fast measurement also.

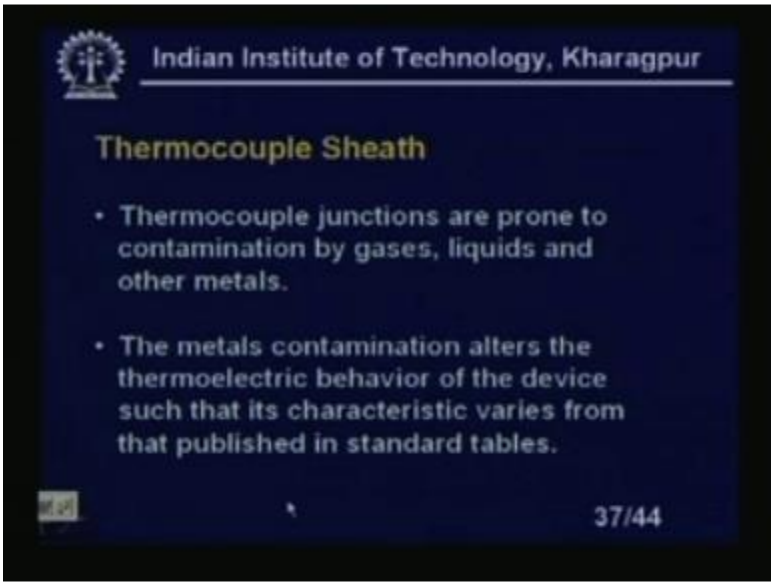
But, the problem is that thermocouple you cannot use as a bare; you need some covering material or sheath material. So, if you use any sheath material, obviously what will happen? The time constants of the thermocouple will increase and the response time, as I, we know that if the time constant increases the respond time, response time will be increased. So, it will take more and more time to find the steady state value of the temperature. So, thermopiles are particularly used for reducing the uncertainty in measuring small temperature differences between the measuring and reference junctions.

(Refer Slide Time: 44:02)



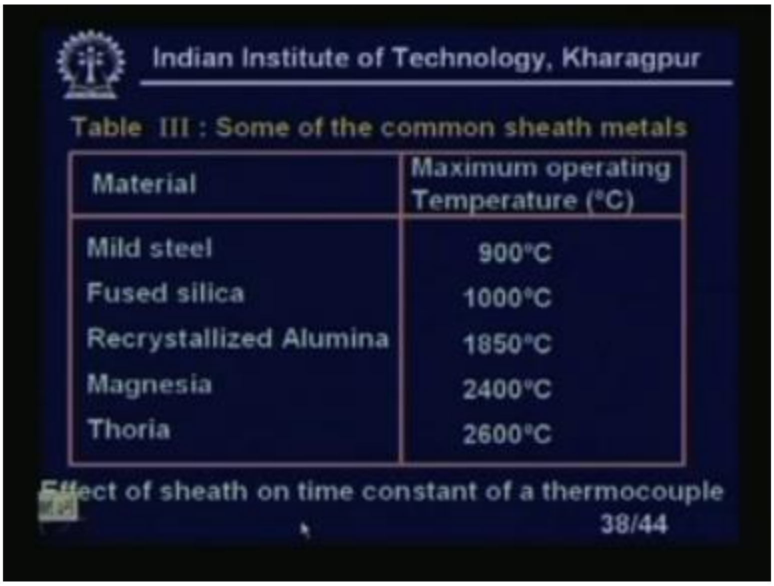
Thermocouple sheath, it is, the thermocouple junctions are prone to contamination by gases, liquids and other metals. So, what you see, it look like this. So, we have, I have a thermocouple, sorry, so, so I have a thermocouple. Entire things are put on a sheath, right? So, this is our thermocouple T/C and this our sheath, right? So, obviously it will increase. It will protect your thermocouple from any hostile environments. Suppose any corrosions, so that type of things it will, I mean protect your thermocouple, but it will increase the time constant of the system.

