Mechanical Measurement Systems
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Lecture – 29
Temperature Measurement (1)

I welcome you all in this course on Mechanical Measurement Systems. Today we will start with the Temperature Measurement.

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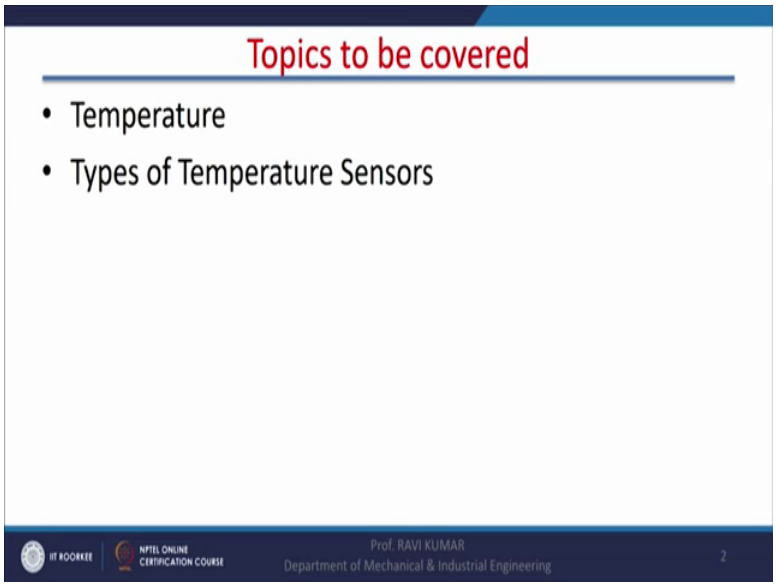

So, when we talk about the temperature measurement temperature and type of temperature sensors, they immediately come in to our mind. So, today, the topics will be covering, first of all, we will have a brief discussion about the temperature and then discussions about temperature sensors.

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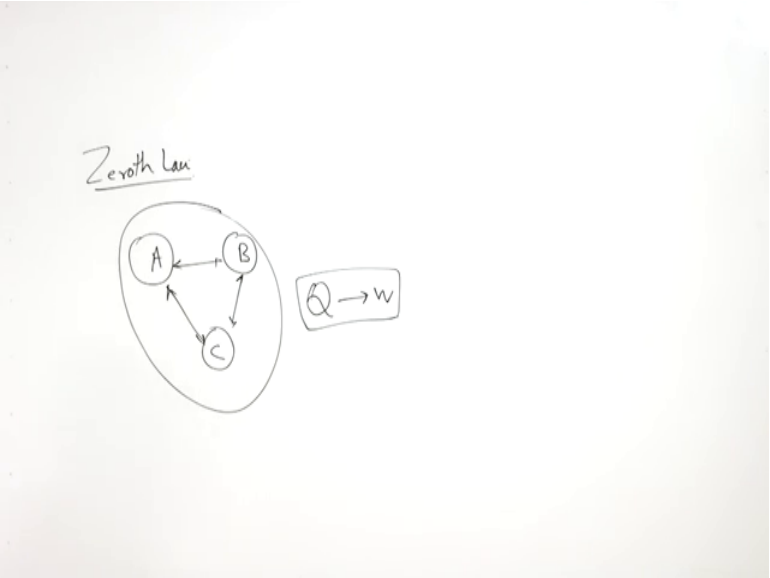

Now when we talk about temperature that immediately Zeroth law thermodynamics comes into the picture and Zeroth law says that if body A is in thermal equilibrium with the body B which itself is in thermal equilibrium with body C, then A and C are in thermal equilibrium. It is it does not speak our temperature right temperature is derivative of the concept of temperature is derivative of the Zeroth law of thermodynamics and from here, the concept of temperature measurement starts Zeroth law is the latest law of thermodynamics.

Actually, it is start with the laws of thermodynamics is started with the fact when we converted heat in to the work or developed the heat engine in 17 late 17th and 18th century and when we developed heat engine which resulted in industrial revolution and it was a big achievement we could because we could any amount of heat could be converted in to the useful work using steam engine that keep the efficiency how to improve the efficiency of the steam engine right.

So, for improving the efficiency first of all, it was explode can we convert 100 percent heat into the 100 percent of work many experiments were conducted in number of experiments conducted for a very long time and ultimately, it was concluded that all heat cannot be work converting into the useful work that is that is derived from the second law of thermodynamics, right, no engine can have 100 percent efficiency till they till that

time, there is nothing there was nothing thermodynamics the thermodynamics was coined in 1849 by Lord Kelvin.

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Lord Kelvin was the first person who coined this world in 1848; not 49, I think 48; 1848, he coined this world thermodynamics before that there was consistent efforts to convert entire heat in to the work which law which was ultimately second law says that it is not possible. Then can we convert heat into the work, this has come from first law of thermodynamics.

