Engineering Metrology
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Lecture - 27
Temperature Measurements

Welcome to the next lecture on Temperature Measurement.

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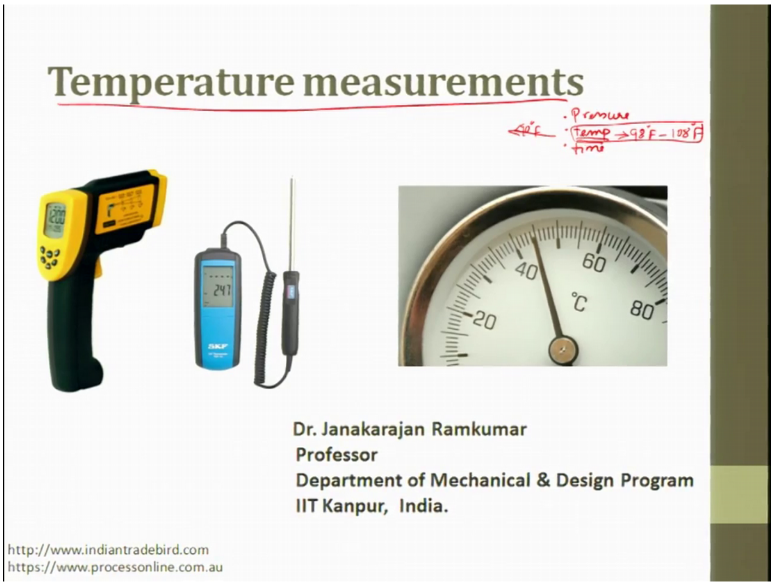

In manufacturing there are 3 process parameters which are very important. One is pressure, other one is temperature, and the last one is time. If I can monitor them; that means, to say measure them and then understand them then I, can dictate the process through which the part is made. So, in these 3 parameters, temperature is also one parameter, which is very very important. If I can know how to measure the temperature and monitor it, then I can understand more about the process.

Let me give you a very simple example; whenever there is a fever, we have a temperature rise. That means to say our body temperature is measured from maybe 98 degree Fahrenheit to 108 degree Fahrenheit, I am just approximating it. So, this is the temperature, when the body moves towards a higher temperature. There is also something called as fever at lower temperature. This in a very crud sense, people call it as cold fever. So, here the body temperature falls below 90 degree Fahrenheit. The temperature which is on this side 98 to 100 and 8 measurement is very much available everywhere. Here you can have contact type, you can have non-contact type ok. When you talk about contact type, measurement you try to keep a thermometer then, you can also have a paint thermal paint, which is there, which we keep it on the 400 measure.

But we currently do not have a technology to measure a temperature anything less than 98 to 90 and measure the body temperature. And once the body temperature goes below a certain limit then it is very deadly in the brain starts failing. See we know this side, but we do not know this side and we do not have devices, which is normally used in the hospital at this side. So, you see temperature still it is a huge challenge to measure ok.

And the next operation what I would take is in machining. In machining what happens we always try to measure the temperature which is getting induced, while the processes happening. But here what happens is when you try to take a surface, there is a thermal conductivity done on the surface. So, the temperature what we measure at a point and a slightly far away there is a difference. And then, we try to measure it by contact type and non-contact type, but still however best we say we are not exactly able to measure the temperature at the contact point.

There is lot of research which goes on and lot of advancement which is happening still, there is a huge challenge in temperature measurement. So, our next topic of discussion is going to be temperature measurement.

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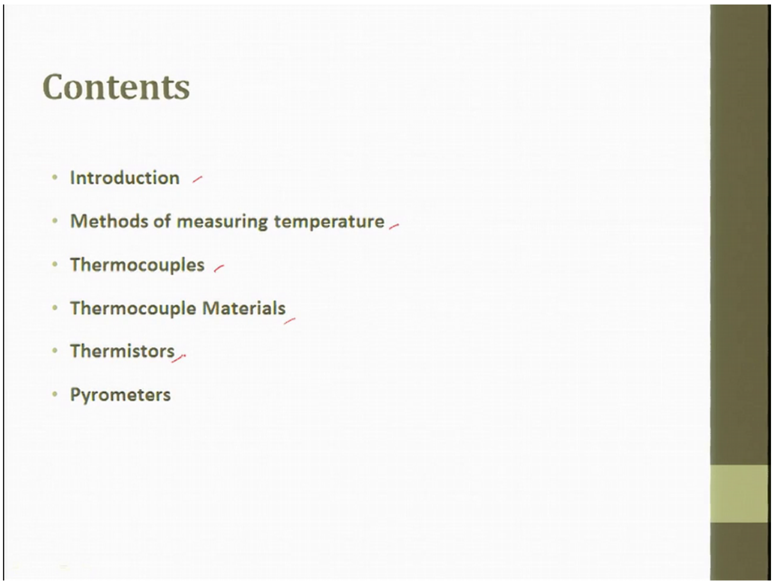

So, our content we will have an introduction, followed by a different methods of measuring, temperature thermocouple which is commonly used in manufacturing platforms are manufacturing industries. So, then we have thermocouple material, we will understand little bit about thermocouple, then we will talk about thermistors, and finally about pyrometers.

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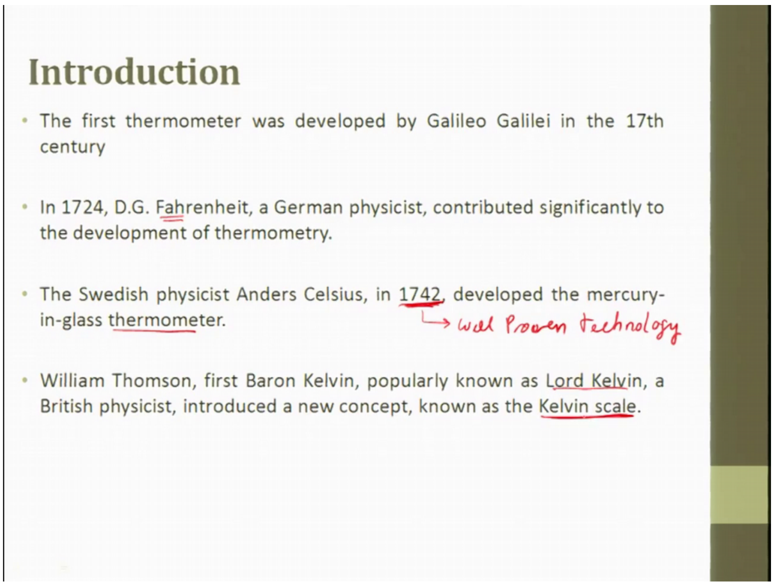

Introduction, the first thermometer was developed by Galileo in 17th century. In 1724 Fahrenheit a German physicist contributed significantly to the development of a thermometer. That is why, we still call it as Fahrenheit. The Swedish physicist Celsius in 1742 developed the mercury in glass thermometer, very long back and even today this is a well proven technology. Look at it is inception is 1742; even today we follow this mercury based glass thermometer for measuring temperature. William Thomas the first boron Kelvin popularly known as Lord Kelvin a British physicist introduced a new concept known as Kelvin scale.

So, Kelvin scale when a temperature goes below 0, all these things come into existence. So, the stars, who contributed towards thermometer are Fahrenheit, Celsius and Kelvin they are all remember today for temperature measurement.

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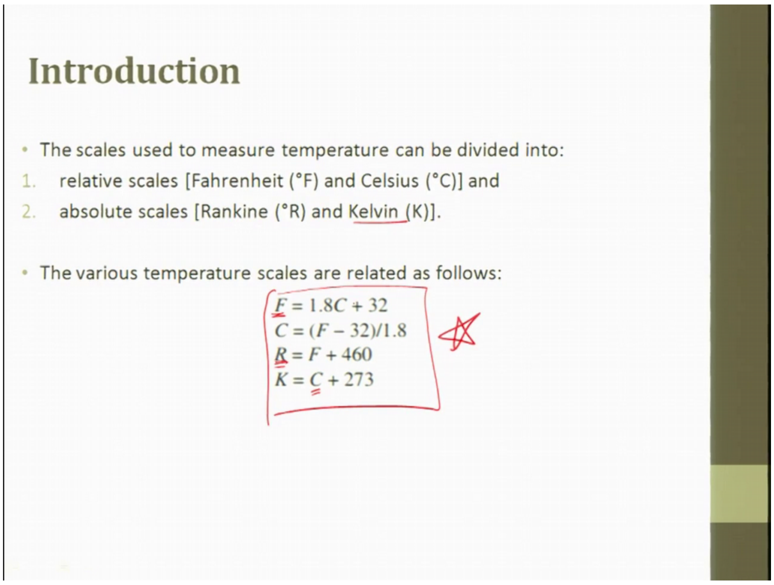

The scales used to measure temperatures can be divided into relate to scale; that means, to say Fahrenheit and Celsius and absolute scale which is Rankine and Kelvin. So, there are they have divided, the measurement of temperature can be divided into two types; relative scale and absolute scale Fahrenheit and Celsius then, Rankine and Kelvin.