(Refer Slide Time: 45:10)



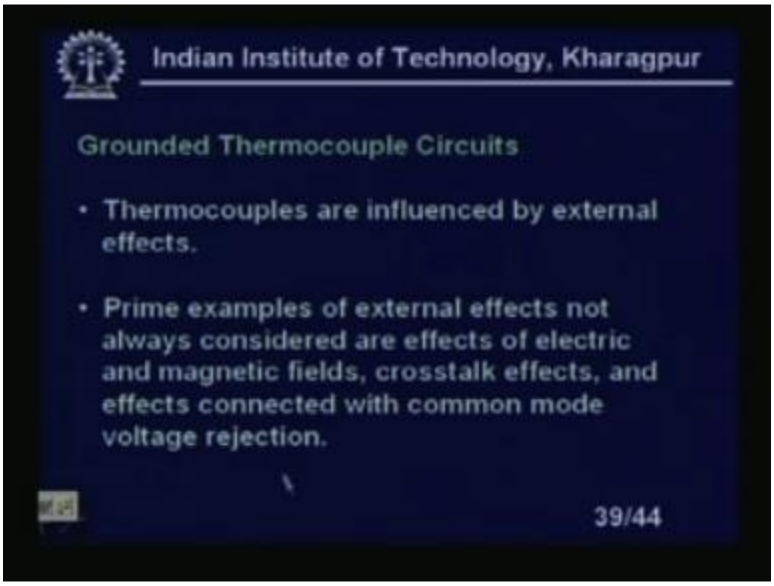
The metals contamination alters the thermoelectric behavior of the device, such that its characteristics varies from the, that published in standard tables.

(Refer Slide Time: 45:22)



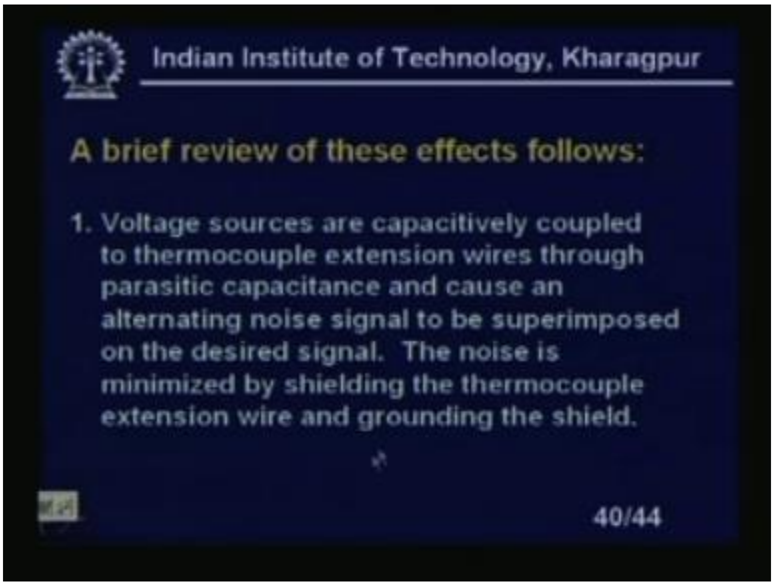
Because the calibration changes, everything will be changed. Some of the common sheath materials, we see the mild steel it can withstand the temperature of 900 degree centigrade; fused silica, it can withstand the temperature of 1000 degree centigrade, recrystallized alumina 1850 degree centigrade, magnesia 2400 degree centigrade, thoria 2600 degree. Effect of the sheath on time constants of the thermocouple, obviously will increase, time constant will increase.

(Refer Slide Time: 45:51)



Now, grounded thermocouple, you see thermocouples are influenced by the external effects. Prime examples of the external effects not always considered are the effects of electric and magnetic fields, crosstalk effects, I mean effects connected with the common mode voltage rejection.

(Refer Slide Time: 46:06)

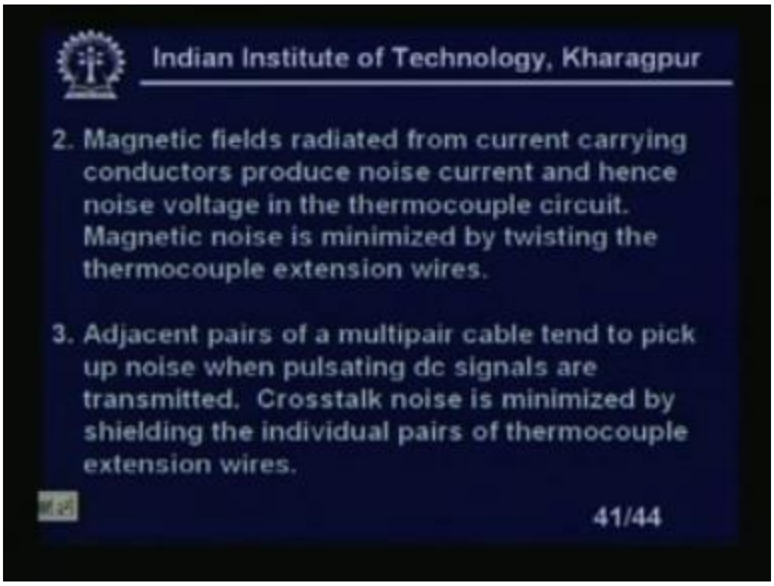


Now, brief review of these follows that the voltage sources are capacitively coupled.

