Chemical Process Instrumentation
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Lecture – 36
Temperature Measurement (Contd.)

Welcome to week 8, lecture 36 we will continue our discussion on Temperature Measuring Instruments. In the previous week we have talked about classification of various temperature instruments and we have talked about temperature measuring instruments based on the principle of thermal expansion of solid, liquid and gas. So, today we will talk about temperature measuring instruments that is based on thermoelectric principles. These are known as thermoelectric sensors and we will talk about thermocouples under this category.

Thermocouple is one of the most widely used temperature sensor in industry. In fact, there was a time when it was the mostly used sensor, now resistance temperature device or resistance temperature detector or RTD is a good competitor for thermo couple we will talk about RTD later. So, today we will concentrate on thermocouples.

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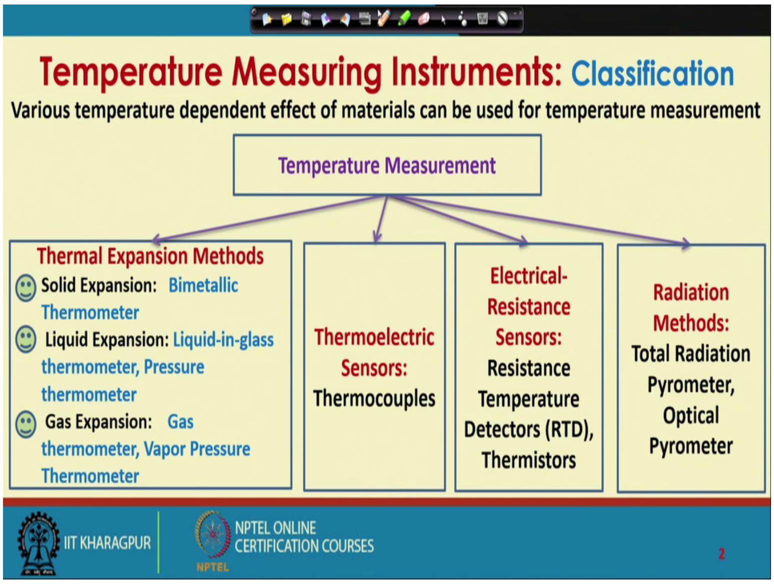

So, we have talked about thermal expansion methods and today we will talk about thermoelectric sensors under which we will talk about thermocouples. And we will go to electrical resistance sensors and radiation methods later.

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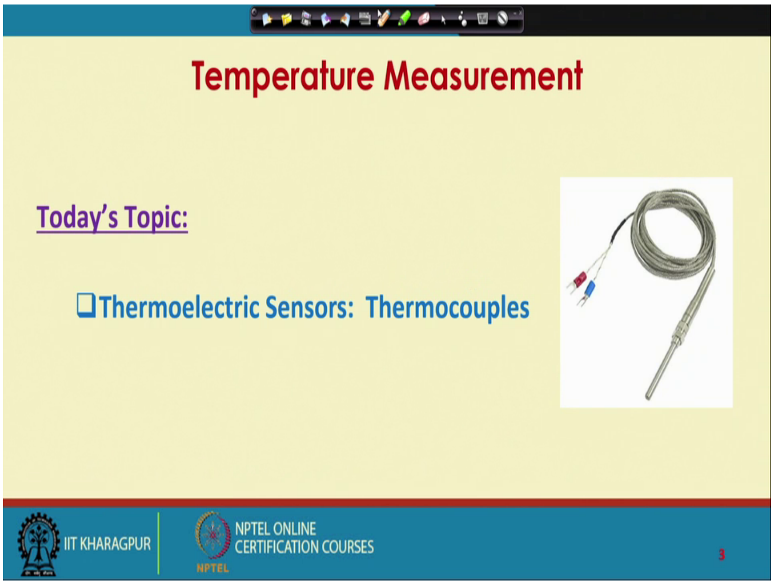

So, today's topic will be thermocouples, the thermocouple looks like this. So, what you see basically is a protective case and you see two leads are coming out. Now, this is known as thermocouple sheath it is essentially a protective case for the thermocouple. So, this is introduced into the medium whose temperature you are measuring and then an EMF will be produced or electromotive force will be produced a small voltage will be produced its in the order of millivolt and that millivolt will be a measure of the temperature of the medium.

Now, we will go into the more details of thermocouples.

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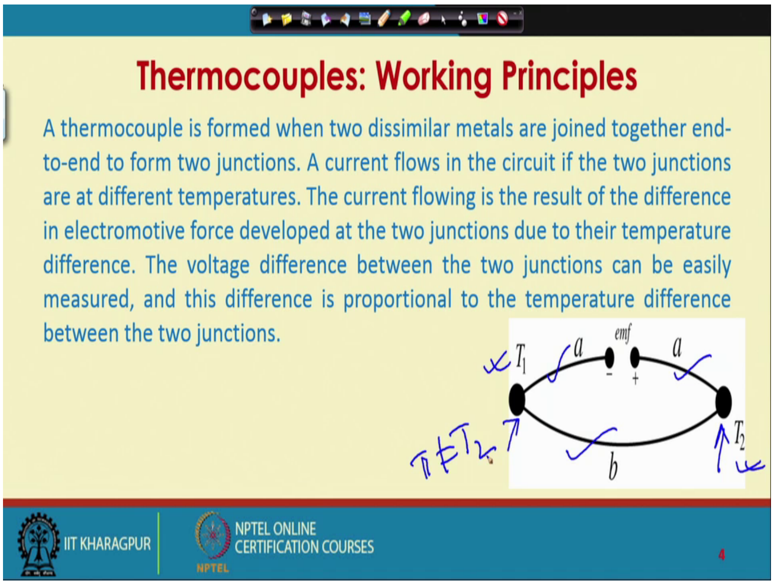