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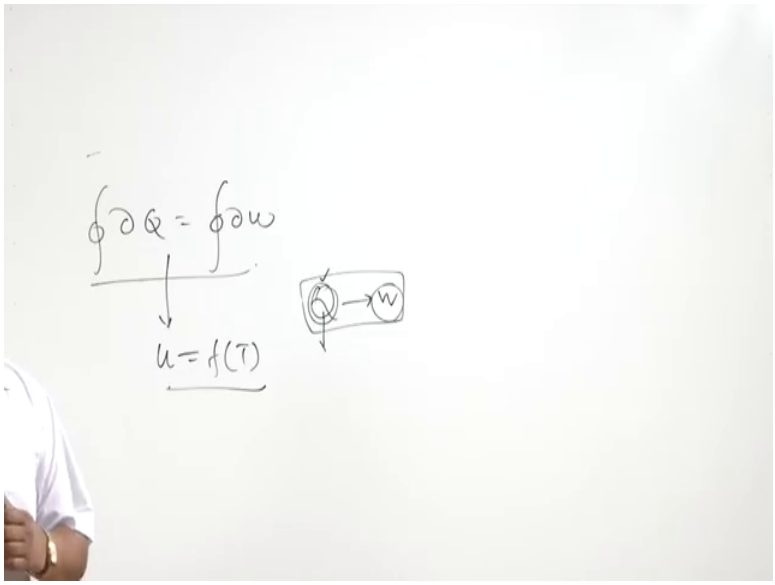

The heat and work are mutually convertible cyclic integral of heat transfer in a cyclic or cyclic integral of work transfer are equal in a cyclic process right in a cyclic thermodynamic process the cyclic integral of heat is equal to cyclic integral of work and derivative of the first law is internally mutual function of temperature.

So, in thermal systems the measurement of temperature is very important and for all thermo system if we take any heat exchanger or we take any turbines or any compressor any machine which is which is based on; which is a thermal system which we call thermal system the temperature measurement is very important part. In fact, energy transmission in thermal systems either say we have to have temperature profile and as well as the mass flow rate they are two things essential things which are required to be measured other things can be determined.

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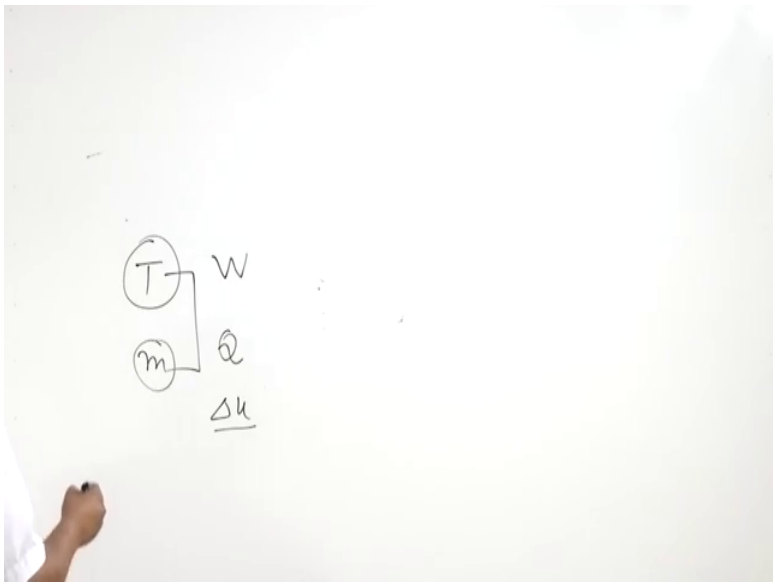

For example, work can be determined heat transfer can be determined change in internal energy can be determined, but we need to have these two values. So, mass flow rate or the flow measurement I have already discussed in the previous lecture and today, I shall start with temperature measurement now regarding temperature measurement we use an instrument which is known as thermometer.

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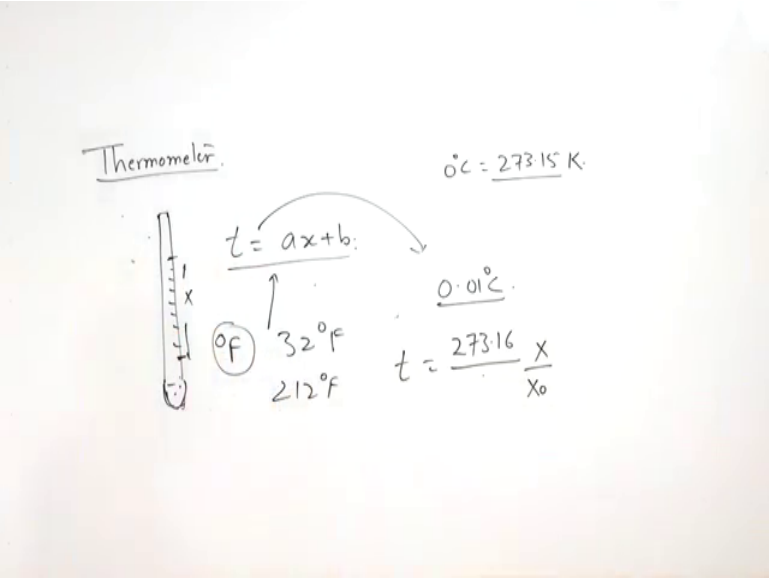

And most popular thermometer is liquid in glass type of thermometer and this thermometer, we have amply discussed liquid in glass type of thermometer here, it is marked x and there is a bulb which has the primary sensing element which comes in to the contact with the measuring. Now these marks are not arbitrary in a thermometer there is a temperature scale. So, for temperature scale earlier it was a degree centimeter scale melting ice was a reference temperature and temperature was considered to be varying linearity is equal to ax plus B.

So, x is equal to 0, the temperature was considered in 0 degree centigrade in degree centigrade scale and boiling point of water was taken and the reference point because they are 2 unknowns and these unknowns were determined before degree centigrade temperature there was a Fahrenheit temperature also Fahrenheit scale also in Fahrenheit scale the boiling temperature of water sorry the freezing temperature of water is 32 degree Fahrenheit right and boiling temperature of water is 180 degree Fahrenheit, sorry, 212 not 180 degree 212 degree Fahrenheit.