So, here is the relationship between each other ok. Suppose you know one, with this relationship you can cross correlate with the other. Fahrenheit is 1.8 time C plus 32, Celsius is F minus 32 divided by 1.8, Rankine is F plus 460. Suppose if I know Fahrenheit, I can now converted into Rankine. Then Kelvin is C plus 272. So, if I know Celsius, I can try to figure out Fahrenheit, I from Fahrenheit I can cross correlate with that of Rankine. So, you can see this relationship is very important, which is used to change the scales from one type to the other type.

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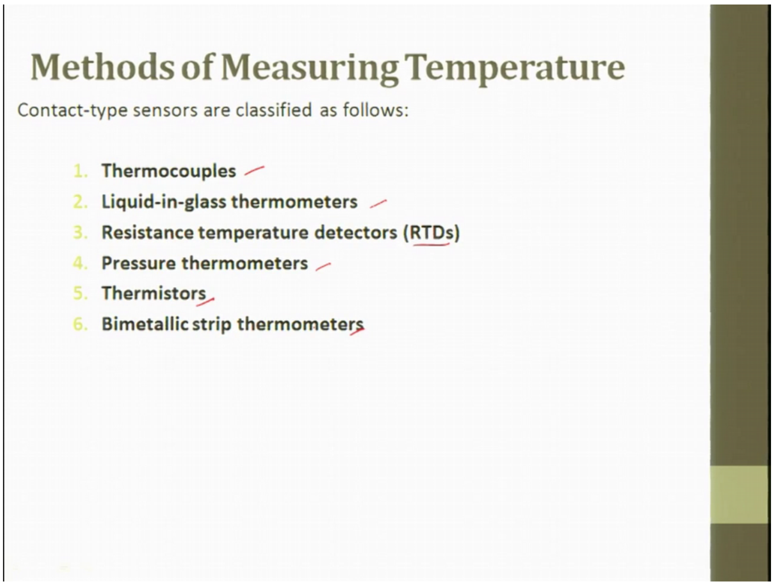

So, different methods of measuring temperature, contact type sensors are classified as the following. Thermocouple, liquid in thermometer, resistance temperature detector; RTD, pressure thermometers, thermistors and bimetallic strip thermometers, bimetallic by two different materials put in a strip form to measure temperature.

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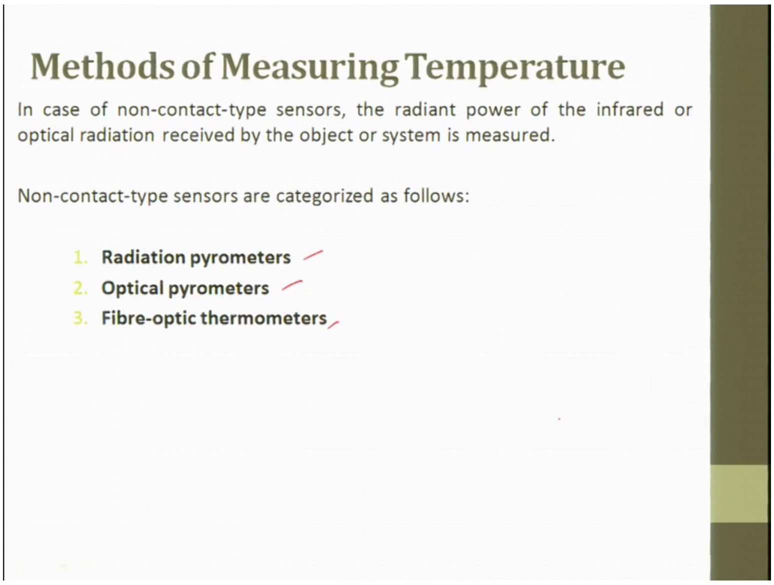

In case of non-contact, contact non-contact, in case of non-contact, the radiant power of infrared or the optical relay radiation received by the object or the system is measured. So, non-contact type sensors are radiation pyrometer, optical pyrometer and fibre-optic thermometer. When you go to airport and just before going for the immigration check, today you can see lot of infrared camera install which they used to try to scan the temperature in a noncontact manner and find out if the person is having any temperature. And if there is any peculiar behavior in his body temperature then, take warrant time.

So, that works on radiation type measurements.

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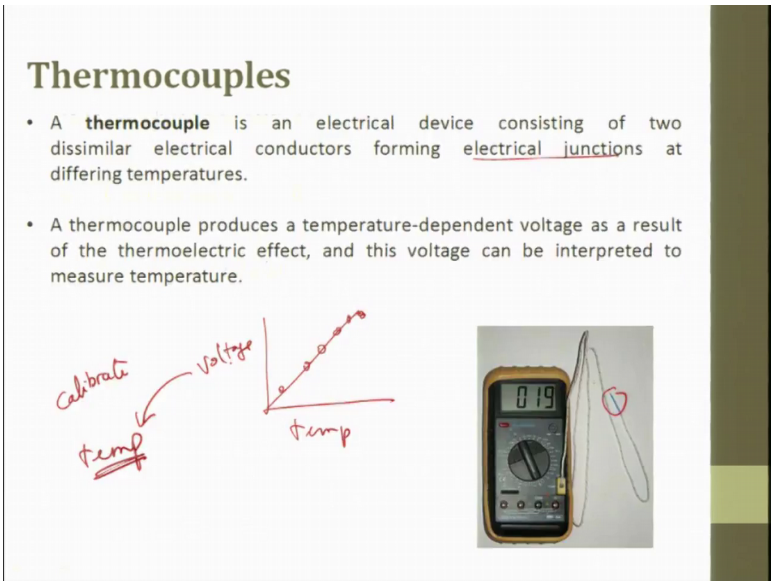

Thermocouples: a thermocouple is an electrical device consisting of two dissimilar electrical contacts forming electrical junctions at different temperatures. A thermocouple produces a temperature dependent voltage. So, as you can say the voltage and temperature, as the temperature increases the voltage increases maybe just for a simplicity I make it into linear ok. As the thermocouple produces temperature dependent voltage as a result of thermoelectric effect and this voltage can be interpreted to measuring temperature ok.

So you measure temperature then, measure temperature converted into voltage then this voltage is calibrated already and then what you get to see is a temperature. So, this is a thermocouple which is used and these are the junction points.

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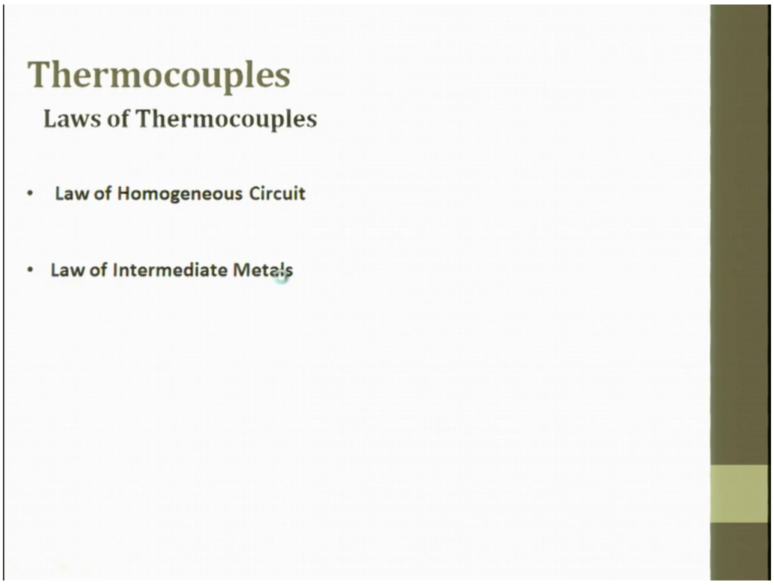

The law of thermocouples, there are two laws of thermocouple: one is called as law of homogeneous circuits the other one is called as law of intermediate metals.

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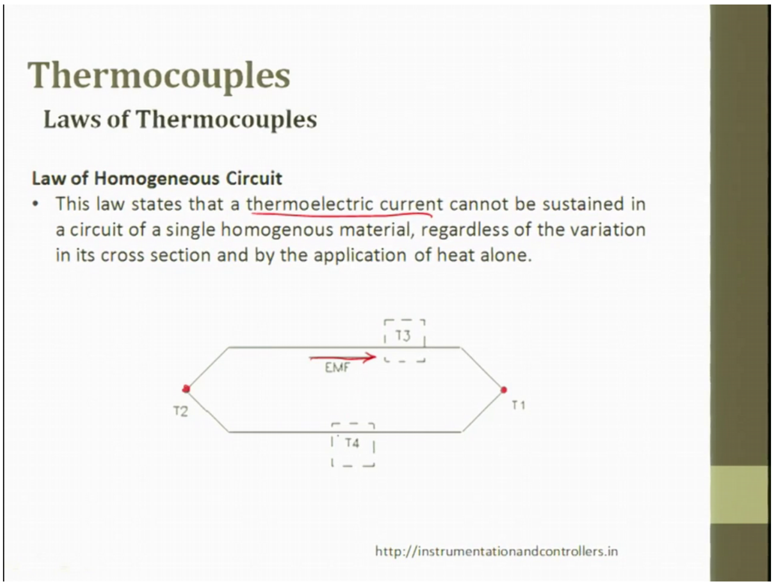

What is law of thermocouple? Law of thermocouple circuit, this law states that a thermo electric current cannot be sustained in a circuit of a single homogeneous material, regardless the variation in its cross section and by the application of heat alone. So, I repeat the law states that the thermo electric current cannot be sustained in a circuit of a single homogeneous material ok, regardless of the variation in the cross section; that means to say thicker thinner and by the application of heat alone.