So, thermocouple is formed when two dissimilar metals are joined together end to end to form two junctions. So, I have taken metal A and I have taken metal B and formed two junctions by joining them end to end. A current flow is in the circuit if the two junctions are at different temperatures. So, I have kept the junctions at temperature T 1 and temperature T 2 and temperature T 1 is not equal to temperature T 2.

Under such scenario a current will flow in the circuit. The current flowing is the result of the difference in electromotive force developed at the two junctions due to their temperature difference. The voltage difference between the two junctions can be easily measured, using a suitable voltmeter and this difference is proportional to the temperature difference between the two junctions.

So, what we are saying is if you take two dissimilar metals and join them end to end to form two junctions, now if you keep this two junctions at two different temperatures an EMF will be produced in the circuit. And this EMF will depend on the temperature difference between these two junctions. This EMF also depends on the thermocouple materials. In other words the two dissimilar metals that you have chosen to form the thermocouple, but given a thermocouple the voltage that is produced will be dependent on the temperature difference between these two junctions.

Now, if I keep one junction temperature constant let us say I call that as reference junction and let us say I keep that call as that some constant temperature. Let us say 0 degree Celsius and put the other junction which I call as measuring junction to the medium whose temperature I am measuring then the EMF produced in the circuit will be dependent only on the temperature of the measuring junction because other junction is being kept constant temperature. So doing that, that means, by keeping one junction temperature at a constant reference temperature and exposing the other junction to the medium whose temperature I am measuring the EMF produced in the circuit can be taken as a measure of the temperature of the medium.

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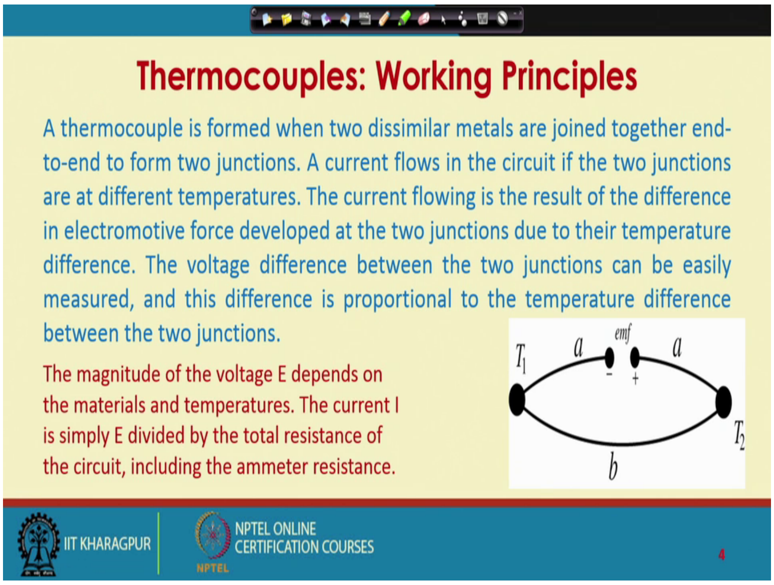

The magnitude of the voltage E depends on the materials and temperature the current I is simply E divided by the total resistance of the circuit, which include the ammeter resistance as well.

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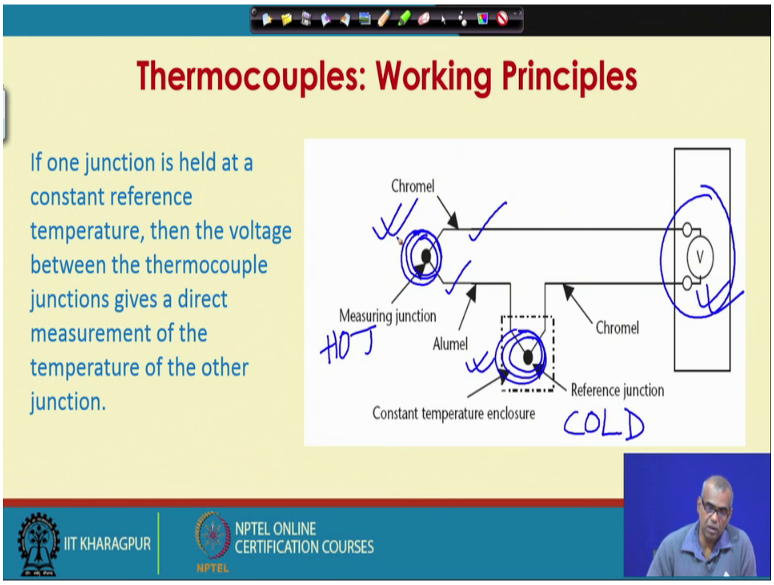

So, this is the schematic of a thermocouple if one junction is held at a constant reference temperature then the voltage between the thermocouple junctions gives a direct measurement of the temperature of the other junction. So, this is one metal, chromel this is an alloy, this is another metal which is alumel, this is another alloy. So, I have made two junctions one is this another is this.

