Chemical Process Instrumentation
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Lecture – 32
Temperature Measurement (Contd.)

Welcome to lecture 32. We are talking about temperature measurement. We have given a brief introduction to what is temperature and various temperature skills in our previous lectures. In this lecture, we will classify all the temperature measuring instruments using some basis; and then we will start talking about various temperature measuring instruments that are available.

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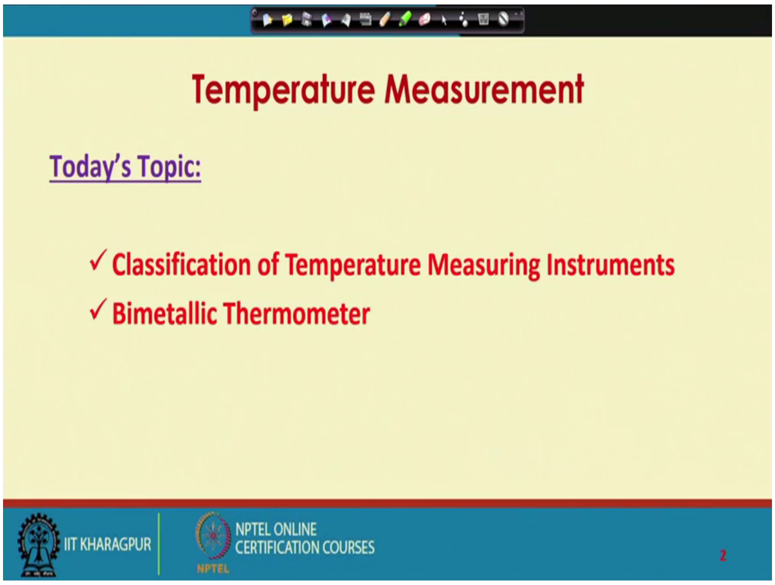

So, today's topic will be classification of temperature measuring instruments and we will start talking about one particular temperature measuring instrument namely bimetallic thermometer. So, first we will start our discussion with classification of temperature measuring instruments.

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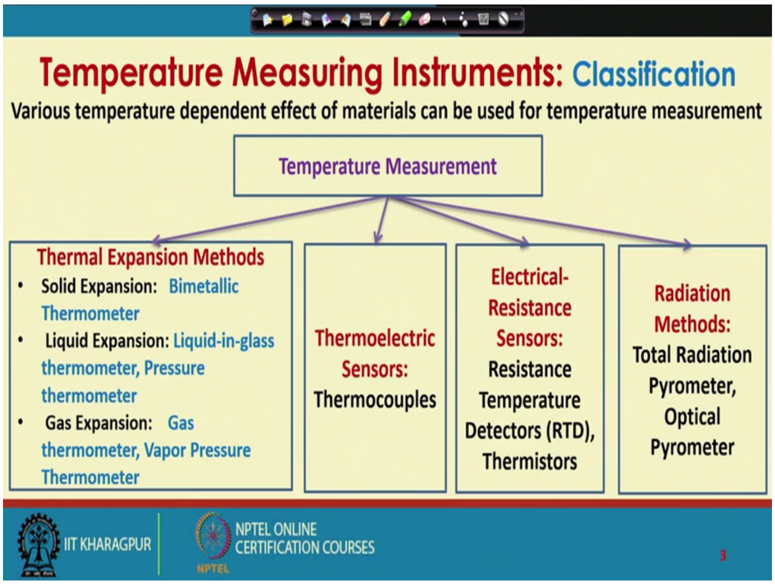

So, how do you classify various temperature measuring instruments? There cannot a single way by which we can do that; there are various temperature measuring instruments; we can classify differently. Let us say we can classify based on their range; we can classify based on whether they are contacting type or non contacting type such has whether it is necessary for the purpose of measurement to bring the instrument in direct contact to the medium whose temperature is measuring.

Or it may be possible to measure temperature even if I do not bring the measuring instrument in direct contact with the body whose temperature I am measuring. Let us say you are talking about the instrument whose function depends on radiation principle. So, there it is not necessary to bring the temperature measuring instrument in direct contact with the body.

So, there may be various means of classification. So, we will classify the various temperature measuring instrument depending on the effect of temperature, effect of temperature on the material. So, various temperature dependent effects on materials can be used to classify temperature-measuring instrument; so, this is just one possible classification. So, we will classify the various temperature-measuring instruments based on various temperature dependent effect on materials. Let us see how.

The first one that you talk about is thermal expansion methods. So, the property that will be used here is how a material under goes change in dimension when there is a change in temperature. So, normally a solid will expand when you supply heat showed as a liquid and gas. And if this happens reproducibly this can be considered as a means of temperature measurement. So, by measuring the change in dimension of a solid material, it may be possible to measure the temperature. So, thermal expansion methods will have solid expansion, liquid expansion and gas expansion.