So, this degree centigrade scheme followed the because it is in nks system right. Now we have si system, now after this scale, another scale tem which is now being used it is a based on the triple point of water and this scale has simple reference point that is 0.01 degree centigrade that is triple point of water and x is equal to 273.16 because to 0 degree centigrade is equal to 273.15 Kelvin.

So, it is 273.16 divided by sorry this is t; this is x by x o x by xo multiplied by this is equal to t. So, it was a it has a it has a single difference point and now a days this scale is in fashion for different temperature ranges, we take different triple points of different substances may be a gas or a liquid metal depending upon the temperature range. Now for the measurement of temperature because temperature measurement is a very challenging job because it varies from minus 273 degree centigrade to it can go up to 4000, 3000 degree centigrade when we are dealing in the cryogenic area when cryogenic starts from 1 minus 150 degree centigrade, right.

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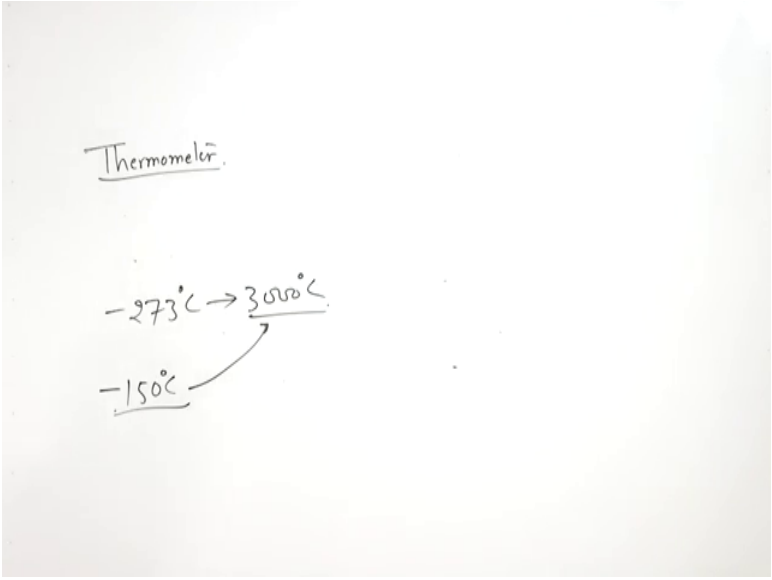

This is required in space applications this is also required in space applications or nuclear power plants when the temperature reaching upto 3000 degree centigrade. So, very wide range of temperature has to be made very wide range of temperature measurement has to be made that is why job of temperature measurement is very typical in any system because with this help of signal device, we cannot cover or with this help of single technology. In fact, we cannot cover the entire range of temperature measurement it cannot be covered. So, we have to for different application for right for variety of applications we have to go for different type of measurement systems. Now, I we will take those measurement systems one by one.

Now, liquid in glass thermometer we have amply discussed in the earlier lecture. So, this is one of the very old and still in fashion measuring device that is liquid in glass type of

thermometer. Now another device which is also used for the purpose of control that is bimetallic thermometer bimetallic thermometer in it works on the principle of thermal expansion.

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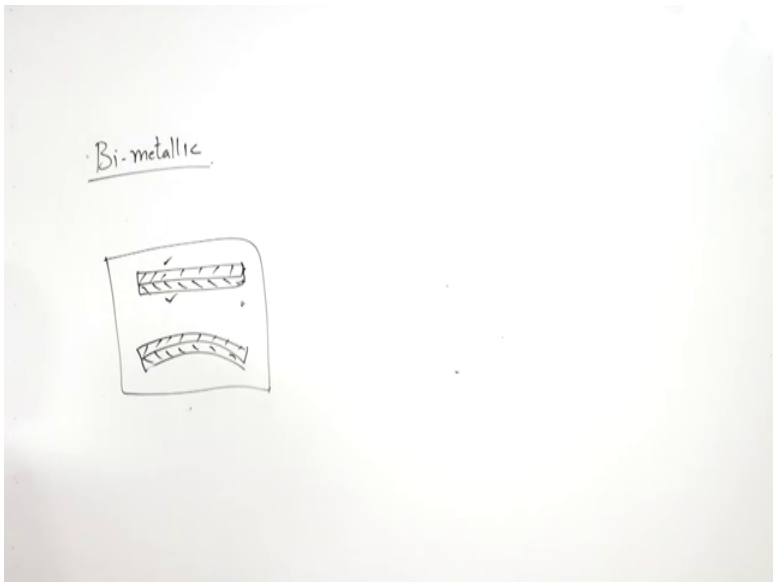

So, there are two steps in bi meta bi bimetallic thermometer as it is clear from the name itself and they are pasted on each other. Now what happens if there is a change in temperature the thermal expansion of this stream is substantially different from thermal expansion of this state and they are pasted on each other in that case, what is going to happen if this has higher thermal expansion these stripes?

You will get curved due to thermal expansion or due to change in temperature right and as the shape of or the curvature of this direction has changed. This can very well related with the temperature difference and this is also used for controlled purpose, it is used in refrigerators also in some of the refrigerators also for contact at non contact type of device because if temperature exceeds certain limit; it will it will deform it will change a curvature will be developed and some contact will be established or contact can be broken depending upon the requirement.