So, you have a temperature 1 here, you have a temperature 2, all temperature 1 here 2 here and you have an EMF, which is created 3 and 4 are the other sources.

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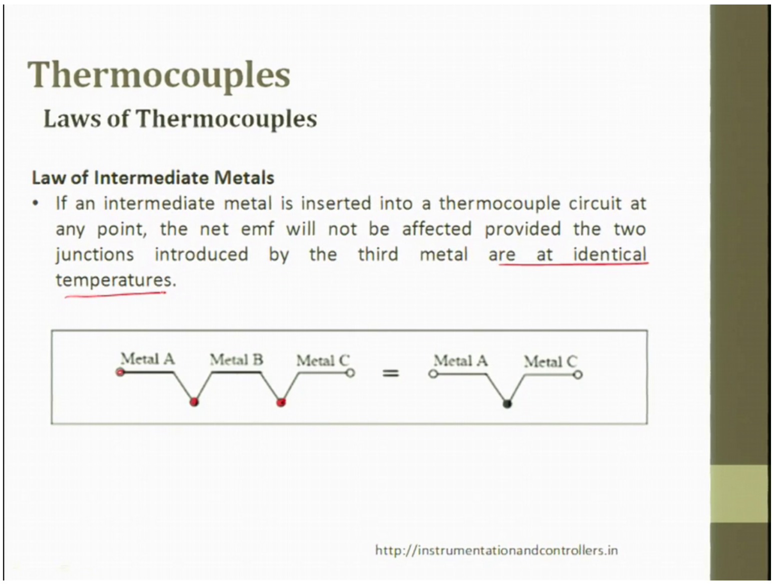

So, the law of intermediate metal, if an intermediate metal is inserted into a thermocouple circuit at any point, the net emf will not be affected provided the two junctions introduced by the third metal are at identical temperature. So, if you have metal A, metal B and metal C, so you have a junction so they say that we net emf will not be affected provided the 2 junctions introduced by the third metal; by the third metal are at identical temperature.

So, two laws, one is law of homogeneous circuits and the other one is called as law of intermediate metals. So, these two are the basic laws, depending upon these laws you can try to develop thermocouples.

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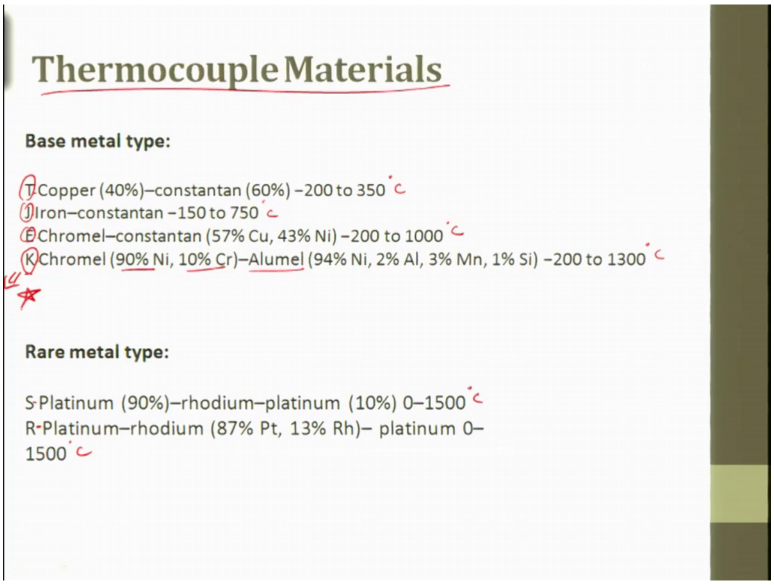

So, what are the different types of thermocouple materials which are available today? The base metal type are T copper 40 percent T, J, E and K. When we try to measure temperature in the manufacturing process, we always say K type thermocouple. So, these are the different types T type, J type, E type and K type. So, each type has a prop has an alloy which is added. So, T type is copper is 40 percent, constantan is 60 percent and it is used from minus 200 to 350 degree Celsius right, so here.

So, next is iron, J type is iron and constantan which is used from minus 150 to 750 degree Celsius. Chromel constantan, which is used from minus 200 to 1000 degree Celsius and K chromel which has 90 percent nickel and 10 percent chromium and alumel will 94 percent nickel, 2 percent aluminium, 3 percent magnesium and 1 percent silicon can be used from 200 degree Celsius minus 200 degree to 1000 degree celsius. The technology is very well known, when you go for higher degree temperature, when foe lower degree temperature it is still a big challenge.

The rare earth metals there are S type, R type. So, S type is platinum rhodium and platinum percentage from 0 to 1500 degree Celsius, and platinum rhodium which is used for a combination which is also used to go up to 1500 degree Celsius. So, most predominantly used one is K type.

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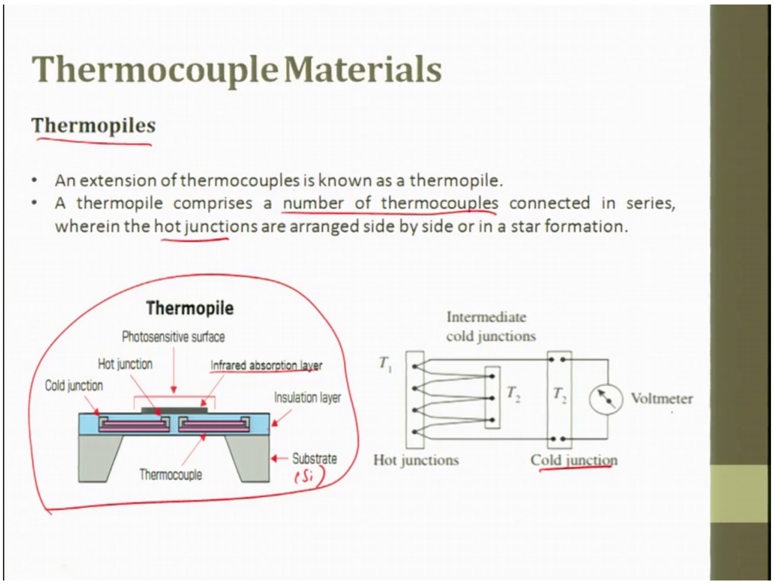

Thermopiles which are now getting little bit popular and extension of thermocouple is called as thermopile. A thermopile comprises a number of thermocouples connected in series where in the hot junction are arranged side by side or in star formation. So, this is a typical thermopile which is made from MEMS structure.

So, these are thermocouples. So, in this thermocouple, you will have a hot junction, you will have a cold junction, you will have a hot junction, cold junction, hot junction, so same junction were cold junction hot junction fine. And then, on top of it you will have infrared absorber layer, then photosensitive surface is put on top of it and this one is insulated. So, in an ulation, you have this cold junction and hot junction thermocouples and then you have a basic substrate, this substrate is made out of silicon. So, this is and number of thermocouples are connected to measure the temperature they are connected in series, where in the hot junction are arranged side by side hot junction are arranged side by side.

So, if you put it in the schematic form, this is your hot junction, this is your cold junction, you have T 1 the hot junction, so T 2 is your T1. So, it is all at attached and then we have a T 2 cold junction here and basically you try to measure the emf and it is displayed in terms of voltage.

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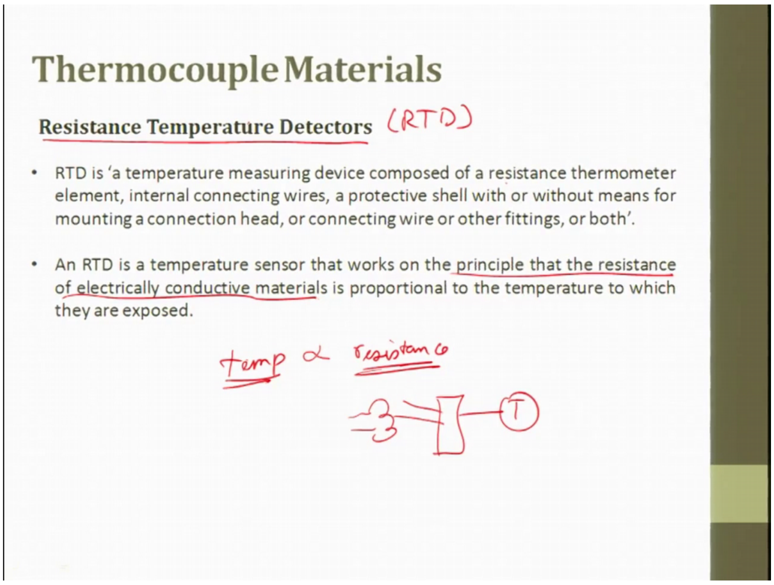

We also have resistance type director which is otherwise called as RTD, RTD is a temperature measuring device composed of resistance thermometer element, internal connecting wire, a protective shell with or without means for mounting a connecting head, or connecting wire or other fittings, on both. And RTD is a temperature sensor that works on the principle of principle that the resistance of electrical conductor conductivity material is proportional to the temperature to which they are exposed to.