Let us call this junction as measuring junction. So, this is the junction which will be put to the medium whose temperature I am measuring. This is also known as hot junction. The other junction will always be kept at some constant temperature. So, the schematic shows that this reference junction is put under a constant temperature enclose. This junction is known as reference junction or cold junction and this is the millivoltmeter usually a digital millivoltmeter that will produce that will measure the voltage produced in the circuit as long as these two junctions are kept at two different temperatures. Now, keeping this reference junction always at some constant temperature the millivolt produced will be dependent on the temperature of this junction. So, this is how thermocouple measures temperature of a medium.

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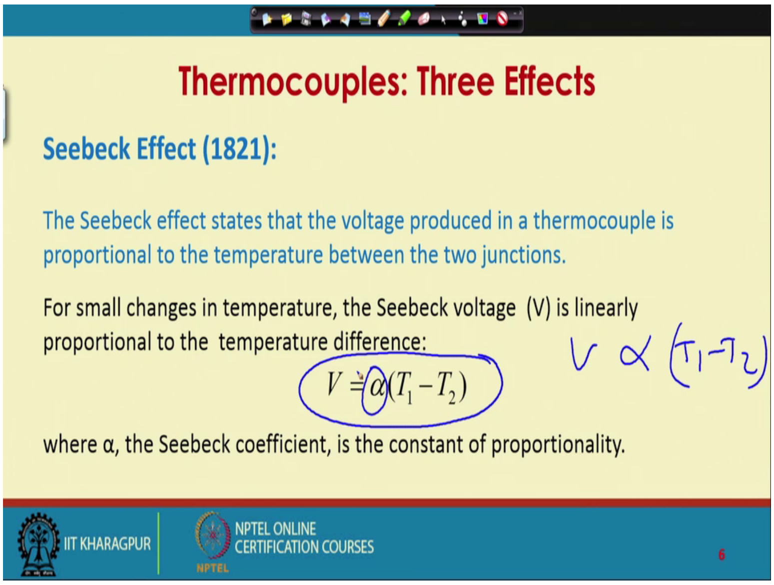

Let us first talk about few effects that are related to thermocouples first Seebeck effect.

The Seebeck effect states that the voltage produced in a thermocouple is proportional to the temperature between the two junctions. For small changes in temperature the Seebeck voltage V is linearly proportional to the temperature difference. So, you can write the Seebeck voltage V is proportional to T 1 minus T 2 where T 1 and T 2 are the temperature of the junctions. So, if V is proportional to T 1 minus T 2 I can introduce a proportionally constant alpha and can write as V equal to alpha into T 1 minus T 2. This proportionality constant alpha is known as Seebeck coefficient.

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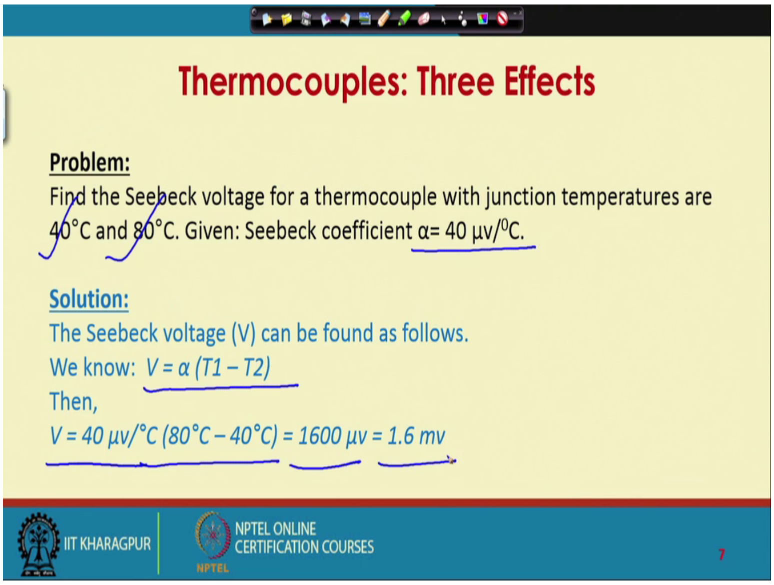

So, let us take a very very simple problem find the Seebeck voltage for a thermocouple with junction temperatures are 40 degree Celsius and 80 degree Celsius, given Seebeck coefficient alpha equal to 40 microvolt per degree Celsius.

We know that Seebeck voltage can be found out as V equal to alpha into T 1 minus T 2, alpha is given T 1 and T 2 is given. So, V equal to 40 alpha into 80 minus 40 which is 1600 microvolt or 1.6 millivolt.