So, this bi-metallic stream can also be used as a controlled device another type of thermometers is filled type of thermometer filled type. Now the filled type may be of gas type or liquid type of thermometer or vapor type of thermometer now there is a difference between gas and vapor, I must tell you here gas and vapor gas follow the ideal

gas equations, we first do not follow the ideal gas equation right all the vapors if they are at very low pressure if the pressure is less than 10 kilo Pascal.

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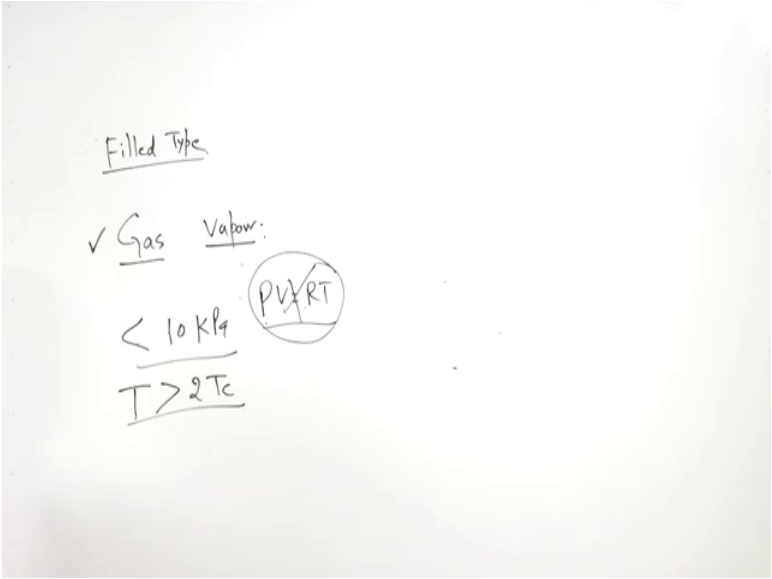

They are considered as a gas for example, mixture of water vapor in air. So, air present in water vapor is considered as a gas, it is treated as a gas or the temperature of the air temperature is greater than two times critical temperature for such an high temperature the vapor is considered as a gas for this reason in steam turbines the steam is not considered as a gas we do not use PV is equal to RT for the analysis of steam turbine as in the case of gas turbines, gas turbine, we use PV is equal to RT because say in gas turbines, we use gases, but in steam turbine their high pressure steam is used, but temperature is not sufficiently high; that is why we do not use PV is equal to RT and for this reason the steam table is used thermal physical properties of steam is taken from steam table.

So, in the gas weld thermometer the working principle is very simple, there is a bulb right.

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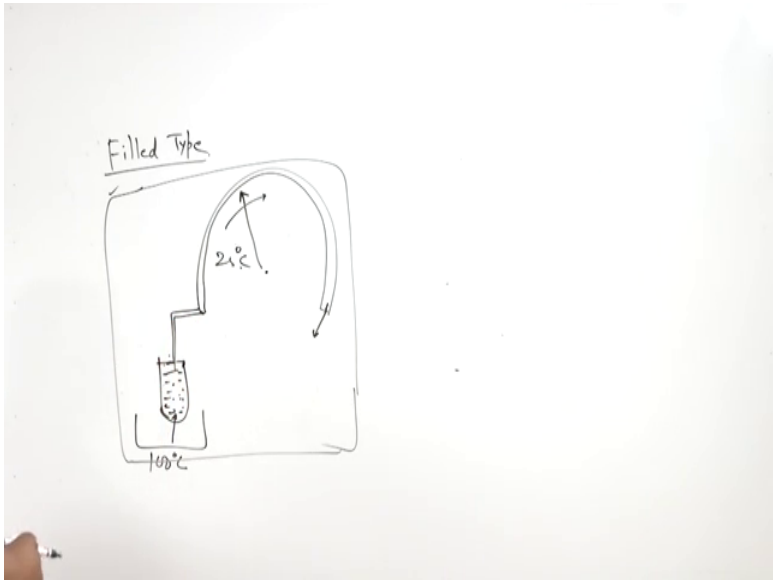

It is filled with some fluid may be a liquid or gas and it is connected to broaden tube as I explain you earlier it is a curve tube right when this broaden tube is connected with this right when this in this bulb it is closed. So, when in this bulb there is a energy addition by virtue of temperature difference or it comes with the contact with the measure end the liquid expands or the fluid expands and this fluid causes the extension of free end of the broaden tube in this direction.

And then we can have and there is a mechanism which transmit this motion on the dial with the help of an indicator this is the basic working principle of a filled type of thermometer and filling can be can be any liquid vapor or any gas, but there are certain; this one disadvantage also in the system because here the temperature is different this is the temperature of room temperature here the temperature of measurement; suppose measuring temperature is 100 degree centigrade room temperature is 25 degree centigrade. This may cause error in the measurement if there is too much change in elevation. This will also cause error in measurement, but grossly this is a very good and reliable instrument and it is I mean used in many process industries, it is very reliable I mean these all these known errors can be compensated.

I mean we can have always have compensation for the errors, but is still this is very reliable instrument for temperature measurement, but the most popular instrument used for or a sensor which is used for temperature measurement is thermocouple.