This all actually occurs when you are measuring the dynamic temperature measurements. This is usually for the steady state temperature measurement. This is not of, for very much important, but in some cases you may have two thermocouple wires, which is going side by side. So, what is the influence of the measurements in the dynamic measurements of temperature that is to be studied.

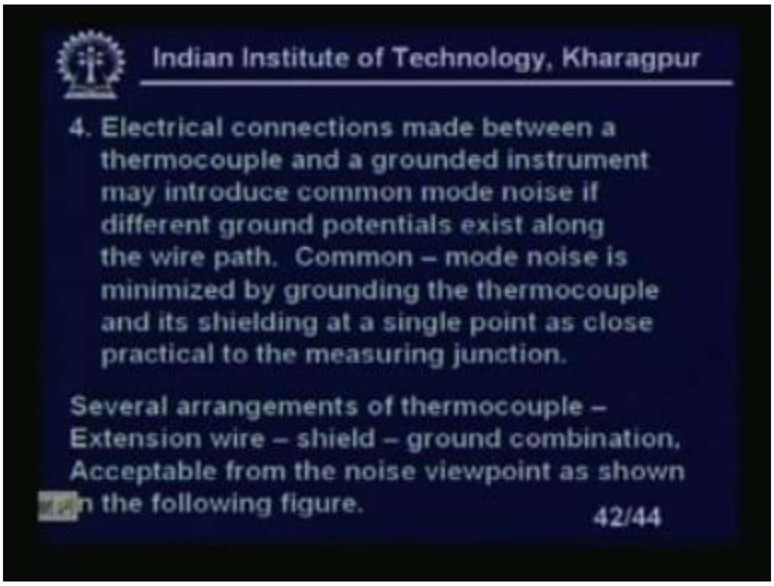
Parasitic capacitances and causes an alternating noise signal to be superimposed on the desired signal. The noise is minimized by the, shielding the thermocouple extension wires and grounding the shield, right?

(Refer Slide Time: 46:47)



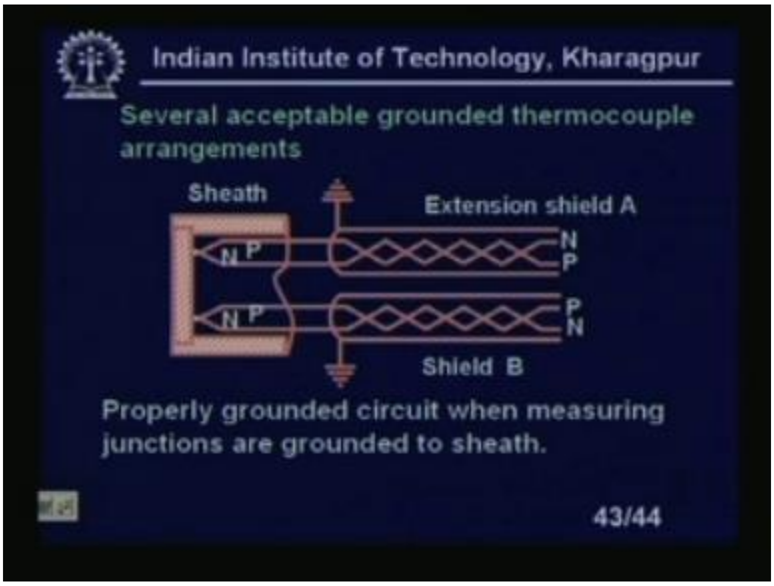
Now, magnetic fields radiated from the current carrying conductors produce noise current and hence noise voltage in the thermocouple circuit. So, magnetic noise is minimized by twisting the thermocouple extension wires. Adjacent pairs of a multipair cable tend to pick up noises when pulsating dc signals are transmitted, as I told you. Now, crosstalk noise is minimized by shielding the individual pairs of thermocouple extension wires.