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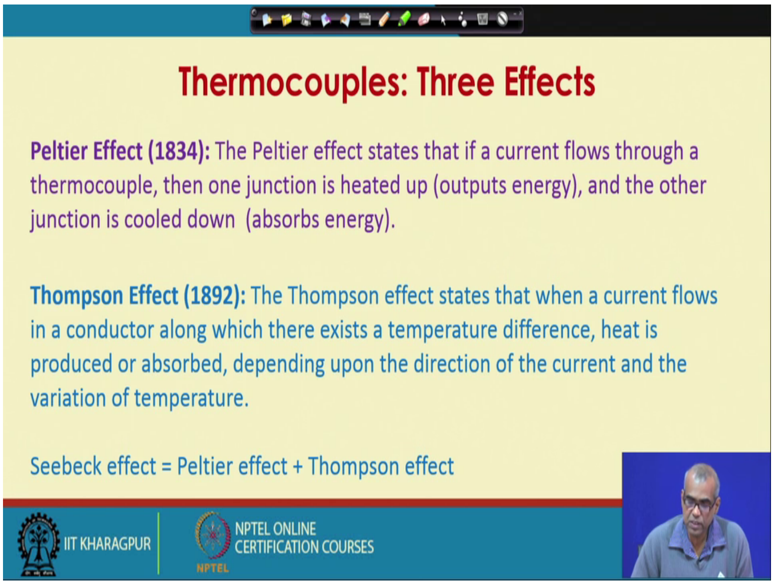

Next let us talk about Peltier effect. The Peltier effect states that if a current flows through a thermocouple then one junction is heated up; that means, outputs energy and the other junction is cooled down; that means, absorbs energy.

Finally, we have Thompson effect the Thompson effect states that when a current flows in a conductor along which there exists a temperature difference heat is produced or absorbed depending upon the direction of the current and the variation of temperature. We can see that Seebeck effect is basically a sum of Peltier effect and Thompson effect.

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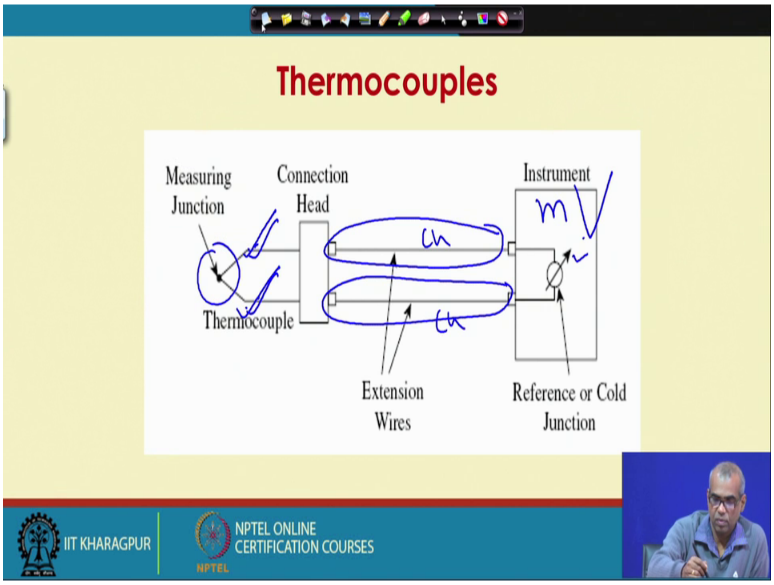

Excuse me. Once again let us take a look at the thermocouple schematic. So, we have this measuring junction and these two are two dissimilar metals let us say chromel and alumel and you have the voltmeter here.

Now, you have to connect these two wires to the voltmeter, one possibility is you take long wires of chromel, you take long wires of alumel and connect it to the voltmeters terminals, but that may be uneconomical. So, what we do is we will take two extension wires let us say they are made of copper and then connect the voltmeter with the thermocouple wires as shown. So, this will introduced several new junctions in the circuit. And next we will talk about certain laws which will tell me what I need to do with this junctions. So, that thermocouple gives me an fairly accurate result for the temperature.

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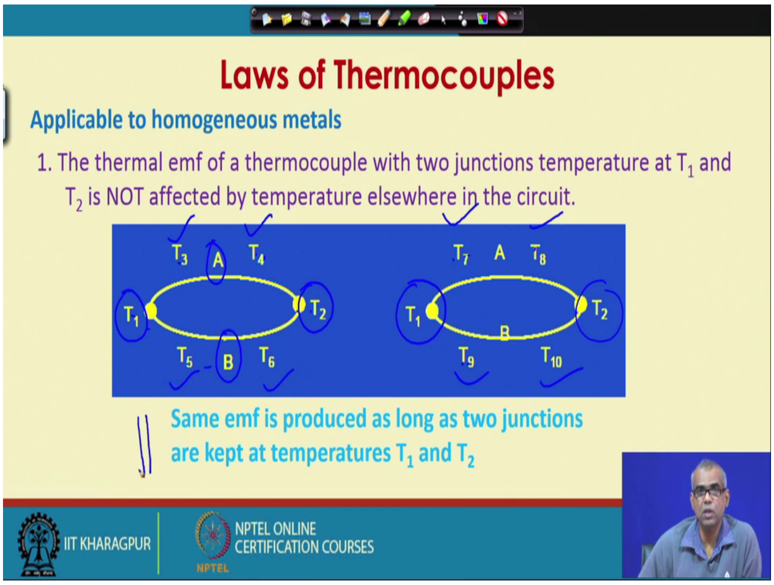

So, let us talk about now few thermocouple laws. All these laws are applicable to homogeneous metals the first law that we talk about is as follows. The thermal EMF of a thermocouple with two junctions temperatures at T 1 and T 2 is not affected by temperature elsewhere in the circuit. So, what we say is I have a thermocouple made of metal A and metal B, two junctions are kept at temperatures T 1 and temperature T 2. As long as these two junctions are kept at temperature T 1 and T 2, the EMF produced does not depend on the temperature elsewhere.