So, here temperature is proportional to the resistance. The principle of resistance of the electrical conductor wire is proportional to the temperature to which it is exposed. So, here you keep a rod, so there is a RTD resistance temperature detector. So, the temperature the source, whatever it is let me put a source here. So, it hits and then what you get measure is a temperature ok. So, this is nothing but resistance base temperature measuring device.

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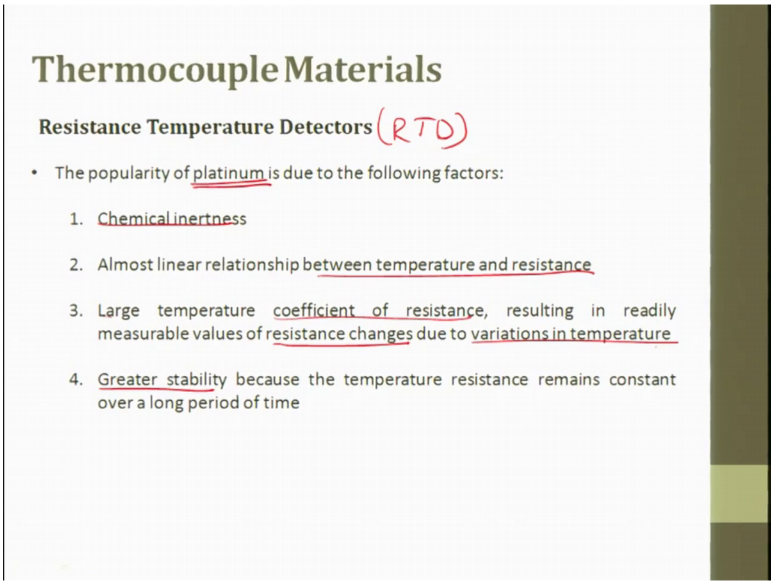

The resistance temperature detector, the popularity of platinum is due to the following factors: Platinum is chemically inert, it is most expensive also costlier than gold, so chemically inert almost linear relationship with temperature and resistance exist. So, this makes platinum a very good a candidate.

The large temperature coefficient of resistance resulting in rapidly measurable values of resistance say resistance changes due to variation in temperature. So, large temperature coefficient of resistance which results in readily measurable values of resistance change due to variation in temperature; the greater stability because of temperature resistance remains constant over a long period of time. The greater stability, chemical inertness, the large thermal coefficient of expansion, readily measurable values of resistance change, all these things make platinum you have popular choice for RTD; what is RTD? RTD is nothing, but resistance temperature detectors.

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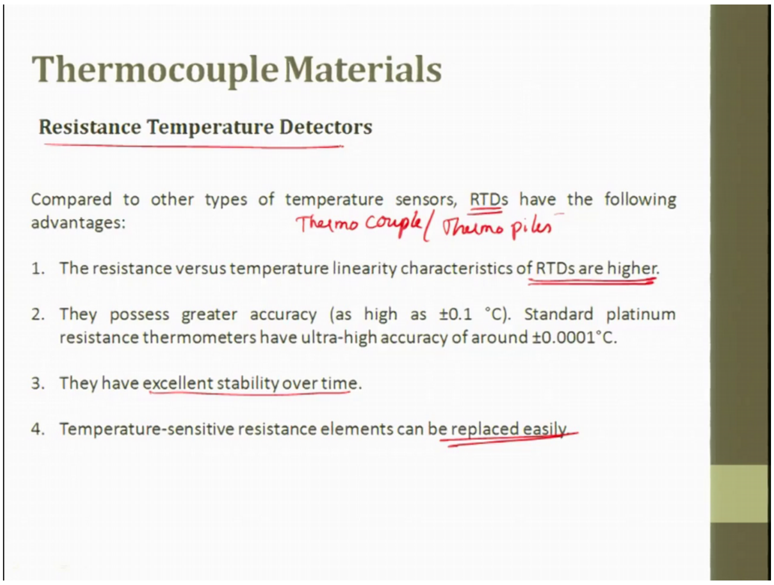

Compared to the other type of temperature sensors, RTD have the following a advantage.

What are the other sensors we studied, thermocouple then, pile thermopiles ok, compared to this how is RTD better, the resistance versus temperature linearity characteristics of RTD are higher. See when you try to choose any sensor. We always make sure that the response falls in the linear range; why, mathematical equation can be expressed only for that we always try to operate the entire sensor in the linear range or we find out the linear range try to use it only during the linear range.

The resistance versus temperature linearity characteristics of RTD are higher, they possess greater accuracy compared to the other two techniques. They have excellent stability over time. Then, temperature sensitive resistance elements can be replaced very easily, which the other things cannot be done, it has to be wiring then this has the and these are the advantage of using RTD over the other temperature measuring devices.

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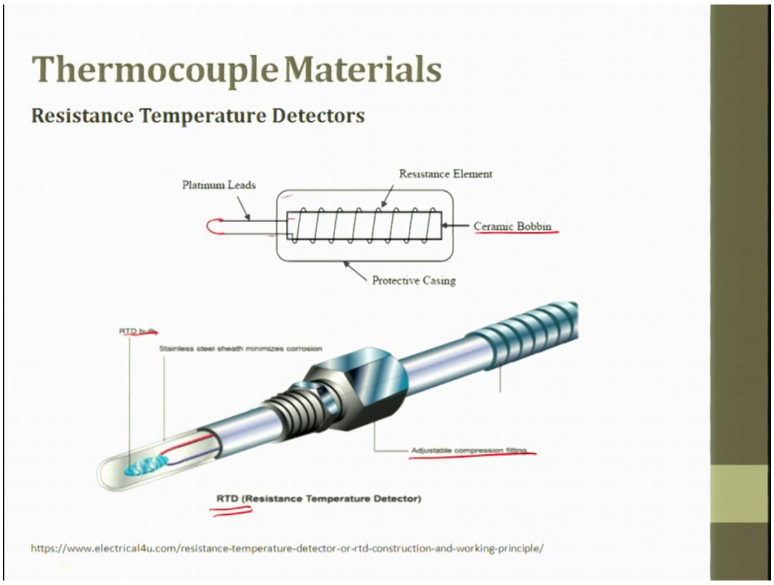

This is how a RTD looks like. A platinum lead is here, so this is how it is exposed to the temperature and then, it is put inside a protective casing and inside the protective casing the lead is wound around a ceramic bobbin ok. So, the temperature is measured then, this is push this is communicated inside and there is a resistance element, these are resistance element ceramic bobbin you try to get it. When you this is a schematic diagram, when you look at a original product you will have a stainless steel a seal sheet, which is kept a around the RTD bulb this bulb. Then, you have two leads which goes and then here is an adjustable compressing fitting, and inside this you have this lead which goes and we try to measure it.

So, this is how a RTD looks like. You can use it something like your thermometer, take it like a, this will be something like this like a pen. So, you can try to push it and then try to get the temperature. So, this is how RTD works or this is how RTD looks.

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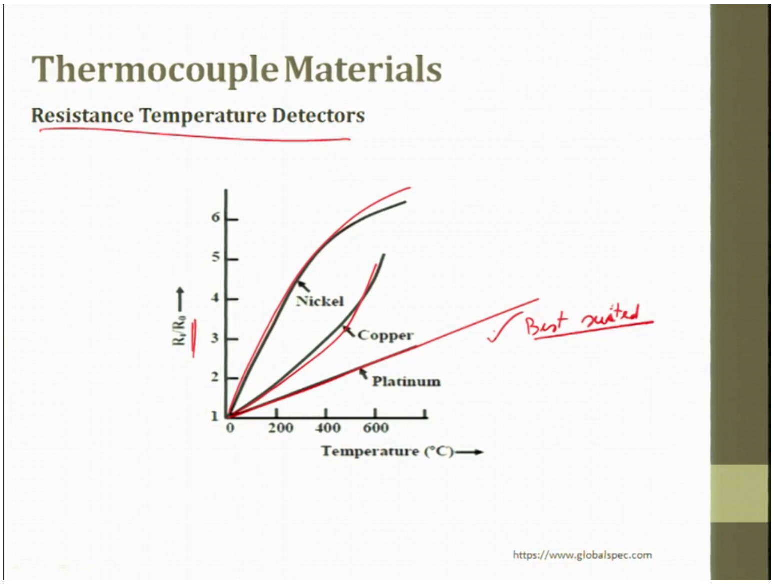

So, the response of RTD, so RT by R0 if you take and with respect to temperature you see there is a linear trend for platinum, copper there is a exponential trend or there is a change in the linearity, nickel it is also there this is the best suited.