Under solid expansion, we will talk about bimetallic thermometer; under liquid expansion, we will talk about liquid in glass thermometer, pressure thermometer; under gas expansion, we will talk about gas thermometer, vapor thermometer. So, all these thermometers have one thing in common which is all undergoes thermal expansion. So, when they are expose to higher temperature, they will undergo thermal expansion.

So, depending on whether I am choosing a solid material or liquid material or gas material, I will have solid expansion thermometers, liquid expansion thermometers and gas expansion thermometers. And we will take various examples under these categories such bimetallic thermometer, liquid in glass thermometer, pressure thermometer, gas thermometer and vapor pressure thermometer.

Then we will talk about thermo electric sensors and will talk about thermo couples here. So, if you take two dissimilar metals and form two joints, so you take two dissimilar metals and form two joints, so one you take one dissimilar metal another dissimilar metal and form two joints. Now, if these two joints or junctions are kept at two different temperatures, an EMF will be produced. This EMF will be in the range of millivolts. Now, the EMF produced depends on the temperature difference between these two junctions.

Now, if I keep temperature of one junction fixed, and the other junction I call measuring junction and put that junction to the medium whose temperature I am measuring then the EMF produced depends only on the temperature of the measuring junction, because other junction is has been kept at constant temperature, which you call that as reference junction. So, this way I am using thermo electric property of materials. So, the basic property that we are using is if you take two dissimilar materials and form two junctions if two junctions are kept at two different temperatures, an EMF is produced; and these EMF is depends on the difference between these two junctions temperature.

Next, we will talk about the electrical resistance sensors. Under this, we will talk about resistance temperature detectors and thermistors. Electrical resistance sensors uses the following property, which depends on temperature. We know that the resistance of a wire will change with change in temperature, and this property is reproducible. So, if I take a resistance wire, and put it into the medium whose temperature I am measuring, and now can measure the change in resistance, then I have a temperature measuring instrument in hand. And in our previous lectures, when we talk about transducers, we have seen that change in resistance can be measured using Wheatstone bridge principle.

So, by measuring the change in resistance of an electrical wire with change in temperature, one can measure temperature. So, using this principle, two instruments we will talk about r - resistance temperature device or resistance temperature detector and thermistors. Finally, we will also talk about instruments that make use of principle of radiation. Under these, we will talk about total radiation pyrometer and optical pyrometer. The word pyro comes from fire; so, it essentially reflects high temperature. So, all these instruments functions based on some temperature dependent effect on the materials.

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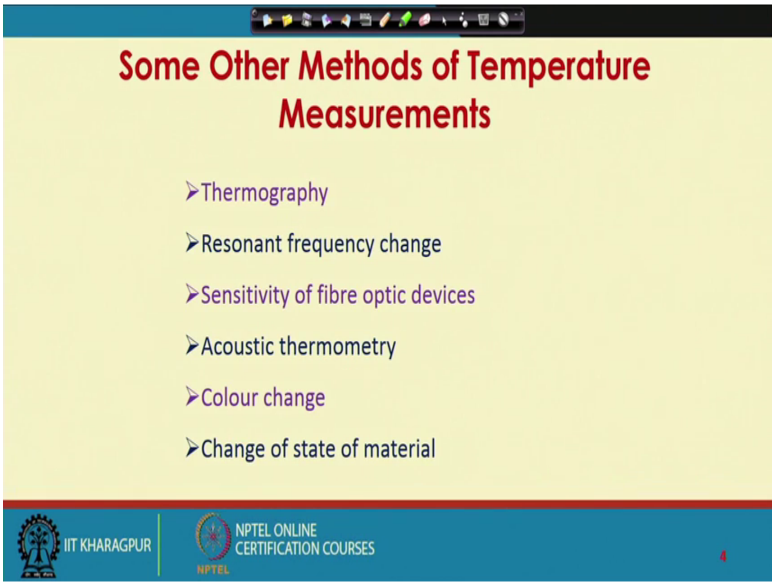

There are several others methods of temperature measurements. Here the other principles or other effect of temperature on materials that can also be used for temperature measurement are listed; thermography, resonant frequency change, sensitivity of fiber optic devices, acoustic thermometry, colour change, change of state of material. So, change of state of material may be as simple as you make a cone say take a metallic cone or take a ceramic cone. Take a metallic cone you know the temperature at which it will start melting. So, you put the cone into the medium whose temperature you are measuring. When it starts melting, you know that you know the temperature of the medium.

So, basically what you do, you take several cones which melts at different temperatures that can be done by take by making a various cones of various materials or we can take ceramic materials and by varying compositions we can vary their melting point. So, by putting various cones say to a high temperature source I can see which cone melts, and I can have an indication of temperature of the medium. So, this change of state a material principle as simple as that. So, basically we have various principles or various temperature dependents defects on materials which can used for temperature measurements. Now, this week and the following week we will be talking about several instruments, which make use of these principles.