So, as long as the two junctions are kept at temperatures T 1 and T 2 in both the cases the temperatures elsewhere may be different look at here it is T 3, T 4, T 5, T 6, it is T 7, T 8, T 9, T 10, but the junctions are T 1 and T 2. So, under this scenario same EMF will be produced as long as the two junctions are kept at temperatures T 1 and T 2.

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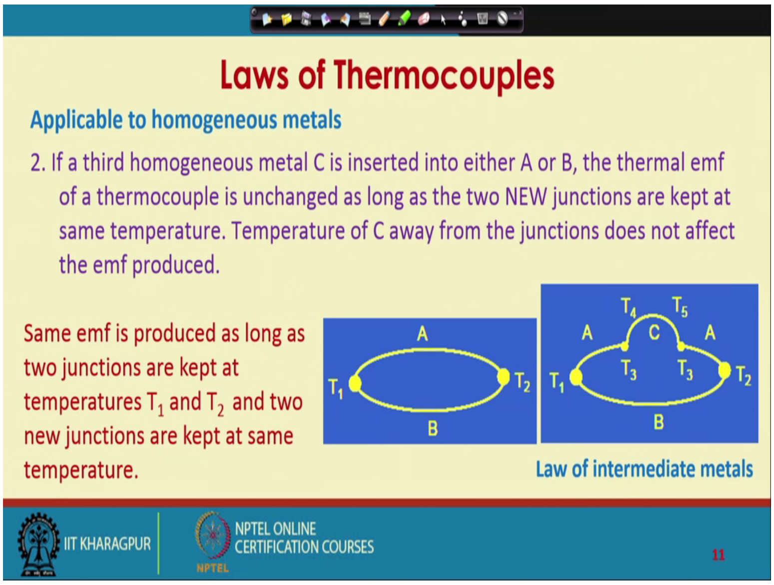

Next, we talk about another law known as law of intermediate metals again applicable to homogeneous metals only. If a third homogeneous metal C is inserted into either A or B the thermal EMF of a thermocouple is unchanged as long as the two new junctions are kept at same temperature, temperature of C away from the junctions does not affect the EMF produced.

So, let us first consider this. So, we have a thermocouple made of metal A and B, the two junctions are kept at temperatures T 1 and T 2. Now, I take a third homogeneous metal C and introduce in A. So, I create two new junctions. As long as these two junctions are kept at same temperature; that means, two junctions are both kept at same temperature T three and these junctions are same as T 1 and T 2 the EMF produced in both the thermocouples will be same. So, the EMF produced in a thermocouple upon introduction of a third homogeneous metal C will not change if the two new junctions that you produced are kept at same temperature.

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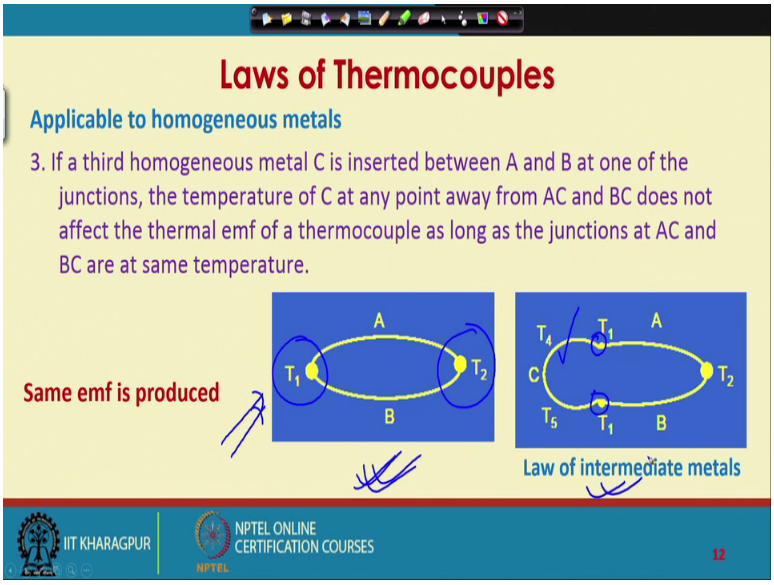

Again this is law of intermediate metals only. But here what we do is instead of putting the metal C in A or B, I put it an I put it at one junction. So, what the law says is as follows. If a third homogeneous metal C is inserted between A and B at one of the junctions the temperature of C at any point away from AC and BC does not affect the thermal EMF of a thermocouple as long as the junctions at AC and BC are at the same temperature. So, before introduction of metal C, I had this thermocouple. So, this is made of metal A and B two junctions are kept at T 1 and T 2.