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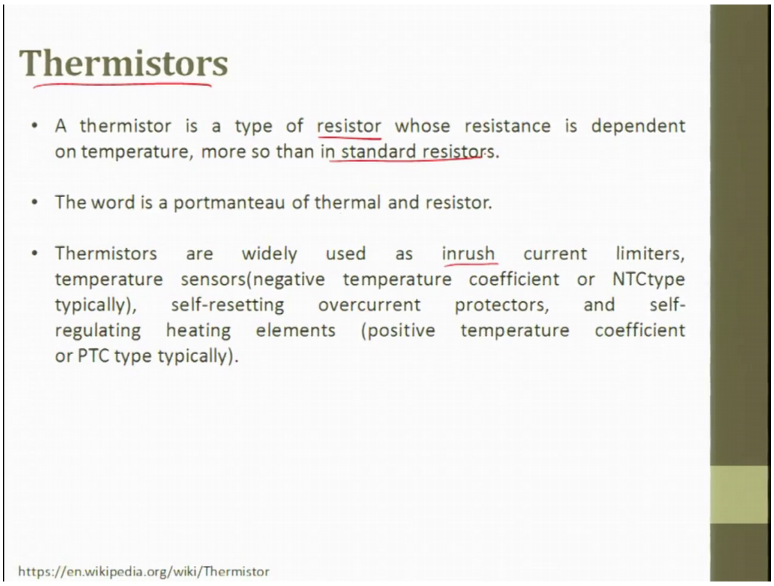

So, the next kind is thermistor. Thermocouple, thermopiles, we studied about resistance temperature detector. Now we are trying to go to the next variety or the type is thermistor.

A thermistor is a type of resistor, whose resistance is dependent on temperature more than it is standard resistor. The word in the portmanteau of temperature and resistor is mixed together and we get a thermistor. Thermistor are widely used in inrush current limiters, temperature sensor, self resetting overcurrent protectors and self regulating heating element, we use thermistor ok. Thermistor is a type of resistor whose resistance is dependent on temperature more than the standard resistance resistor. .

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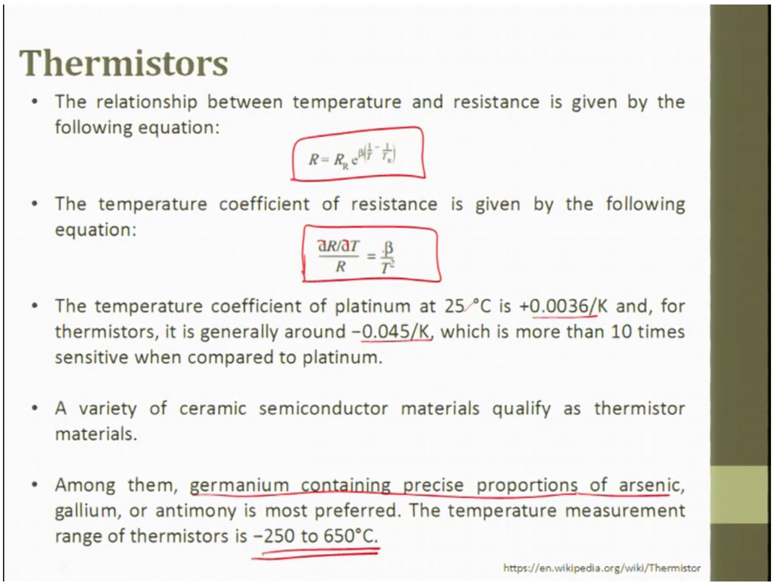

The relationship between the temperature and the resistance is given by this equation where R equal to R suffix R, E to the power beta 1 minus T by 1 minus T R. The temperature coefficient of resistance is given by the following equation RT by dou R by dou T dou R by dou T divided by R which is nothing, but beta by T square.

The temperature coefficient of platinum at 25 degree Celsius is this much and for the thermistor it is generally rounded up to this much ok, it is very low, which is 10 times more than the sensitivity when compared to platinum thermistor. A variety of ceramic semiconductor material qualify for thermistor, among them germanium coating precise proportional to arsenic, gallium and antimony is the most preferred one. The temperature what they can measure is minus 250 degree Celsius to 650 degree Celsius.

So, this is the relationship for thermistor temperature and resistance.

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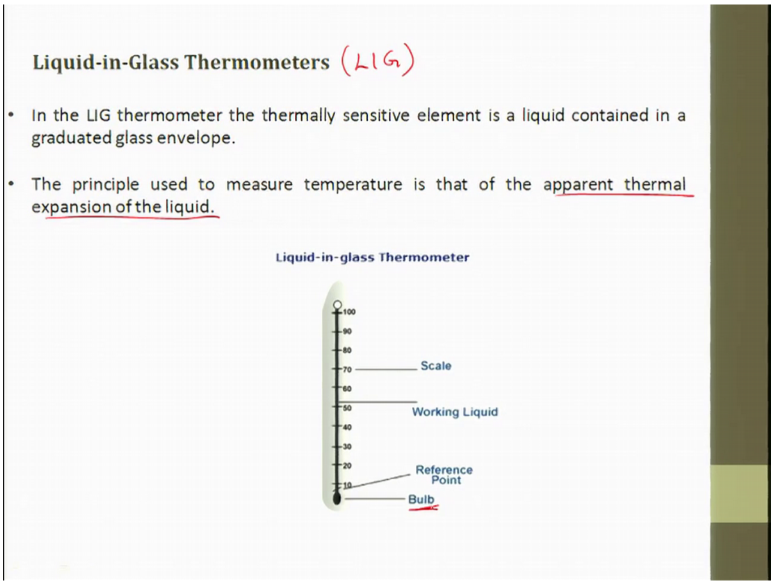

Liquid in glass thermometer, the next type, this is what is called as LIG. The LIG thermometer the thermally sensitive element is a liquid contained in a graduated glass envelope. The principle used to measure temperature is that the apparent thermal expansion of the liquid is measured and we do it.

This is a scale here is a working liquid which is generally mercury and here is a reference point and here is a bulb.

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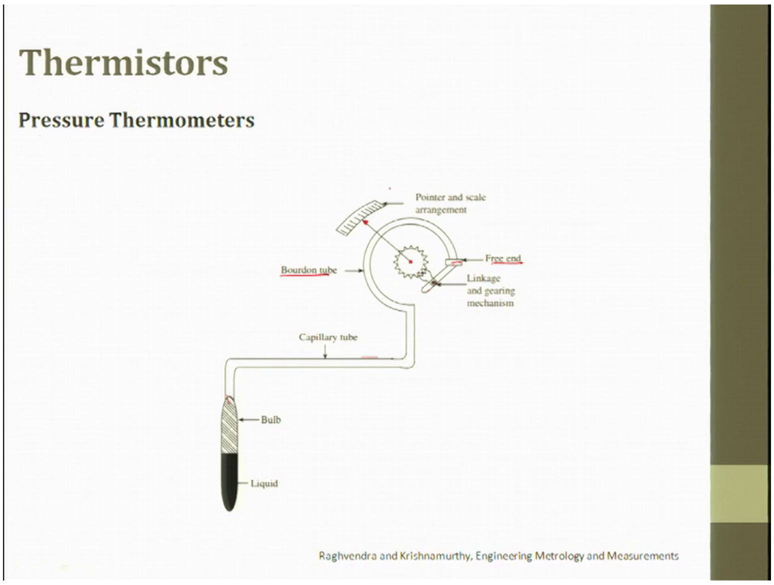

So, there is also pressure thermometer. So, pressure thermometer are where there is a liquid, there is a bulb, there is a capillary tube, and then this is a bourdon tube and then this one is attached to a link it is attached. So, this link intern is attached to a gear attachment. So, this gear mechanism is attached to a pointer and this tries to show in the graduation what is a response. A capillary tube the bulb capillary tube then, a bourdon tube then, you have a free end, this is a free end and this free end is attached to a link that has a gear mechanism this rotates and you show the graduation.

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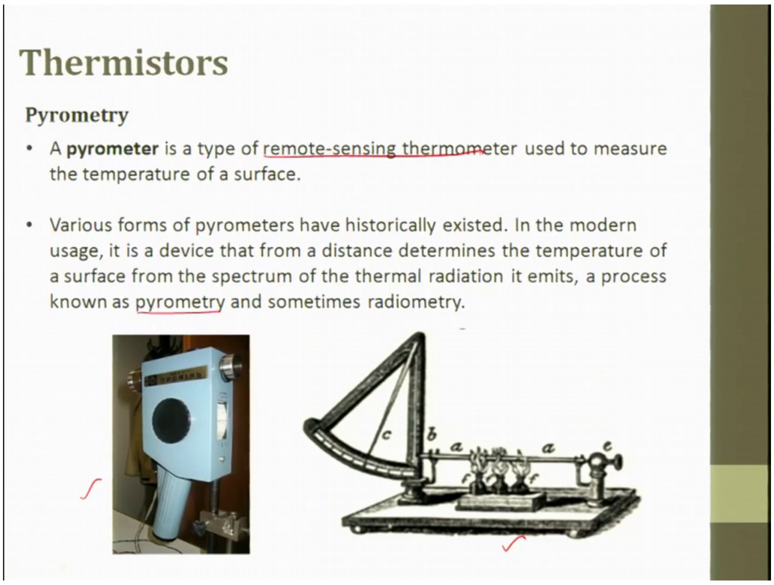

The next type is pyrometer. Pyrometer is a remote sensing, it is a non-contact type, it is a remote sensing thermometer used to measure the temperature of a surface. Various forms of pyrometers have historically existed. In the modern usage it is a device that from a distance determines the temperature of the surface from a spectrum of thermal radiation it emits; a process known as pyrometer are sometimes radiometry is also called this is a modern pyrometer, which is used to measure the temperature. And this was in the olden days they used to measure the temperature using pyrometer.