(Refer Slide Time: 47:14)



Electrical connections made between the thermocouple and the grounded instrument may introduce common mode noise, if different ground potential exists along the wire path. Common mode noise is minimized by grounding the thermocouple and its shielding at a single point as close practical to the measuring junction. Now, several arrangements you can have for extension wire shield and ground combination acceptable from the noise view point, as shown in the following figure.

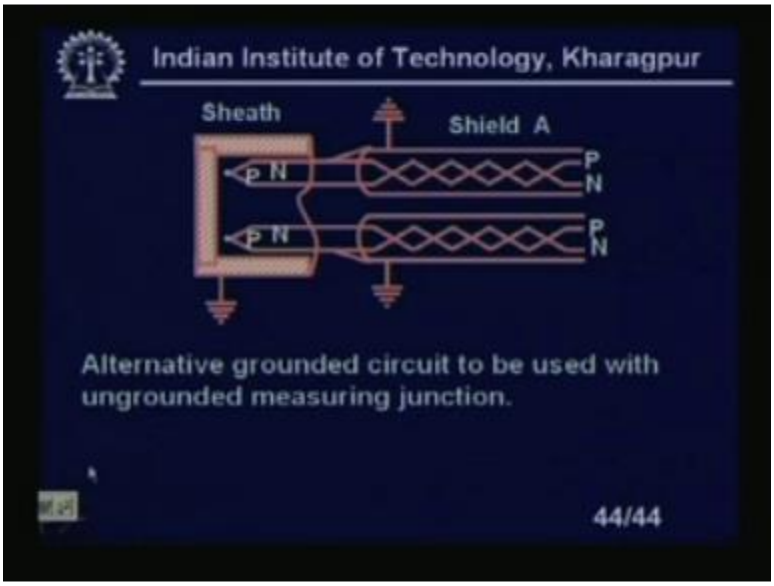
(Refer Slide Time: 47:46)



Now, you see, that is one junction. You will find that this junction has been grounded, right? Several …, now properly grounded circuit, when the measuring junctions are grounded to the sheath. Measuring junction is not grounded, but it is grounded to the sheath and you see that, this is the, this is the extension shield. There is an extension shield, because to protect your environment, protect the, your thermocouple extension wires from the external electrical circuits, electromagnetic fields, this is to be grounded because any electrical wire was, once you have shielded it, whether you all, almost all of you are using the oscilloscope; you have seen that the oscilloscope is a very sensitive device.

When you are measuring the voltages, you always, we cannot give a bare wire like this one. There is a shielded cable through, wire through which the signal will go, right? So, that shielding is very much necessary, because the shielding and if you, if you shield that wire and if you, two wires and if you ground that shield, obviously all the problems of the parasitic capacitance can be easily eliminated. Any capacitively coupled signal also can be grounded easily.

(Refer Slide Time: 48:57)



This is another alternative arrangement. You see, this is alternative grounded circuit. You see here the, the thermocouple is not grounded while the sheath is grounded and you see this, all the, one of the junctions either p-type of materials or n has been grounded also. So, this is another grounding circuit which is used in the ungrounded measuring junction. Now thermocouple, you will see that it is extensively used, because of the, I mean because of, because it has a problem. Problem is, you see it is a nonlinear device, obviously. All the temperature sensors, except RTD, we will find that the RTD are nonlinear.

A thermistor is highly nonlinear. For a very short range, I think very, very short range, you can assume the thermocouple as linear, but in all the cases we will find all this for any unknown temperature I have to refer, in the case of thermocouple I have to refer to the thermocouple chart. That means there is a temperature, I mean emf chart is available, usually I mean available in some, published by some National laboratories or something like that and sometimes you will find that the industry people, they make their own chart.

You will find that in industry they make, because they are used suppose in the, you are, they are using all Chromel Alumel thermocouple, so they make a chart of the Chromel Alumel. Once they get the wires from the, your welder, they immediately, they take a sample and make a calibration chart. It does not take much long, I mean time. So, once you get and publish that one, so once you have that is distributed throughout the plant. You will find that wherever there is an unknown temperature, using Chromel Alumel, so you can immediately refer to that. Obviously with the cold junction compensation and all those things, what will happen? You will find that that type of problem you can immediately find the unknown temperature, right? Obviously, you will find ...