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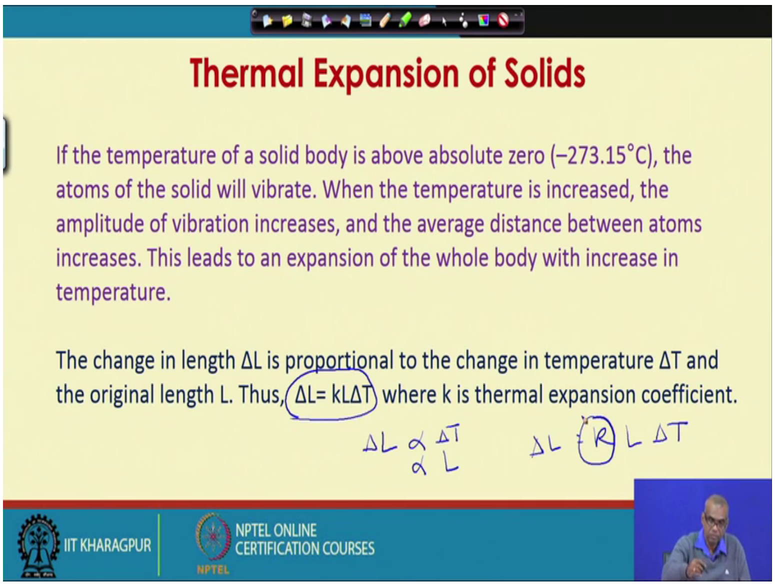

So, we will start our discussion on thermal expansion of solids. Under these, we will be talking about bimetallic thermometer. If the temperature of a solid body is above absolute 0, now you know it is minus 273.15 degree Celsius or 0 degree Kelvin, the atoms of the solid will vibrate, when the temperature is increased the amplitude of vibration increases and the average distance between atoms increases. This leads to an expansion of the whole body with increase in temperature. So, a solid body will expand upon heating because when temperature increases the amplitude of vibration increases and the average distance between atoms increases.

The change in length is proportional to the change in temperature and the original length. So, we can write the change in length as directly proportional to change in temperature directly proportional to length. So, you can write change in length is k L delta T, where k is known as thermal expansion coefficient; different solid material has thermal expansion co efficient. So, given the change in temperature and the original length of a solid body, if I know the thermal expansion coefficient, I can find out what will be the change in dimension upon change in temperature.

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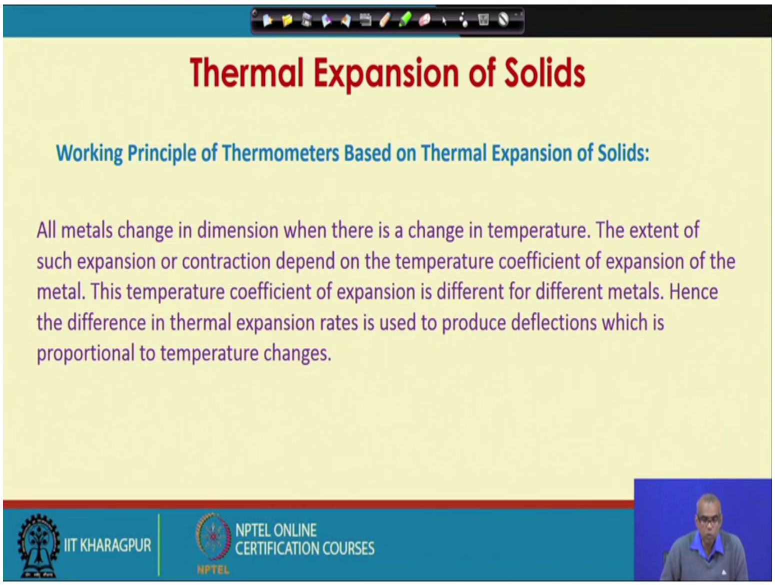

So, following is the working principle of thermometers based on thermal expansion of solids. All metals change in dimension when there is a change in temperature. The extent of such expansion or contraction depend on the temperature coefficient of expansion of the metal. This temperature coefficient of expansion is different for different metals hence the difference in thermal expansion rates is used to produce deflections which is proportional to temperature changes.