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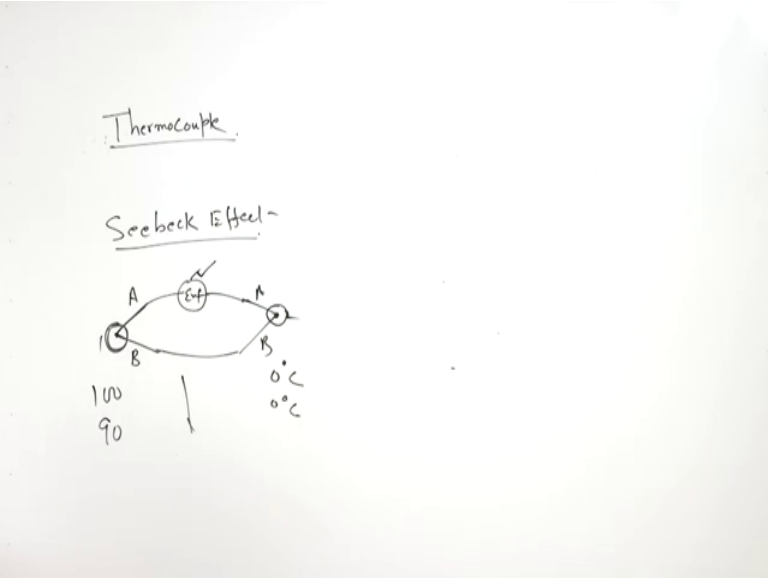

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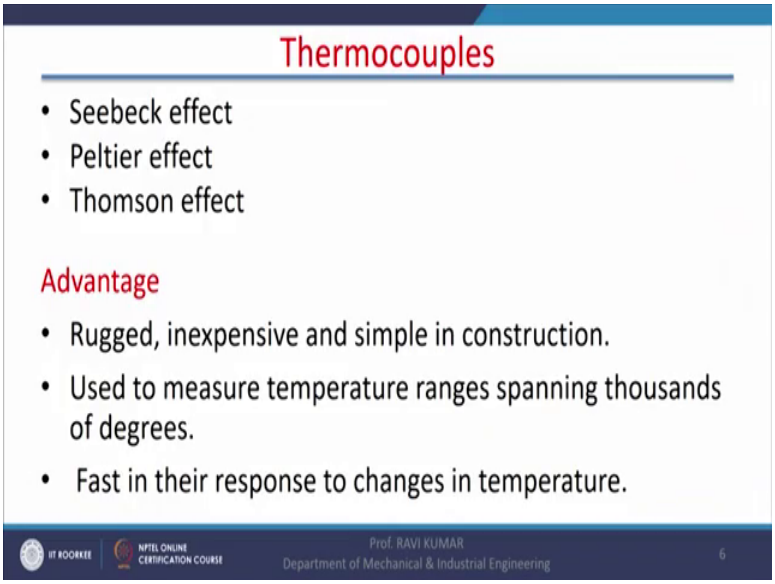

Now thermocouple works on a on the principles of physics that is see beck effect. Now see beck effect is all about the fact that when there is a temperature difference if there is a joint of two dissimilar materials suppose they are a and B and they are kept at different temperatures a and B one and two one and two are different suppose this is boiling water and this is melting ice. So, 100 and 0 some EMF will be generated and this EMF will I mean some EMF will be generated now if we are able to measure this EMF, we can find the unknown voltage for known would temperature suppose this is 100 this is 0 degree centigrade. Now this is 90, this is 0 degree centigrade, now we can have the

characteristic curve for this thermo couple and we will be getting different EMF for these temperatures now for a known or a measured EMF we can immediately find the unknown temperature.

So, this is the basic principle or the working principle of a thermo couple. So, thermo couple is a combination of one wire. So, the two wires of similar material right and when these dissimilar junctions or the junctions of dissimilar material are kept at a different temperatures the EMF is generated. Now in addition to this, there is another effect which is known as Peltiar effect. Now Peltiar effect is opposite to the see back affect a Peltiar effect says when current is passed through a junction of a dissimilar material if we pass a current through a junction of dissimilar material either heating or cooling of this junction will take place.

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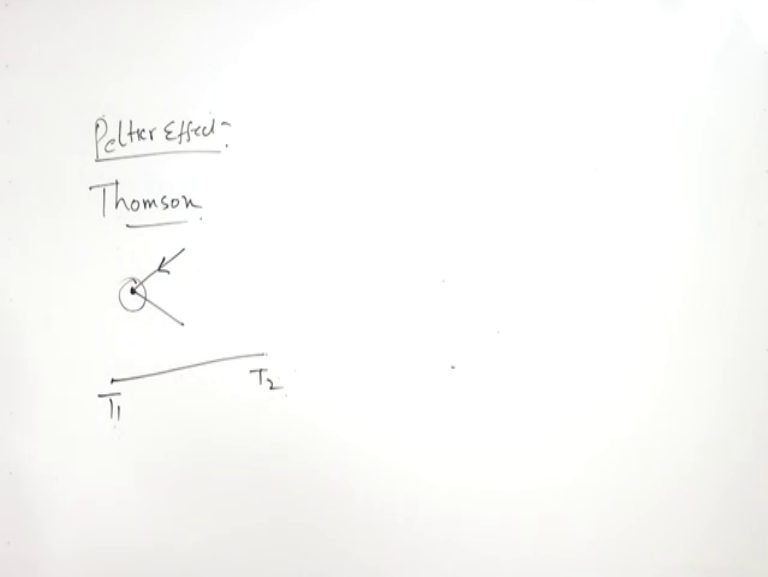

So, it is opposite to see beck see beck effect says if junction is placed at two different temperatures then EMF will be generated here when the current is passed through a junction of a material right either heating or cooling of this junction will take place. So, it is just a opposite of see beck effect another effect which is very important is Thomson effect Thomson effect. Now Thomson effect speaks about the development of EMF due to temperature gradient in a conductor suppose there is a wire conductive wire and it is at a different temperature T 1 and T 2 ends in that case also EMF will be generated.