So, pyrometer is remote sensing thermometer.

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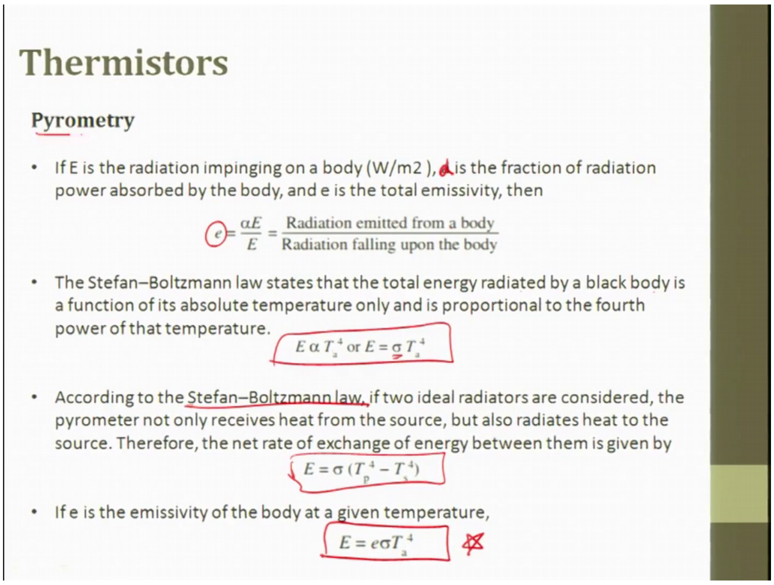

In pyrometer, we have a E, E is the radiation impinging on the body which is nothing, but watt per metre square.

A is the fraction of radiation alpha. Alpha is the fraction of radiation power absorbed by the body and e is the total emissivity e is a total emissivity which is nowadays given in a standard calibration scale or if you want to figure it out it is alpha into E divided by E, radiation emitted from a body divided by radiation falling on the body right. The Stephen Boltzmann Law states that the total energy radiation by a black body is a function of its absolute temperature only and is proportion to the fourth power of the temperature. The total energy radiation by a black body is a function of absolute temperature only and is proportional to the fourth power of temperature.

So, E is equal to alpha times T to the power 4. According to Stephen Boltzmann law if two ideal radiations are considered, the pyrometer not only receives heat from the source, but also radiates heat to the source. Therefore, the net rate of exchange will be this which is nothing, but E is equal to sigma T P to the power 4 minus T S to the power 4, T P is the pyrometer receive from the heat source and also the radiation to the source. So, the emissivity and if you try to link emissivity and Stefan Boltzmann E is nothing but e to the emissivity into alpha T to the power 4 is the final equation with Stephen Boltzmann's Law, this is used in pyrometer measurement.

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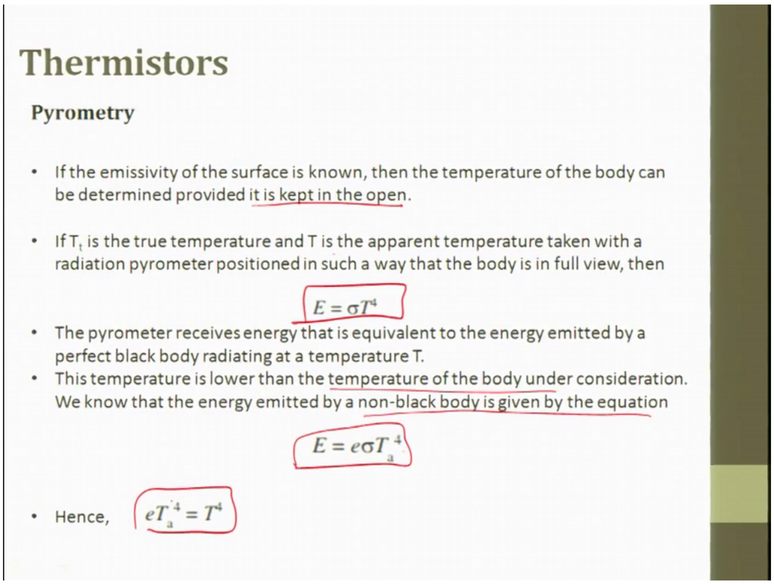

If the emissivity of the surface is known then, the temperature of the body can be determined provided it can be kept in open. If T is the true temperature and T is the apparent temperature taken with a radiation pyrometer position in such a way that, the body is fully viewed then E is equal to sigma T to the power 4, which is the apparent temperature. The pyrometer receives energy that is equivalent to the energy emitted by the perfect black body radiation and a temperature T. This temperature is lower than the temperature of the body under consideration. We know the energy emitted by a known black body is given by this equation right. And hence, e T suffix a to the power 4 is nothing but T to the power 4.

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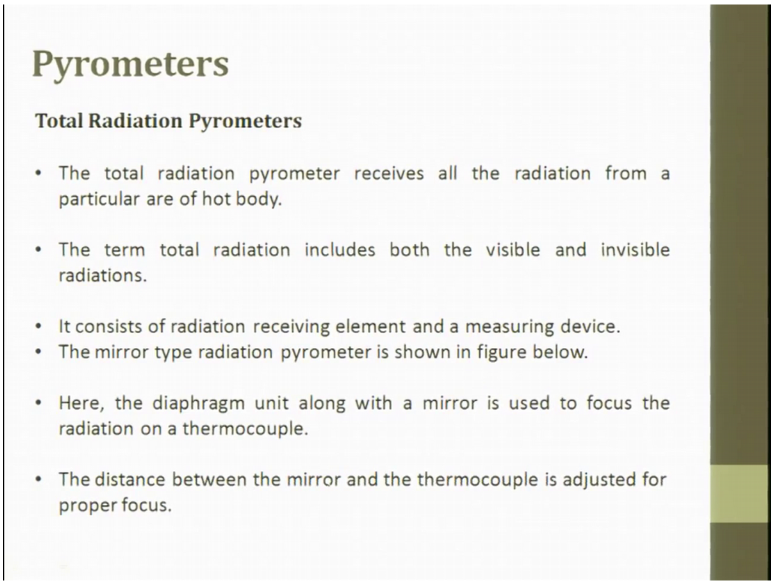

So, the total radiation pyrometer, the total radiation pyrometer receives all the radiation for a particular object are of hot body. The term total radiation includes both the visible and the invisible radiation. It consists of radiation receiving element and the measuring device. A mirror type radiation pyrometer as shown in the figure below next we see. The here the diaphragm unit along with the mirror is used to focus the radiation on a thermocouple. The distance from the mirror and the thermocouple is adjusted for proper focusing.

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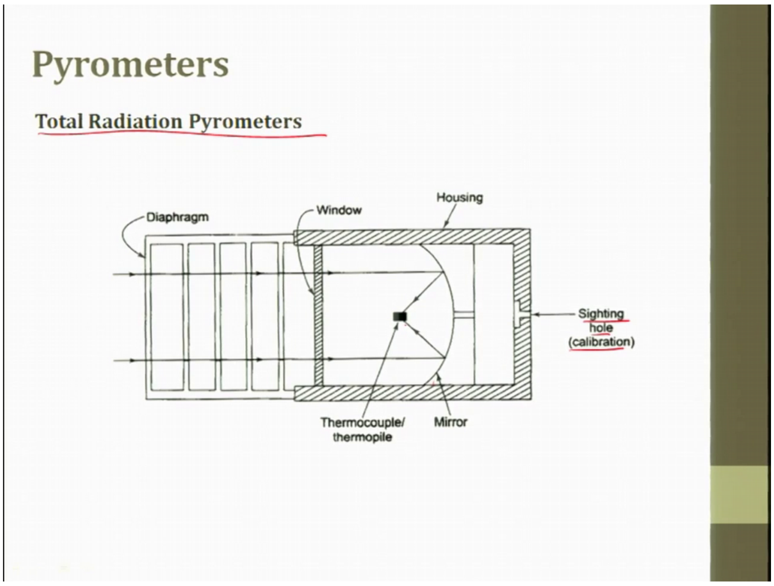

So, this is a (Refer Time: 27:39) total radiation pyrometer looks like this. These are the diaphragm, this is a window, here is a housing, so here is a mirror which is polished very well. Here is a thermocouple and as a hole through which you see and then you calibrated.

So, we see through it, so this is there. So, we adjust the diameter and then we try to measure what is the temperature.