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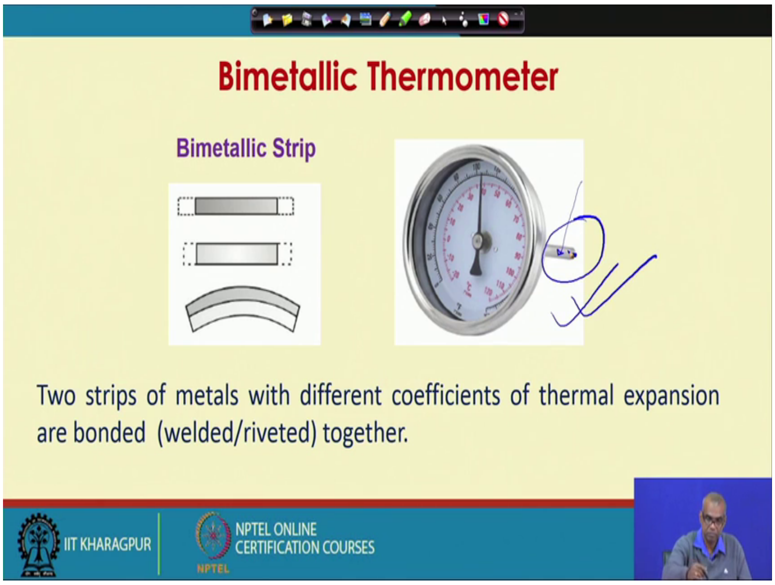

Now, let us see how the principle is used to make a bimetallic thermometer. The bimetallic thermometer looks like this. So, what you see from outside is a pointer and scale dialer. And you see this part. This is put in to the medium whose temperature you are measuring. So, inside this there is a bimetallic strip whose one end is fixed here, and the other end is connected to the pointer and scale.

So, what is bimetallic strip? It is simply two strips of metals with different coefficients of thermal expansion. So, you take two metallic strips which has different thermal expansion coefficients and bond them together, they may be welded or riveted. So, take two different metals with different thermal expansion coefficients, and they are bonded together, this will be a bimetallic strip.

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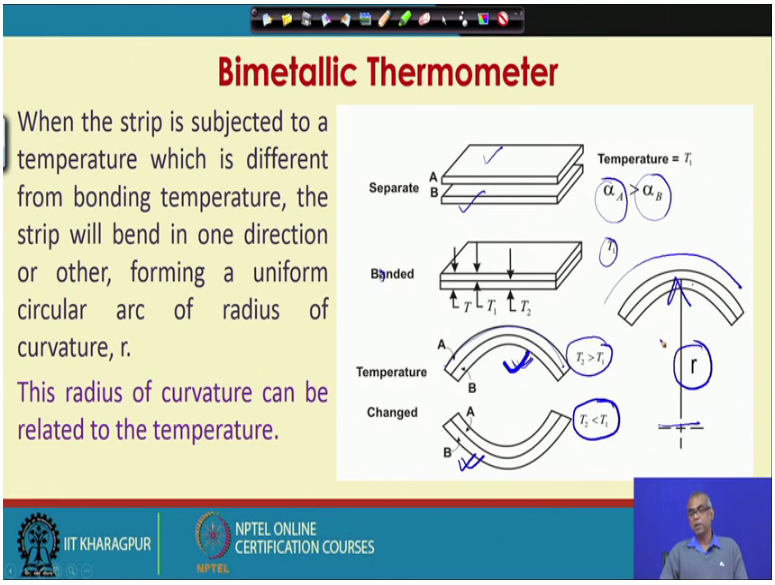

When the bimetallic strip is subjected to a temperature which is different from the bonding temperature, the strip will bend in one direction or other forming a uniform circular arc of radius of curvature r. So, what do you mean is you have two metallic strips A and B. Thermal expansion coefficient of A let us call alpha A; and thermal expansion coefficient of B, let us call alpha B. Let us consider alpha A is greater than alpha B. Now, these two metallic strips let us say are bonded at temperature T 1. So, this is bonded there are there well let us say there are welded at temperature T 1.

Now, I take this bimetallic strip to a temperature source which is different from the bonding temperature T 1. So, if I take it to a temperature which is higher than the bonding temperature, the bimetallic strip will form a circular arc like this; why because a has thermal expansion coefficient more than that of B. So, A will bend more, A will be changing in dimension more compare to B. So, together they will bend like this, A will be on the top of B like this.

If I take these bimetallic strip to temperature which is lower than the bonding temperature that means, T 2 less than the T 1 now since the thermal expansion coefficient of A is more than B, A will contract more than B. So, it will bend like this. So, whatever it does the radius of curvature is related to temperature. So, this is the radius of curvature. This has bent as a circular arc it has formed a uniform circular arc and the radius of the circular arc, if we call r, this r is related to a temperature for given bimetallic strip.