We do not require; I mean dissimilar materials in the same conductor or a homogenous conductor of homogenous or the material is homogenous in nature and then if there is a temperature gradient in the wire the EMF will be generated. Now advantage of thermocouples is they are very in expensive, they are in expensive.

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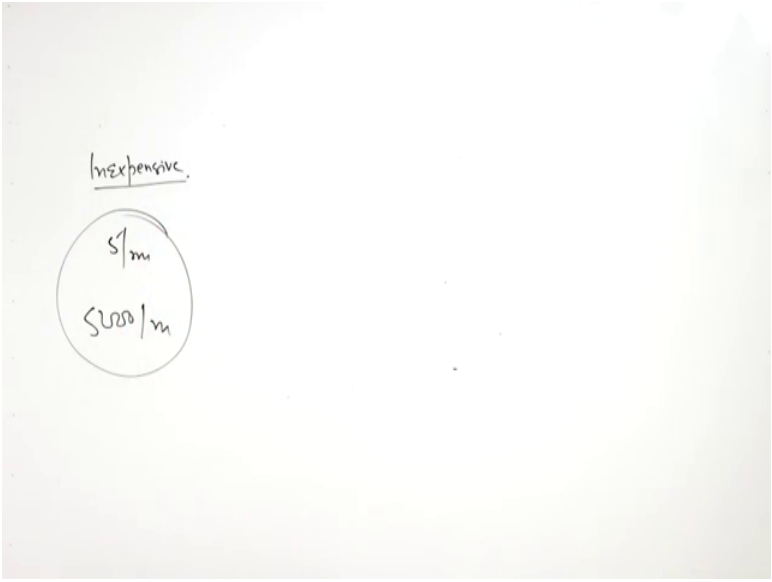

They were cost you 5 rupees per meter and they are expensive as well they may cost you 5000 rupees per meter also. So, they are they are not absolutely in expensive at all, they cause to be very from 5 rupees or 3 rupees per meter depending upon the requirement and sophistication is required it can go up to 5000 rupees per meter or 10,000 rupees per meter, but the beauty of these thermo couples is you can use thermo couples for the temperature measurement for span of let us say 1500 degree centigrade.

You can comfortably use thermo couples from minus 200 to 1300 degree centigrade though the type of thermo couples will change the type of junction will change, but this temperature range can be covered by thermo couples that is why they are popular in temperature measurement and second the last point in the favor of thermo couples is the time response is very fast because in thermo couple tip can be made as small as 0.25 mm or less than that.

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So, in 2.25 mm tape, there are 2 wires connected with each other and the diameter of the sheet is 0.25 mm and these thermo couples have very response time. So, very low response time there I mean the response is very good. So, they have very lower response time, if you compare with the liquid in glass type of thermometer or bulb type of thermometer or any other temperature measuring device the thermo couple, we can manage we can manage very high response of thermo couples. So, that is also one of the advantage of advantages of using thermo couples in temperature measurement applications.

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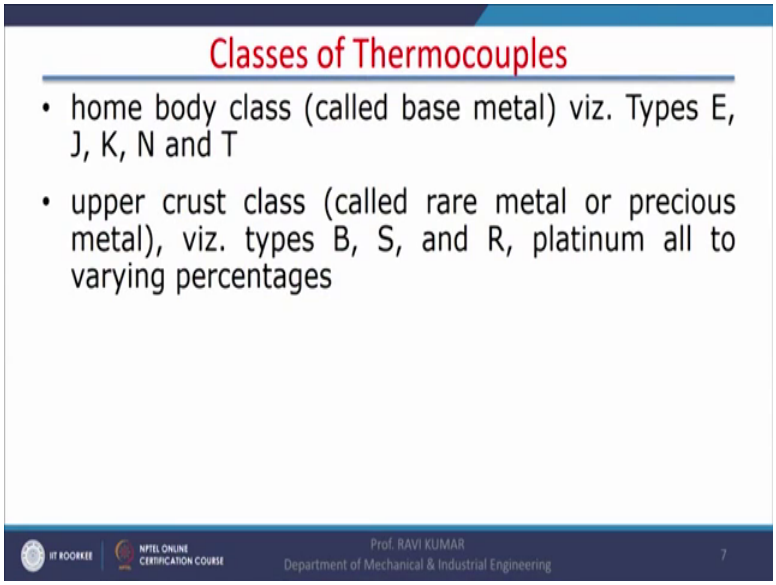

Now there are different classes of thermocouples, we have because we have to cover a wide range. So, they are different classes of thermo couples and will start with home body class or base metal cover thermo couple base metal or home body class and in this class the thermocouples are T, J, K,, E, these type thermo couples another class of the thermocouples is rare metal class in rare metal class, they are costly thermocouples and they are B, S, R B, S and R thermo couples. Now these thermocouples have different compositions let us start with T we will shift a little.

So, let us start with T type thermocouple, this thermocouple is very popular, it is made of copper and constantan copper 1 wire is copper wire pure copper wire; another wire is copper constantan.