Now, in this junction I introduce metal C. So, I create two junctions now if this two junctions are kept at temperature T 1 and the other junctions at T 2 EMF here and EMF here will be same. So, this is basically the law of intermediate metals that we discussed in previous slide, but here we have introduced the metal C in one junction.

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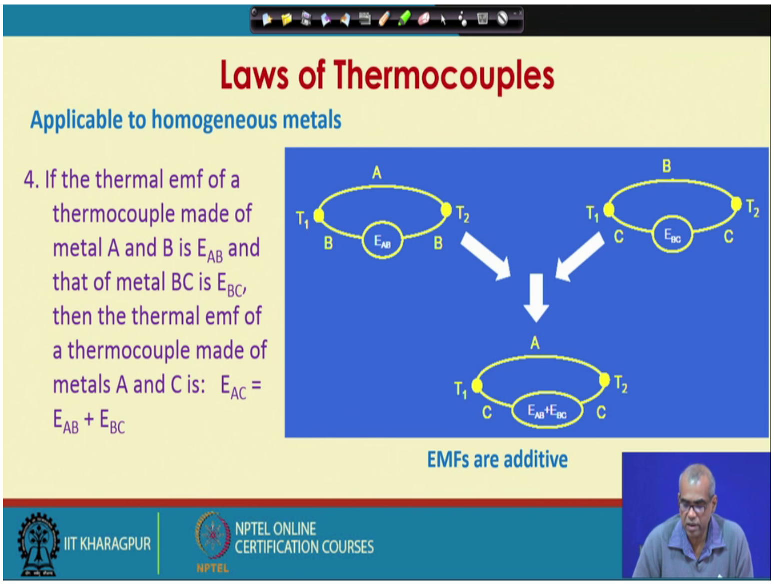

Fourth law states that EMFs are additive. If the thermal EMF of a thermocouple made of metal A and B is E AB and that of metal BC is E BC then the thermal EMF of a thermocouple made of metals A and C is E AC will be sum of E AB and E BC. So, this thermocouple is made of metal A and metal B. So, the EMF produced is E AB.

Now, I take metal B and metal C and let us say the EMF produced is E BC. Now, I take metal B now I take metal A and metal C to make a thermocouple then EMF produced will be AB plus E BC of course, I have kept the junctions at temperatures T 1 and T 2 in all the cases.

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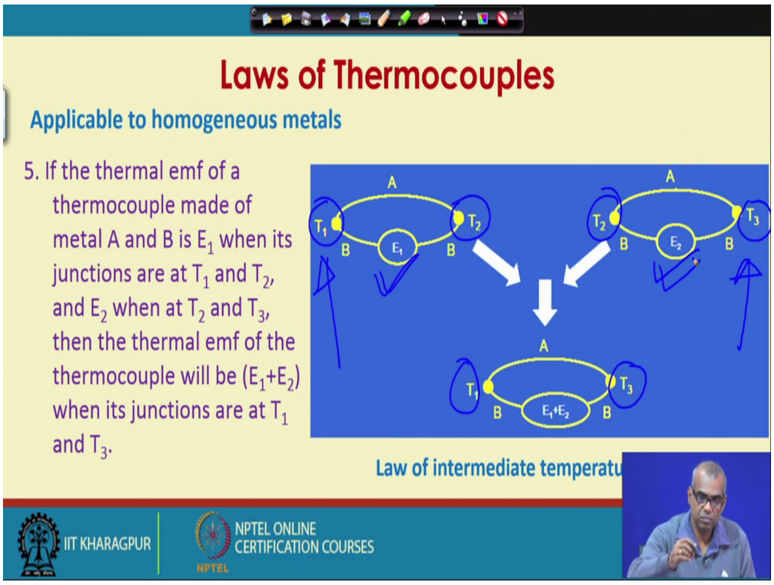

Finally, we will talk about law of intermediate temperature. Again all these laws are applicable to homogeneous metals. If the thermal EMF of a thermocouple made of metal A and B is E 1 when its junctions are at temperatures T 1 and T 2 and E 2 when at T 2 and T 3 then thermal EMF of the thermocouple will be E 1 plus E 2 when its junctions are at T 1 and T 3.

So, here my thermocouple is made of metal A and B. I am now varying temperatures of the junctions. So, I keep the junctions at temperature T 1 and T 2 my EMF is E 1. Now, I take the same thermocouple keep the junctions temperature as T 2 and T 3, my EMF is let us say E 2. Then I take temperature T 1 and temperature T 3. So, the EMF produced will be E 1 plus E 2. So, this is known as law of intermediate temperature.