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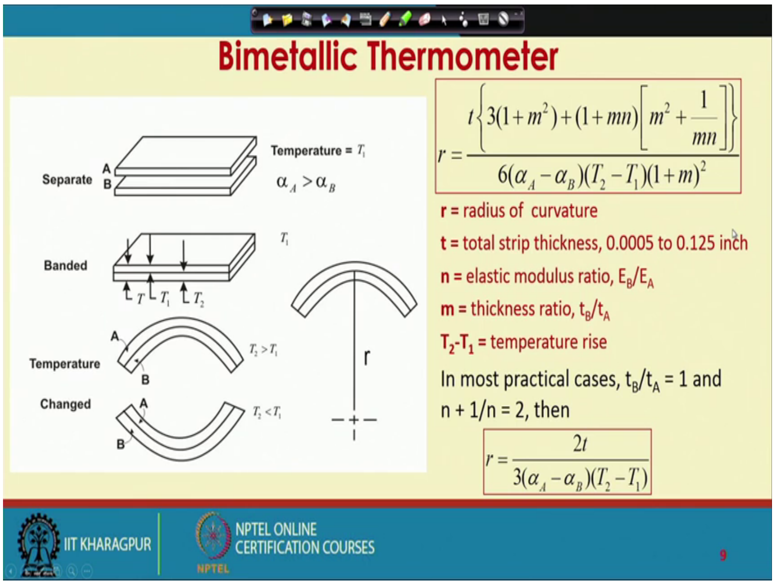

This is an equation which relates this radius of curvature to different parameters related to the bimetallic strip. Here r is radius of curvature; t is total strip thickness. So, total strip thickness usually varies between 0.0005 to 0.125 inch. So, remember the total strip thickness is the thickness of strip A plus thickness of strip B; say if I call thickness of strip A is t A and thickness of strip B is t B, t is the total strip thickness equal to t A plus t B. m is the thickness ratio t B by t A; n is elastic modulus ratio E B by E A. And T 2 minus T 1 is the temperature rise.

Now, this equation can be simplified under the assumption that we can choose the strip thickness equal meaning the thickness of metal strip A and thickness of metal strip B may be same. And in most practical cases it will be like that only, so t B by t A equal to 1. And if you also consider n plus 1 by n equal to 2, then this equation you will see that can be greatly simplified to this.

So, r is 2 t divided by 3 into alpha a minus alpha b into T 2 minus T 1. So, this equation will allow you to find out the radius of curvature for a bimetallic strip given the total strip thickness the expansion coefficient for strip A and strip B and the temperature rise. See this information are given you can find out the radius of curvature or the deflection for the bimetallic strip.

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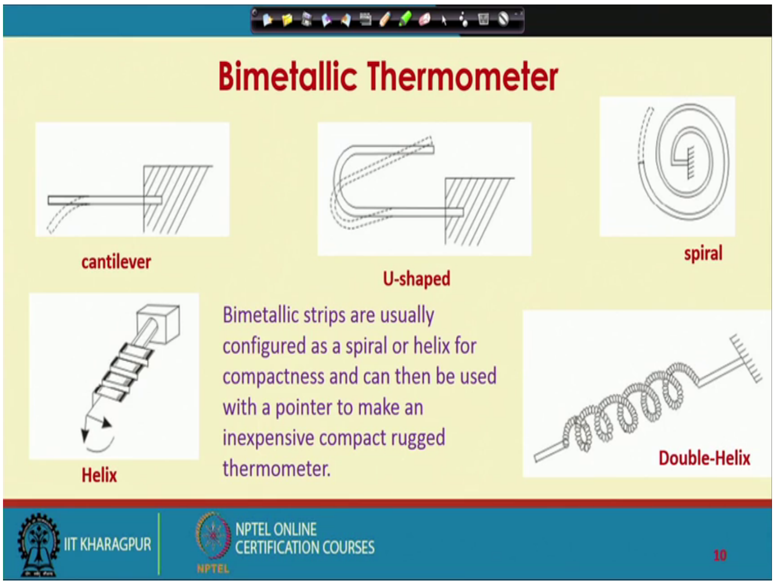

Biometric strips are usually configured as a spiral or helix for compactness and can be used with a pointer to make an inexpensive compact rugged thermometer. So, these are the usual configuration of bimetallic strips, cantilever, U-shaped, spiral, helical and double helix; very commonly spiral and helical configurations are found. In all these cases you see that one end is fixed, and the other end is subjected to the medium whose temperature you are measuring.

So, it is the deflection of the other end that is related to the temperature. So, the deflection of the other end will cause a movement of the pointer against the scale, and you can measure the temperature. So, bimetallic strips are usually configured as a spiral or helix for compactness and can then be used with a pointer to make an inexpensive compact rugged thermometer.