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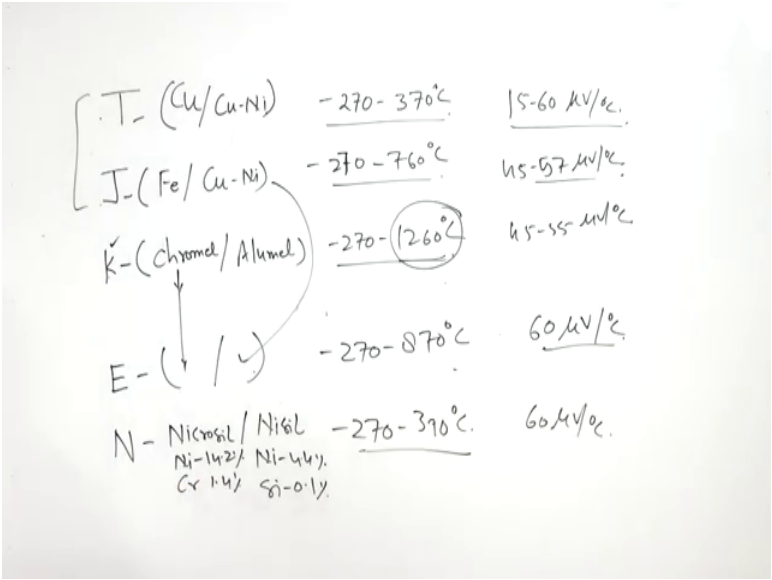

It is cupper nickel alloy copper constantan this is capital C, it is known as commercially it is known as T type of thermocouple we call it copper constantan thermocouple. So, ok; if you want to go to market and purchase these type of thermo coil you have to write T type; T type of thermocouple right and this thermo couple can measure temperature in a range of minus 270 to 370 degree centigrade.

So, this is the temperature range for this thermocouple and sensitivity of the thermocouple is 15 to 60 micro volt per degree centigrade sensitivity is change in the output change in the output in milli volts for per second change in the temperature. So, it is 15 to 60 because this EMF and this relation temperature change in EMF relation is not

linear it is non-linear. So, which range your operating is important for low temperatures this is the sensitivity this is the sensitivity for higher temperatures similarly for J type of thermocouples which is second popular thermo couple it is J type it is instead of a copper, here the iron is used.

So, iron constantan thermocouples, it is again copper nickel constantan is copper and nickel iron and the temperature range is minus 270 to 760 degree centigrade if you refer different authors you will find different ranges even manufacturers have given different ranges for temperature measurement of thermo couples, but what I am depicting here is the say average if you have to measure up to 700 or you can go up to 800 also with J type of thermocouples, but not beyond 800, right.

And if you are operating at the fake end of the range of fake end of the range definitely the performance will not be as expected by the thermocouple, right and here 45 to 57 micro volt per degree centigrade. This is the sensitivity of this thermocouple. Now the next one is K type of thermocouple K type. Now K type of thermocouple is a combination of Chromel and Alumel. Now Chromel is an alloy. So, Chromel is an alloy and Alumel is also alloy this is Chromel is nickel; nickel, chromium, alloy; nickel, chromium, alloy and alumel is nickel, aluminum, alloy.

So, both are alloys now this thermocouple K type of thermo couple it can go up to minus 270 to 1260 degree centigrade quite high, it can go up to 260 degree centigrade and the sensitivity of this thermocouple is 45 to 55 micro volt per degree centigrade. So, if you want to measure up to 1200 or even 1300 degree centigrade we can comfortably use K type of thermo couple.

So, for high temperature applications because most of the thermal applications are in this range; so, most of the for high temperature applications K type of thermo couples are used. So, definitely these thermo couples are costlier than these two type of thermo couples after K type of thermo couples there is a E type of thermocouple E and N. Now E type of thermocouple it is Chromel and constant N. So, Chromel it is Chromel and constantan Chromel and constantan thermo couple now this E type of thermocouple can have minus 270 to 870 degree centigrade and the sensitivity is 60 approximately 60 micro volts per degree centigrade, right.

So, it is relatively stipple it relatively linear. Now N type of thermocouple it has nicrocil nicrocil, it is nickel 14.2 percent, chromium 1.4 percent and nicil nicrocil and nicil. So, nickel chromium and this is nicil is nickel 4.4 percent silica 0.1 percent and magnesium. So, N type of thermocouple is used for this often used for as a reference thermo couple for calibration for N type of thermocouple it is minus 270 to 390 degree centigrade right and for and the type of thermocouple it is again 60 micro volt per degree centigrade this is J type also is 270 this is also 270, there is nothing like two time. So, it is all most of thermocouples are in starting from minus 270.

So, N type is minus 270 to 390 and sensitivity is 60 micro volt per degree centigrade. So, this range of minus 270 to 390 is used for. So, N type of thermocouples are quite stable and normally, they are used for as a reference temperature for temperature measurement now another if type of thermocouple, they are rare metal type of thermocouples in rare metal type of thermocouples there are R S and B.