Another problem you see that if you are measuring very high temperature, suppose I am measuring temperatures of 1500 degree centigrade, right and in, in such a high measuring, I mean temperature, you can have your, I mean cold junctions, you will find even in a, in a bare that means without any cold junctions you can bare it; just we can leave it in the atmosphere, your cold junctions. The reason is, you will see that the, you have to calculate that how much error you are introducing. See, even if you, if the cold junction changes the temperatures of 15 degree centigrade, I mean 15 to 35 degree centigrade, total change you will find is not long. So, in that type of situations you will find it is not very difficult to make, you, I mean to leave these cold junctions bare. That means leave it in the atmosphere, let the temperature change, let it change the output voltage, but if we have changed the output voltage, you will find that it will not change our, it will not introduce any significant error.

If the error is suppose 1%, if the error is, this error is just 1%, we can ignore that error. We can ignore this, all the complexity of the cold junction compensation circuit, right? So, this is the beauty of your thermocouple and you will see that in the thermocouple, another I mean, another great advantage, as I told you earlier is the time constant also. Its time constant is very small. It is easily available, all the RTD’s we will find it is very bulky, its time constant is large. Thermistor is semiconductor devices, its calibration is problematic. Two semiconductor, two different semiconductor having the same amount of resistance is also very difficult to achieve. So, all these problems are not there.

That is the reason over the years you will find it is most widely used, I mean temperature range, I mean up to suppose 700, 1700 degree centigrade or 1800 degree centigrade, I should say, I, I am not that, I mean I should not go to that high temperature. Suppose a 100, 1500 degree centigrade, I can easily use thermocouple. Obviously, if you have to go higher temperature, suppose above 1800 degree centigrade or 2000 degree centigrade, we have optical pyrometer sort of temperature measuring devices.

Otherwise, for the temperature range, typically industrial range is suppose from 500 to 800 or 900, 1200 degree centigrade, I can easily use thermocouple. But, please note that all the things you have to, even though we are saying the thermocouple, what about the associated circuit? That means compensation circuit, then your, the sheath materials which must withstand the temperature. No, you will usually find no thermocouples used in bare, always there will be a sheath, because you do not know you might have been, you might be interested to measure temperature of the, temperature of the hot sulfuric acid, you cannot use that above, you cannot use copper constantan, iron constantan; it will immediately react.

Pure copper constantan, iron constantan thermocouple will immediately react with the, that acid. So, I have to put the thermocouple in a sheath material like steam in, so which will not react with the acid. That will lead to our safe measurements of the thermocouple, I mean of temperature. So, with this I come to the end of this lesson that is lesson 8 on thermocouple.

(Refer Slide Time: 54:20)

(Refer Slide Time: 54:22)

Welcome to the lesson 9 of Industrial Instrumentation. In this lesson, we will basically cover one of the most important temperature sensor that is resistance temperature detector.

(Refer Slide Time: 54:49)

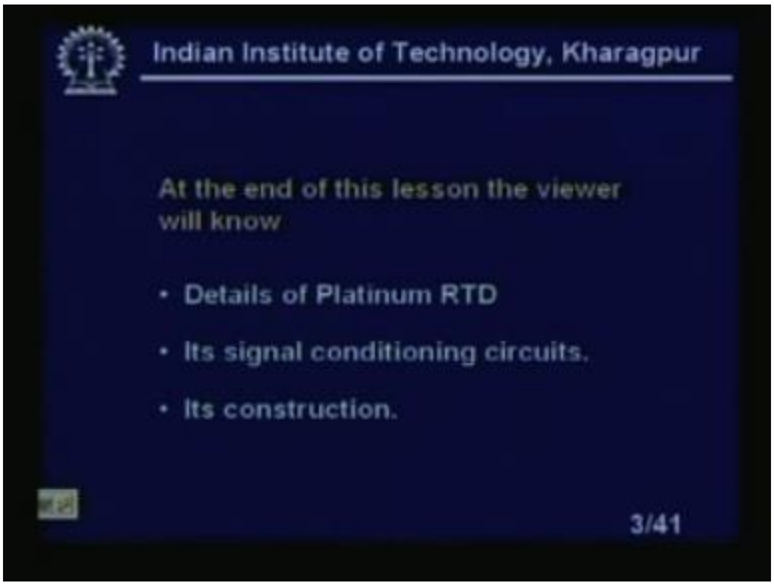
Resistance temperature detector, even though it is not much, I mean used in the industry, I mean in the plant, we will find the thermocouple is huge in number than you will find the thermistor, but I should say for precision thermometry that means if I want to measure the temperature with high accuracy, resistance thermometer is the, resistance temperature detector is the only solution, because this, even though it is resistance thermometer, now what you call nowadays we call it resistance temperature detector and there are three basic classes of the resistance temperature detector.