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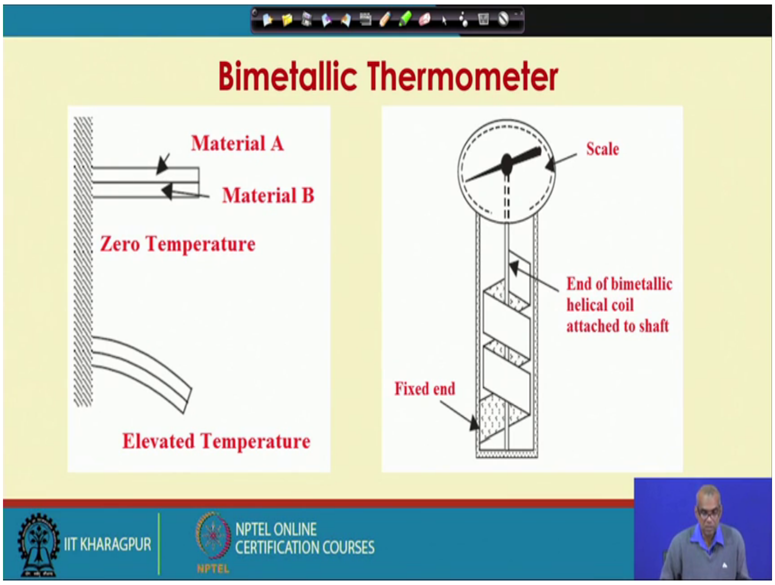

So, this is another example or schematic. You have this bimetallic strip made of material A and material B. One end is fixed. If you take it to a temperature different than the bonding temperature or elevated temperature, it has bend like this. So, this deflection is a measure of the temperature. So, here you see inside, you have a helical coil of bimetallic strip.

So, you have a bimetallic strip, and you have formed a helical coil out of it. So, the helical coil is attached to the shaft which is connected to the pointer and scale. One end of the helical coil is fixed. So, if I subject it to the medium whose temperature I have to measure, the other end of the bimetallic strip will show a deflection which will cause this pointer to move against the scale, and you can calibrate the scale directly in units of temperature for temperature measurement.

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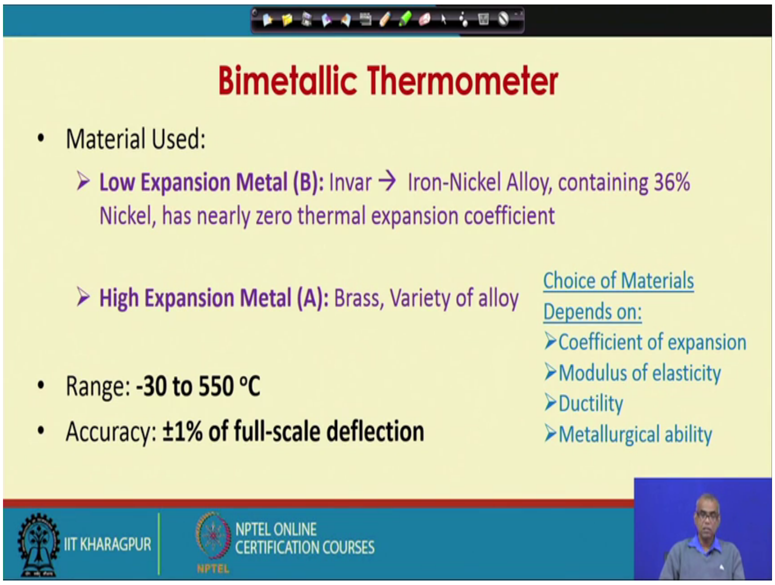

So, what are the different materials that can be chosen for making bimetallic thermometer. Choice of materials will depend on coefficient of expansion coefficient of thermal expansion, modulus of elasticity, ductility, metallurgical ability etcetera. Commonly the low expansion metal B that is used is invar which an iron-nickel alloy containing 36 percent nickel, and has nearly zero thermal expansion coefficient.

So, what is normally done is bimetallic strip will require two metallic strips. So, we choose one strip or we choose one metal whose thermal expansion coefficient is very low. So, you call that low expansion metal, and another metal you choose which has high thermal expansion coefficient.

So, the low expansion metal commonly used is invar which is an iron-nickel alloy containing 36 percent nickel, and it has 0 thermal expansion coefficient. The high expansion metal normally chosen as brass and variety of alloy. Typical range of a bimetallic thermometer is minus 30 to 55 degree Ccelsius. The accuracy is plus minus one percent of full scale deflection. So, these are indicating range and accuracy.