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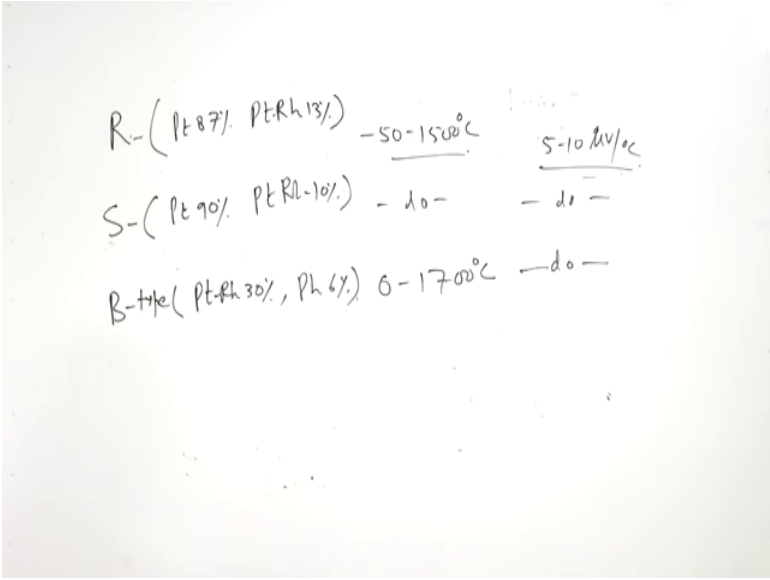

So, R type of thermocouple. So, here platinum is used in rare metal type of or precious metal type of thermocouples the platinum is used. So, here the R type of thermo couples has platinum 87 percent and platinum rhodium alloy of this is 30 percent, this is the combination that is why it is costlier they are quite costlier. So, R type of thermocouple and the temperature range is minus 15 to 1500 degree centigrade, this is the temperature range and sensitivity varies from 0 to 10; sorry, 5 to 10 not 0; 5 to 10 deg micro volt per

degree centigrade, it can go up to 12 also 12 or 13 also and normally, we take around 6 to 7 micro volts per degree centigrade the sensitivity of R type of thermocouples. Next is S type of thermocouples. Now in S type of thermocouples it is also platinum based alloy, it is platinum 90 percent. So, the amount of platinum has increased and platinum rhodium is 10 percent and S type of thermocouple also it is same range and sensitivity is also same.

So, next is the last one is B type and B type of thermocouple it is platinum rhodium thirty percent and rhodium is 6 percent right and this also the range is 0 to 1700 degree centigrade and the sensitivity is same no. So, yes sensitivity is same in addition to these their other number of exotic thermocouples I mean there is a long list and with the help of thermocouples. Nowadays, we can measure up to 2200 degrees centigrade and efforts are still on to go for because beyond that temperature, we will have to go for indirect temperature measurement or non conduct type of temperature measurement acting which is not considered to be very reliable.

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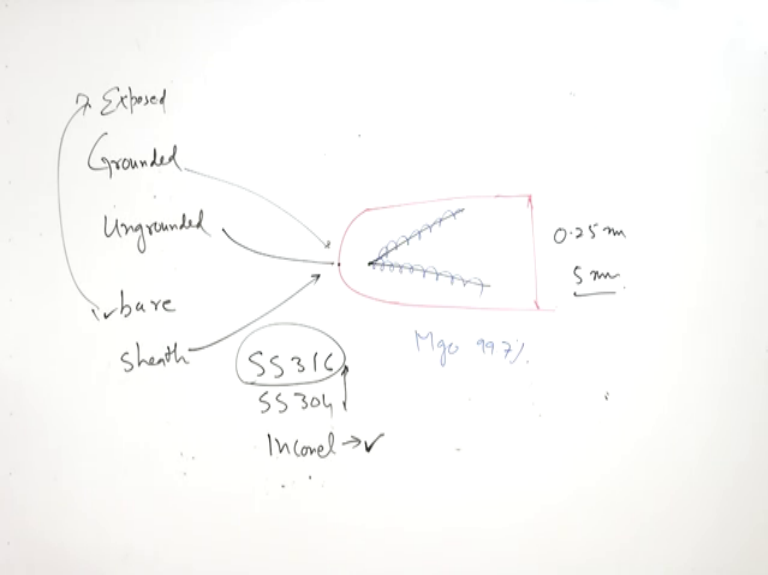

So, after this material of thermocouple we will discuss about the different combinations of different type of thermo couples for example, grounded thermocouple there is that two terms grounded and ungrounded and bare and sheath thermo couple. Now bare thermocouple are simple wires are they are connected and ends are fused and they are

used for temperature measurement, but sometimes production is required from oxidation oxidat oxidizing or reducing environment or for example, am measuring temperature.

Water if I put just bare wire type of thermo couple the short circuiting earlier short circuiting will short circuiting will take place and I will not get the appropriate reading, right. So, these wires have to be insulated this the insulation has to be provided on these wires and sometimes insulation is not sufficient because if you provide the insulation temperature may not be correct in hostile environment. So, entire thermocouple has to be covered.

So, sheathing is done now for sheath there are two wires thermocouple wires there is the tip of thermocouple and wire is coated with magnesium oxide that is MGO 99.7 percent, right and entire system is put under a sheath it is a long thin tube I mean it if you look from outside it appears to be wire because diameter of this sheath this varies from 0.25 mm to 5 mm or more than that. So, it can be as small as 0.25 mm with all this measurements when this tape is in contact with the with the surface of the ship tip of the sheath then it is known as grounded thermocouple.

The response of the grounded thermocouple is faster when it is ungrounded thermocouple then response is not that faster, right. So, we can further classifies classify thermocouple as a exposed thermocouples exposed grounded ungrounded or bare I have already written this both are the same thing same meaning the same exposed or bare and sheath thermocouple right and sheath it comes from different material, it is made from different materials it can be of SS 316, it can be of SS 304 and it can be of inconel. So, inconel is a alloy. So, inconel is an alloy.

So, inconel is alloy and it is it used for highly corrosive environment if the en environment is not corrosive, then we can go for SS 304 or SS 306, but if you compare these two; this SS 316 has higher; if you compare these two has higher corrosive resistance.

This is all for today in the next class. We will continue that discussions on thermocouples.