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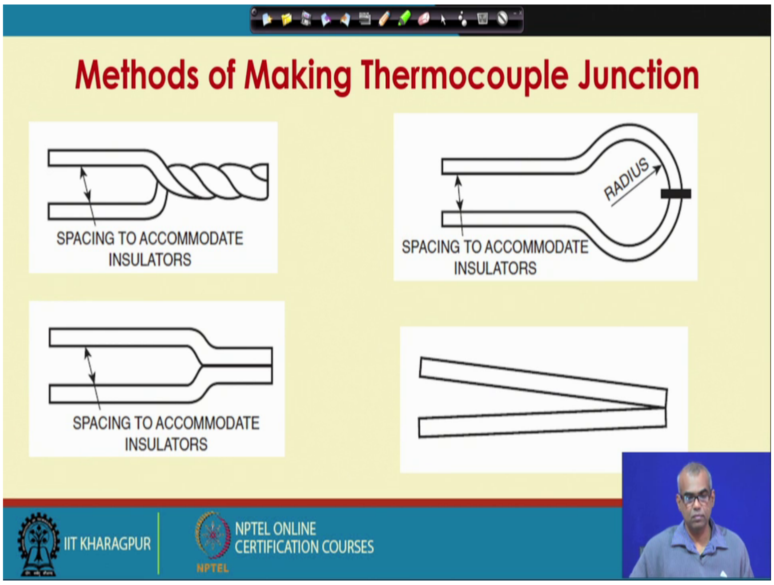

So, this is how the thermocouple junctions are made. Basically you take two dissimilar metals and join them rigidly it can be welded or it can be just mechanically joined like this. So, various junctions are possible.

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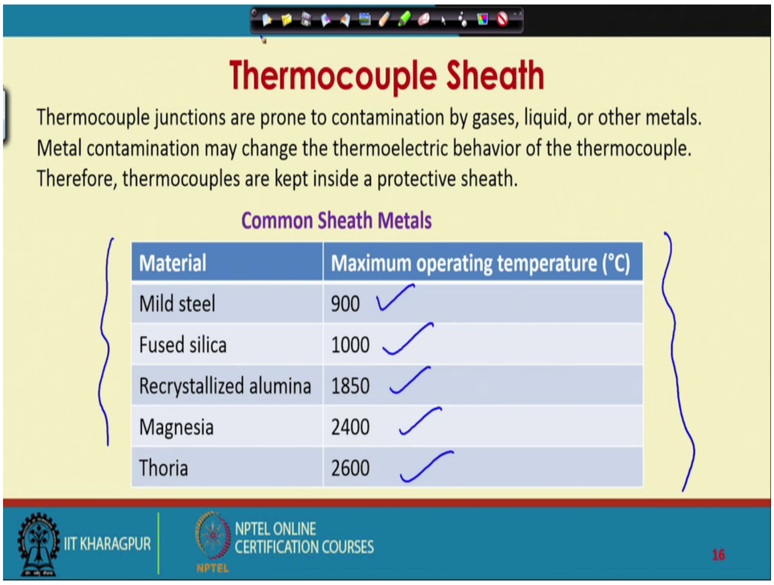

Thermocouple junctions are prone to contamination by gases, liquid or other metals. Metal contamination may change the thermoelectric behavior of the thermocouple. Therefore, thermocouples are kept inside a protective sheath.

These are some common sheath material and also the maximum operating temperatures are indicated. So, the common sheath metals are mild steel, fused silica, recrystallized alumina, magnesia, thoria and the corresponding operating maximum operating temperatures are indicated. So, basically the thermocouple junction the measuring junction will be kept inside let us say a metal sheath made of mild steel and it can be used to measure a maximum temperature of 900 degree Celsius.

So, this way you can protect your thermocouple junction from the effect of environment.

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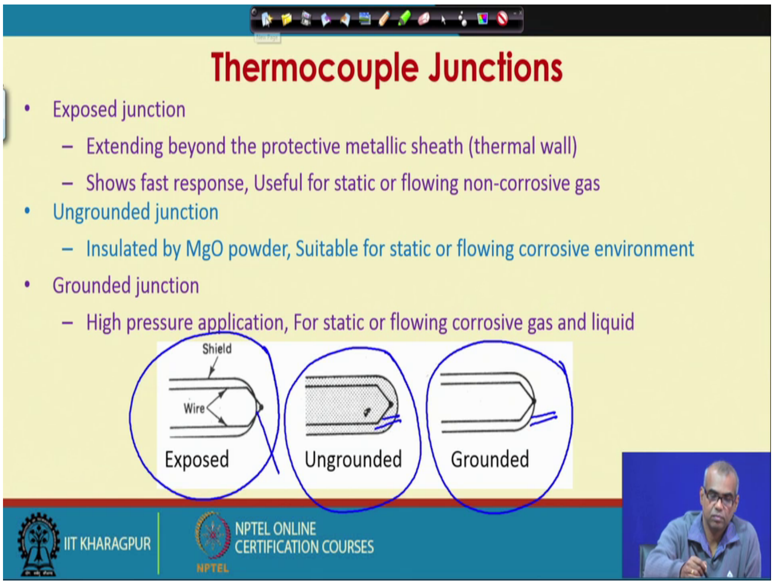

There are 3 types of thermocouple junctions exposed junction, ungrounded junction and grounded junction. This is a schematic of exposed junction. You can see that the thermocouple junction is exposed from this yield. So, in exposed junction the thermocouple junction is extending beyond, the protective metallic sheath the protective metallic sheath is also known as thermal wall or thermal well.

Since this is exposed the junction is directly coming in contact with the medium whose temperature you are measuring such thermocouples will show first response, but this is risky for non corrosive environment. So, the exposed thermocouples exposed junction thermocouples will show first response and it is useful for static or flowing non corrosive gas. This is schematic of ungrounded junction this is insulated by magnesium oxide powder suitable for static or flowing corrosive environment.