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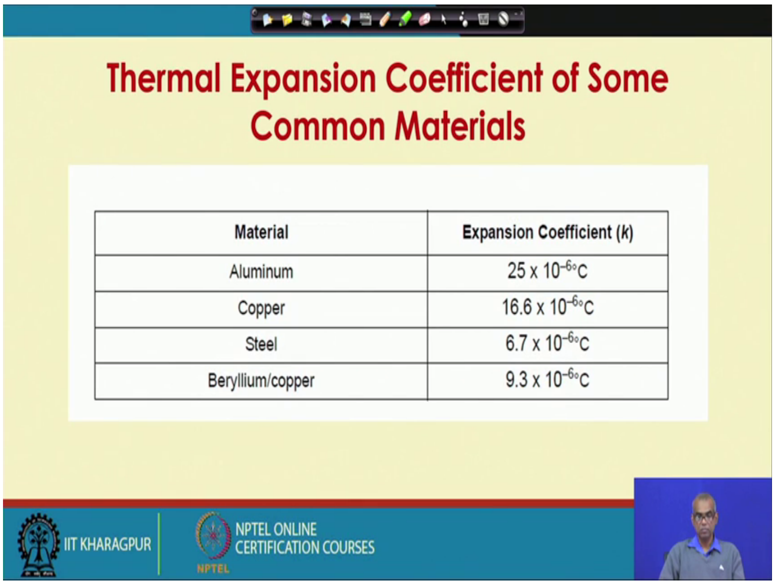

Material	Expansion Coefficient (*k*)
Aluminum	25×10^{-6}°C
Copper	16.6×10^{-6}°C
Steel	6.7×10^{-6}°C
Beryllium/copper	9.3×10^{-6}°C

Here we have expansion coefficient of some common materials, aluminum, copper, steel, beryllium copper. The order is all same 10 to the power of minus 6. Among these aluminum has highest thermal expansion coefficient.

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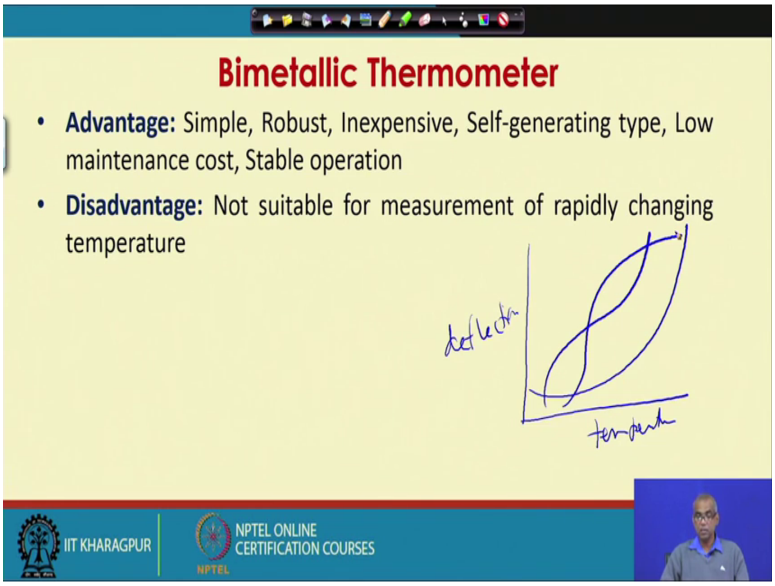

The advantage of bimetallic thermometer is as follows. It is simple, robust, inexpensive, self-generating type; that means, external power source is not require, low maintenance cost and stable operation. Disadvantage; not suitable for measurement of rapidly changing temperature. Also the deflection of different materials typically show non-linear relationship like this for different materials. So, the bimetallic thermometer typically shows non-linear deflection characteristics.

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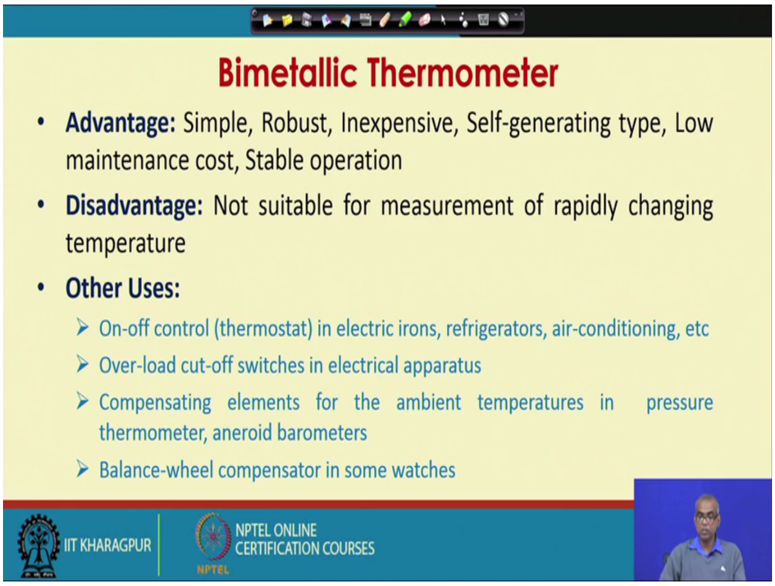

There are some other uses for bimetallic thermometers or bimetallic strips. It is used as on-off controller or thermostat in electric irons, refrigerator, air-conditioning etcetera. It is used as over load cut off switches in electrical apparatus, can be used as compensating elements for the ambient temperatures in pressure thermometer, aneroid barometers. It is also used as balance wheel compensator in some watches.