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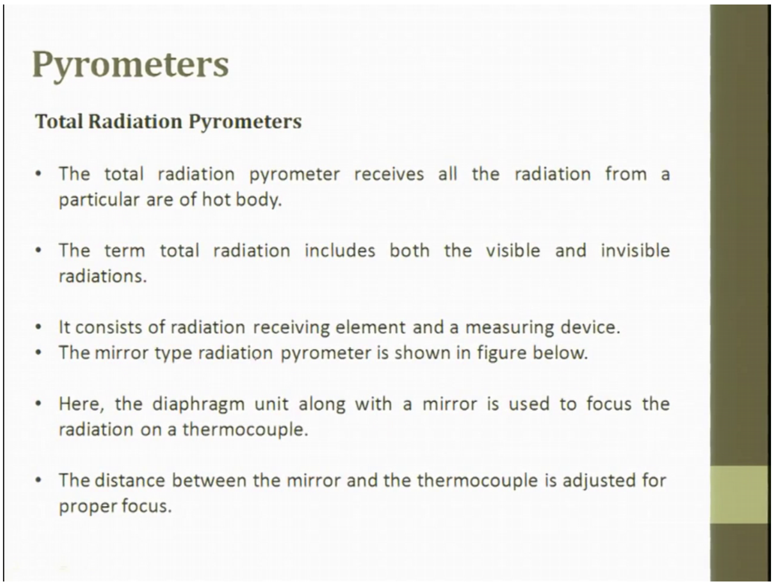

So, the mirror type radiation pyrometer is shown in the figure below. Here, the diaphragm unit along with the mirror is used to focus the radiation of a thermocouple that distance between the mirror, and the thermocouple is adjusted for proper focusing and you get it.

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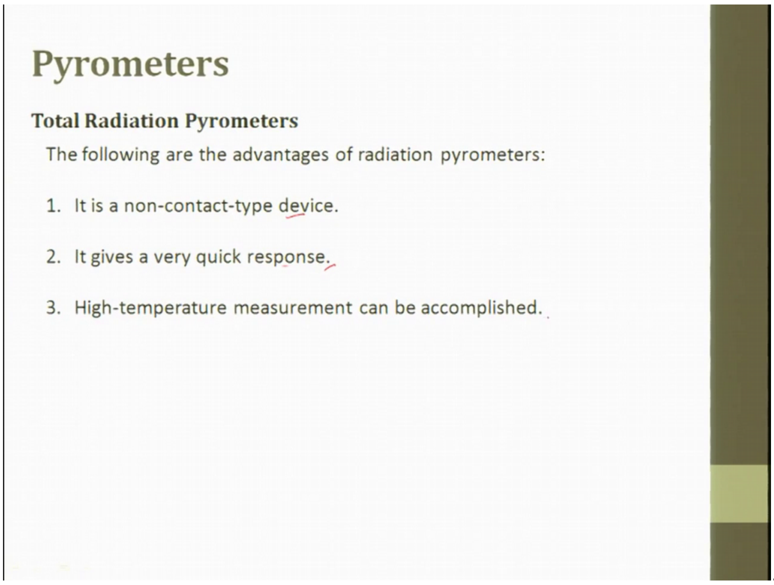

So, what is the advantage: it is a totally non-contact type you can measure the temperature by focus it on the thermocouple you get the temperature. It gives you a very quick response the high temperature measurement can be accomplished.

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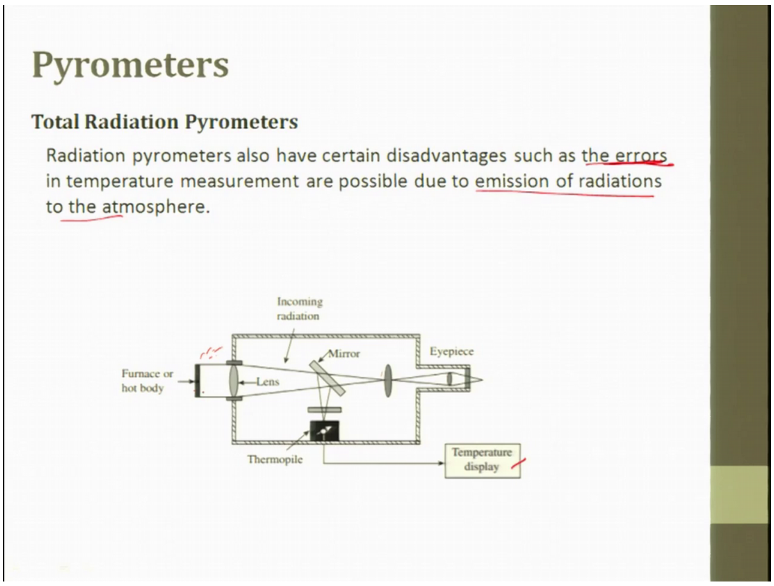

So, total so you can see here another type, a total radiation pyrometer also have certain disadvantage such as, the error in temperature measurement are possible due to emission of radiation at the atmosphere. For example, this is a furnace or a hot body, then the temperature which is seen, which is get the infrared lens is there then, it goes to a mirror then here it is taking to a thermopile then, you have a mirror you have a lens and then it goes to the ip's and you start locating it. The incoming radiation by focusing the lens on the body you try to get the ip's and you try to measure the temperature displacement.

So, the radiation also has a certain disadvantages such as, the errors in temperature measurement are possible due to emission of radiation to the atmosphere. So, what we say is, here also you get losses because of this losses you might get the temperature.

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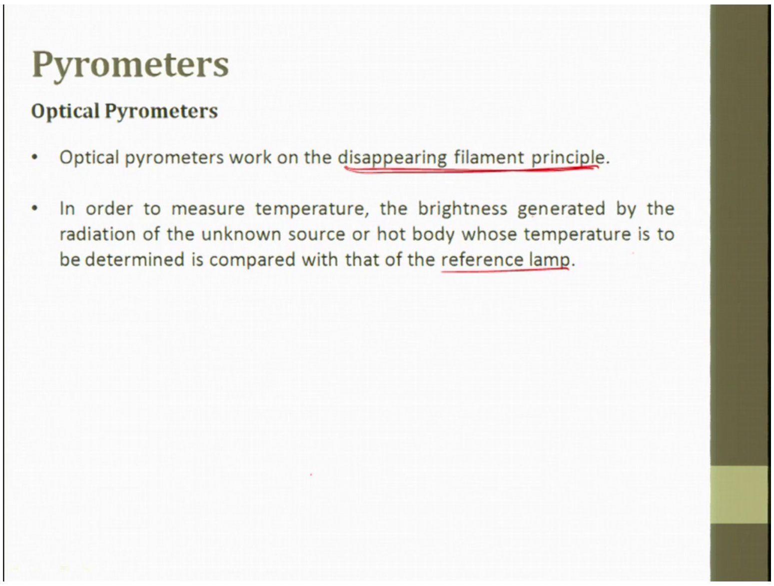

So, optical pyrometer, so optical pyrometer works on disappearing filament principle. In order to measure the temperature, the brightness generated by the radiation of an unknown source or a hot body whose temperature is to be determined is compared with the reference lamp. So, you check with reference lab and then you try to see at what temperature the filament disappears, and this is the principal we used for optical pyrometer.

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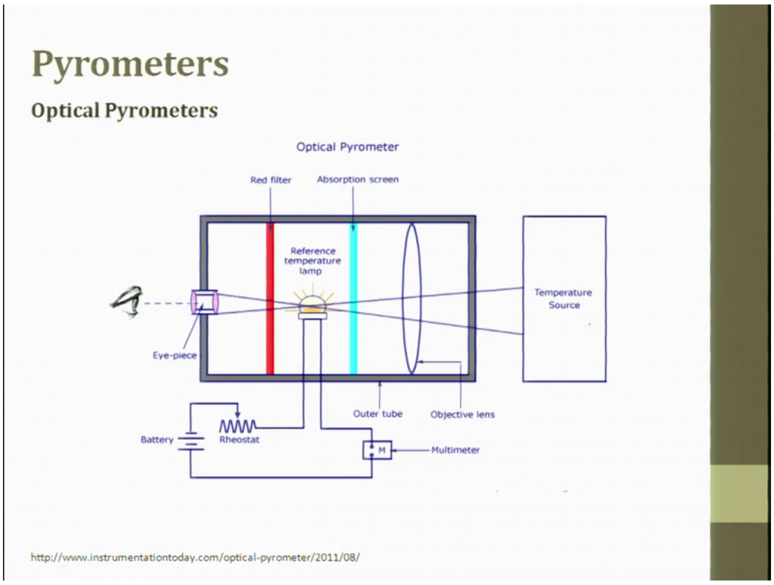

So, optical pyrometer a temperature source, you will have objective lens then, you have a screen, you have a reference bulb right and then you have a red filter, you watch through it. So now, this bulb is given a temperature, so now, what you do is you try to look at the heat source adjust the lenses or the resistance here and make sure that, the light intensity and the temperature the image gets disappeared and based on that you try to measure the output voltage and then you try to measure the temperature ok. Other a rheostat is there you adjust it a battery and then this is used for this. So, you just it such that the brightness is adjusted.