So, the thermocouple junction is completely inside the protective metallic sheath and this is grounded junction look at the difference between ungrounded and the grounded. Grounded junction is useful for high pressure application, it can also be used for static or flowing corrosive gas and liquid.

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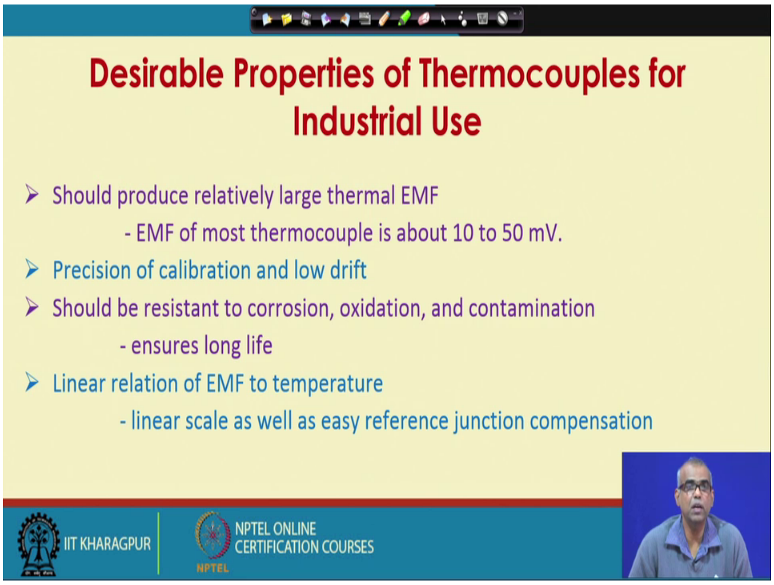

Here are some desirable properties of thermocouples for industrial use. See several materials show thermoelectric behaviours. So, if you take two dissimilar metals and join them end to end and thereby you form two joints and as long as you keep this two junctions at two different temperatures an EMF will be produced.

But there is only a handful of materials which can be used for making thermocouples for the purpose of temperature measurement. Essentially the temperature and the EMF relationship is non-linear, but there are materials or there are metals or pair of metals to form thermocouples where the relationship is approximately linear over a range of temperature. So, there are certain desirable properties that you are looking for. So, that we can make an useful thermocouple.

So, here is list of desirable properties of thermocouples for industrial use. Thermocouples should produce relatively large thermal EMF. So, that it becomes easy for measurement. EMF of most thermocouples is about 10 to 50 millivolt. It is always in the range of millivolt. Precision of calibration and low drift. So, we desire high precision of calibration and low drift so that error in measurement is less. Thermocouple materials should be resistant to corrosion, oxidation and contamination, this will ensure long life for the thermocouple. Linear relation of EMF to temperature. So, this gives us linear scale also easy reference junction compensation. We will talk about this junction compensation later. So, these are the desirable properties of thermocouples for industrial use.

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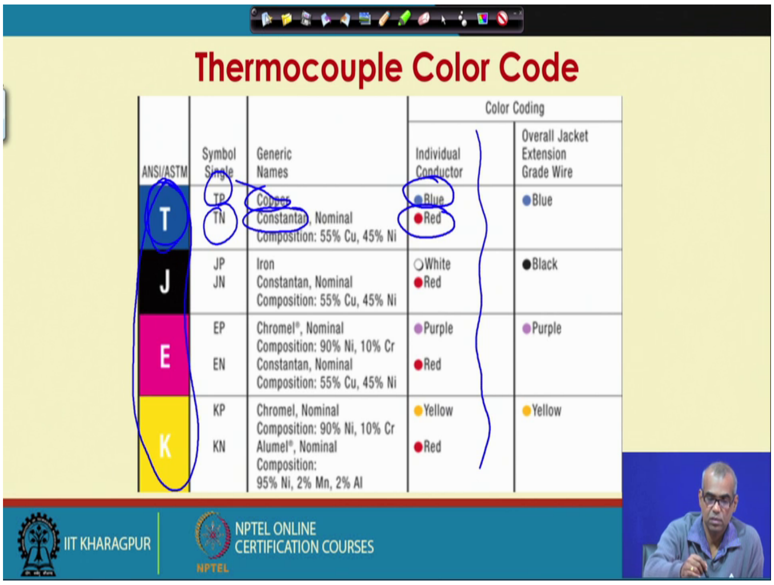

So, we will end this discussion with a note on thermocouple color codes. Now, what you see is T J E K all these things are written they basically indicate a type of thermocouple. So, every thermocouple is made of two dissimilar metals let us say thermocouple T, it is known as type T, type J, type E, type K, so on and so forth.

So, there are two different materials or metals one is positive another is negative. So, positive is let us say for type T it is copper and the negative for type T is constantan, copper constantan thermocouple. Now, the color code that is followed is the copper is coloured blue and the constantan is coloured as red. Similarly for type J, type E, type K, and there are other types as well. So, these color coding informations are available when you buy thermocouples from manufacturer, the manufacturer will supply you the color code and you can find out the two extension leads that are coming out will be coloured and these are the color codes that you will be followed.

So, we will stop our discussion on thermocouples here. And in the next class we will continue our discussion with the thermocouple because certain portions are thermocouples I had left yet.