We will find we have platinum, then nickel, copper, tungsten, all these things will be, I mean discussed in details. Also, the signal conditioning circuit of the resistance temperature detector, which are basically nothing but some bridges. Either, we have seen in previous cases also, we can use it either in the, in the unbalanced voltage mode or you can use it as balanced mode, right?

(Refer Slide Time: 55:53)

Let us look at the contents of this lesson. First, we will consider the theory of the resistance temperature detector. Then, we will discuss the measuring bridges. What are the different measuring bridges in the resistance temperature detector? Then, we will see the construction. What is the basic construction of the resistance temperature detector?

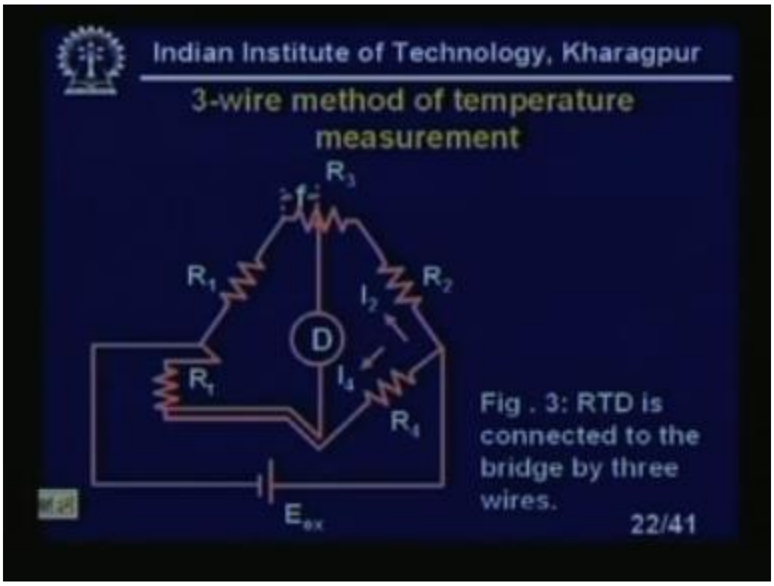
(Refer Slide Time: 56:13)



So, obviously at the end of this lesson the viewer will know details of platinum RTD, then its signal conditioning circuits, its construction.

So, this is the circuit.

(Refer Slide Time: 56:33)



You see, this RTD is connected to the bridge by three wires. You see, three wires means you see here there is one wire, there is another wire, there is another wire. Now you, interestingly you will see this R 3 now is known in the bridge. R 3 is in the bridge, but the contact resistance is not in the bridge circuit, it is in the galvanometer circuit or it is all in the detector circuits. How do you know it is the galvanometers or you can say it is just a multimeter or a voltmeter, is not it, right?

So, if there is little increase in contact resistance or little decrease in the contact resistance, nothing will happen. What it will do? It will simply make your bridge more sensitive or less; your detector more sensitive or less sensitive, you shall use it, is it not? Suppose in the case, some cases I want to make a, use a milliammeter in bridge circuit, which is carrying a current of suppose 500 milliampere. Even though our detector circuits can only, can read 10 milliampere, even you can use a shunt, is it not, right?

You use a shunt and when I am very close to the measurements, so I remove the shunt, so that, because I know that bridge is almost balanced. There is also a little chance of, I mean passing a large current through the bridge, through the detector. So, that type of situation may arise, so any contact resistance will not, this contact resistance will be more in the bridge circuit. So, no calculation, nothing whatever the bridge balance equation will …… That will be absolutely correct, but it will be in the detector circuit. So, it, make the detector more sensitive or less sensitive, it does not matter, it is no way, I mean, I mean coming …...

So, I am denoting some current, because we have to calculate something. This I 2, which is the resistance, which is the current through the resistance R 2. I 4 is the current through the resistance R 4 and at balance, this R4 is, I 4 is also flowing through R T and since it is, no current is flowing through a detector balance and also this I 2 is, full is flowing through the, this R 3 as well through R 1 back to the battery, right? This is called the, RTD is connected to the bridge by three wires ….., right? So, this is all about your RTD, one of the most accurate temperature sensors.