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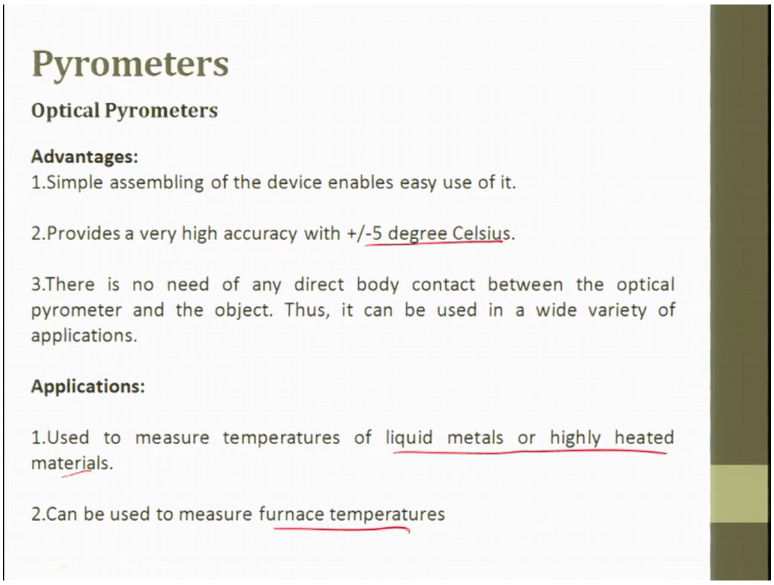

So, advantages simple assembly it provides to very high accuracy of 5 degree Celsius. There is no need for any direct body contact with the optical pyrometer.

Applications it is used to measure liquid metal, for example, when you may want to measure a crucible temperature, we try to use a crucible temperature in steel industry or iron industry or copper industry. We always used optical pyrometer for measurement and it is used to measure furnace temperatures.

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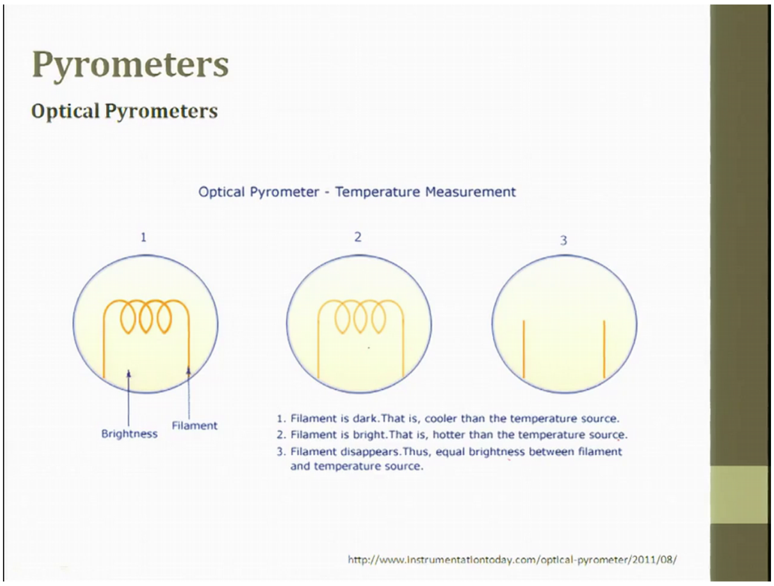

So, here is a optical pyrometer. So, this is a bright the brightness is here and this is a filament. So, filament is dark, that is cooler than the temperature source, the filament is bright that is hotter than the temperature source, the filament disappears thus this is equal to the brightness of the filament and the temperature source.

So, this is what is called as disappearing filament principle.

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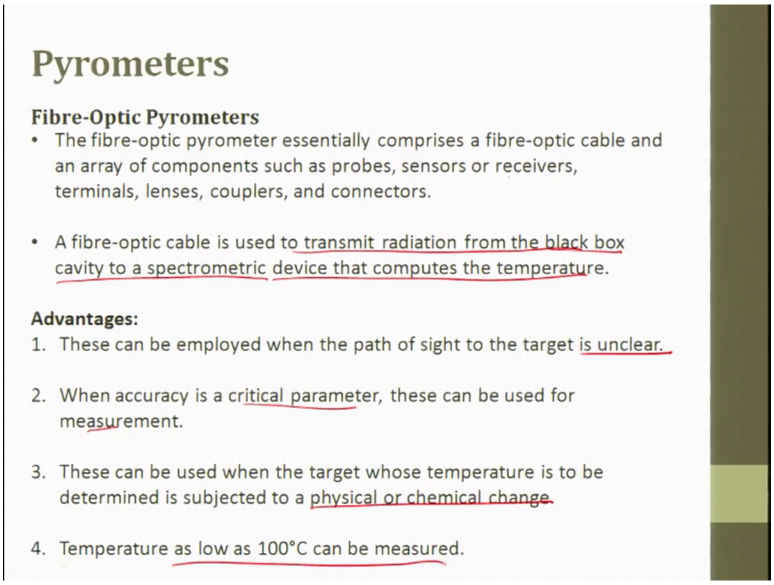

So, fiber optic pyrometer, the fiber optic pyrometer essentially comprises a fiber optic cable and an array of components such as probes, sensor and receivers, terminals, lens, couplers and connectors. A fiber optic cable is used to transmit radiation from a black box cavity to the spectrometric device that computes the temperature.

So, this is a technique with which fiber optics pyrometer works. So, it tries to transmit radiation from a black box cavity to a spectrometric device that computes the temperature and lets you know. They can be employed, when the path of sight of the target is unclear we use fiber optic pyrometer, when accuracy is a critical parameter then, we can use this measurement. This can be used when the target whose temperature is to be determined is subjected to physical or chemical change right.

When from the solid it goes to liquid and all we can use this fiber optic cable. The temperature as low as hundred degrees can be measured.

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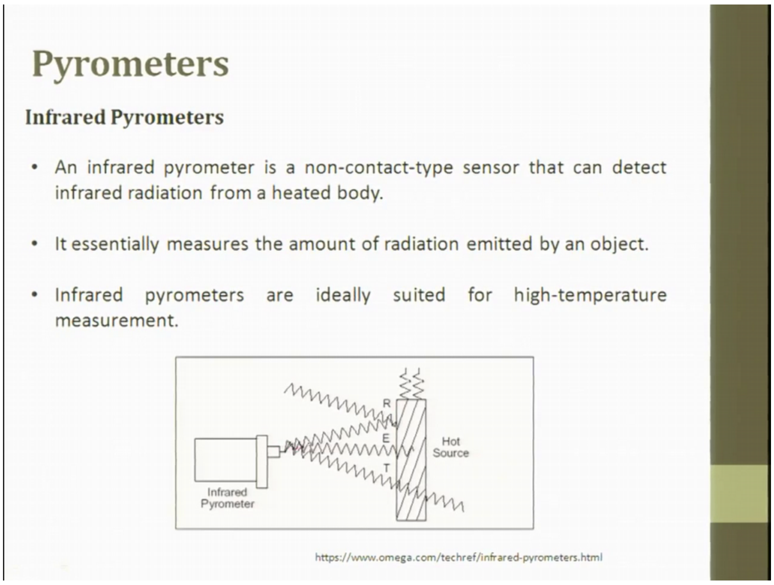

Then it is infrared pyrometer. So, this is infrared pyrometer, when there is a hot body, so the infrared pyrometer it emits. So, here you can see the infrared getting transmitted, getting reflected, getting absorbed right; so it so an infrared pyrometer is a non-contact type sensor that can detect infrared radiation from the heat body.

It is essentially measures the amount of radiation emitted by a object. The infrared pyrometers are ideally suited for high temperature measurements.

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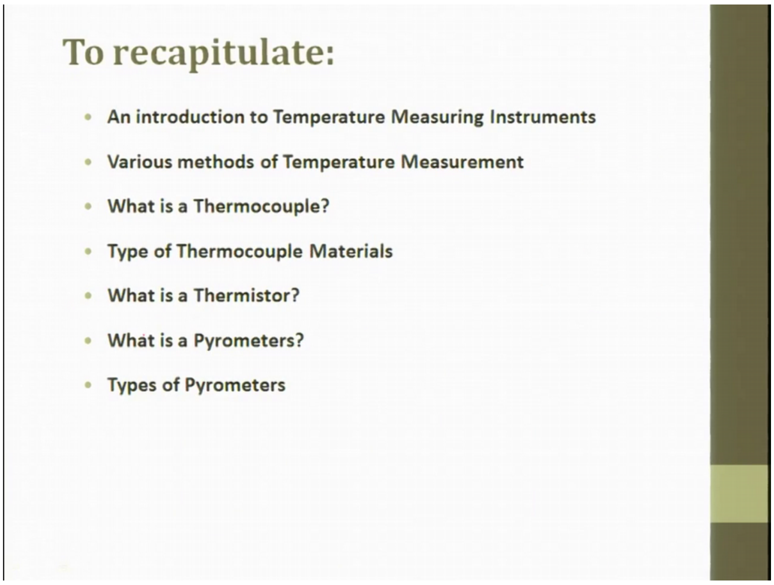

So, with this we come to the end of this chapter on temperature measurement. We started with an introduction to temperature measuring, various methods of temperature measurements, thermocouple, different types of thermocouple, thermistor, pyrometer and different types of pyrometer.

Thank you very much.