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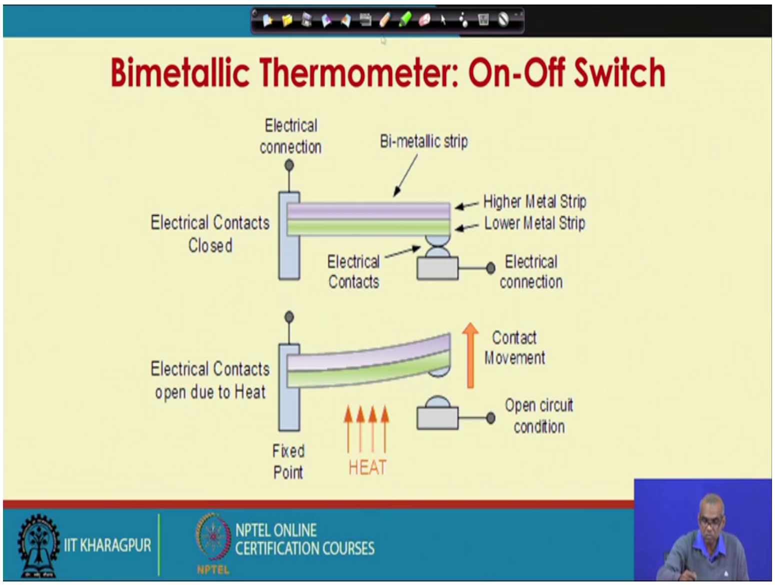

So, this is how it can be used as on-off switch. So, here you see the electrical contacts is established. You have this is bimetallic strip. Now, if I heat it, it will bend. And depending on a particular temperature, the bending will be such that the electrical connection will no longer be there. So, the circuit will be opened. So, you can close the circuit and open the circuit at high temperature. So, if you want that the circuit will be broken if the temperature exceeds certain value, I can then suitably design a bimetallic strip and can make an arrangement like this.

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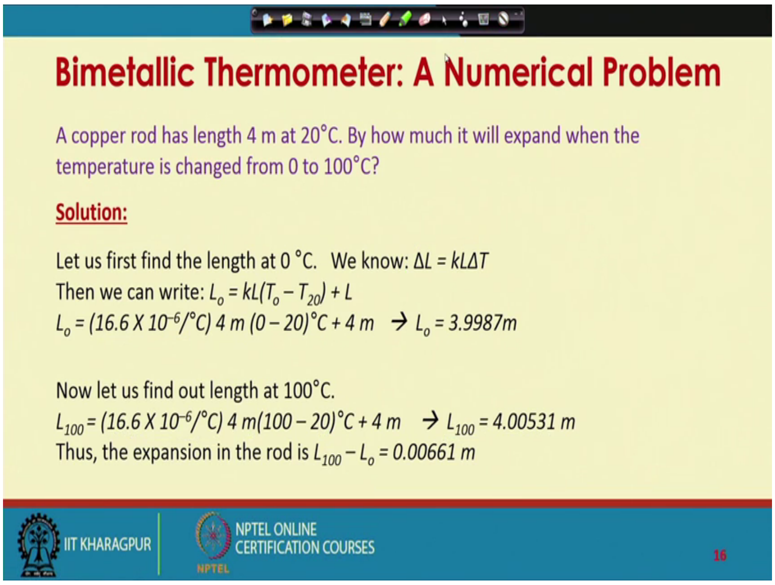

So, we will stop this discussion with a numerical problem. Let us consider a simple numerical problem. A copper rod has length 4 meter at 20 degree Celsius. By how much it will expand when the temperature is changed from 0 to 100 degree Celsius. So, I know that a copper rod has exact length 4 meter at 20 degree Celsius, I want to how much it will expand when the temperature is changed from 0 to 100 degree Celsius. So, how do I solve is all we have to do is you have to find out what will be the temperature at 0 degree Celsius and what will be the length at 0 degree Celsius, and what will be the length at 100 degree Celsius and then I can find out. So, information I need to know is thermal expansion coefficient.

So, first let us find out the length at 0 degree Celsius. We have talked about this relationship. So, simply make use of this relationship. So, this is the thermal expansion coefficient of the copper L is 4 meter at 20 degree Celsius. So, the length at 0 degree

Celsius is this. Similarly, you can find out the length at 100 degree Celsius, thermal expansion coefficient length at 20 degree. So, 100 degree Celsius it becomes this. So, just take the difference, so the expansion of the rod will be this. So, this is a say straight forward simple application of this formula. Of course, we need to know the thermal expansion coefficient of the material; here it is copper rod. So, we will stop our discussion on bimetallic thermometers here.