Cryogenic Engineering
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Lecture No. # 39
Instrumentation in Cryogenics

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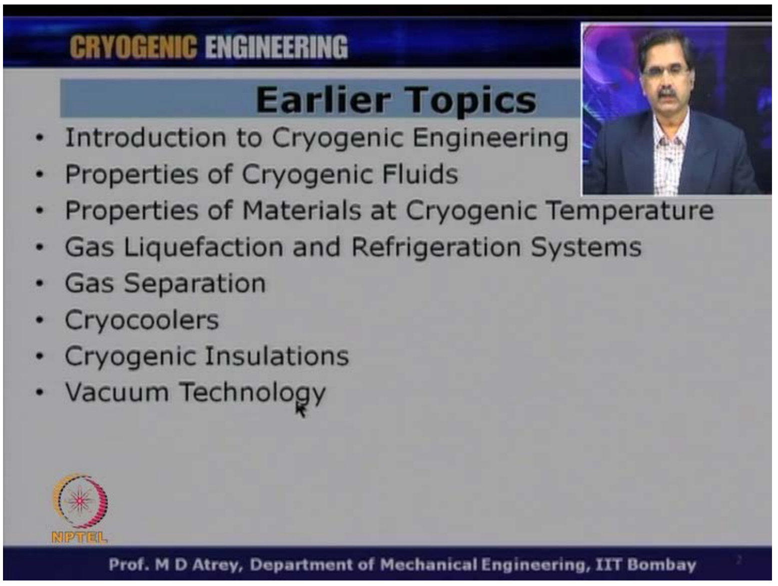

So, welcome to the 39 lecture of cryogenic engineering under the NPTEL program. So, we have covered several topics till now, and just to get a glance of what topics we have covered under cryogenic engineering is introduction of to cryogenic engineering, properties of cryogenic fluids, properties of materials at cryogenic temperature, gas liquefaction and refrigeration systems, then gas separation, cryocoolers, cryogenic insulations, and vacuum technology.

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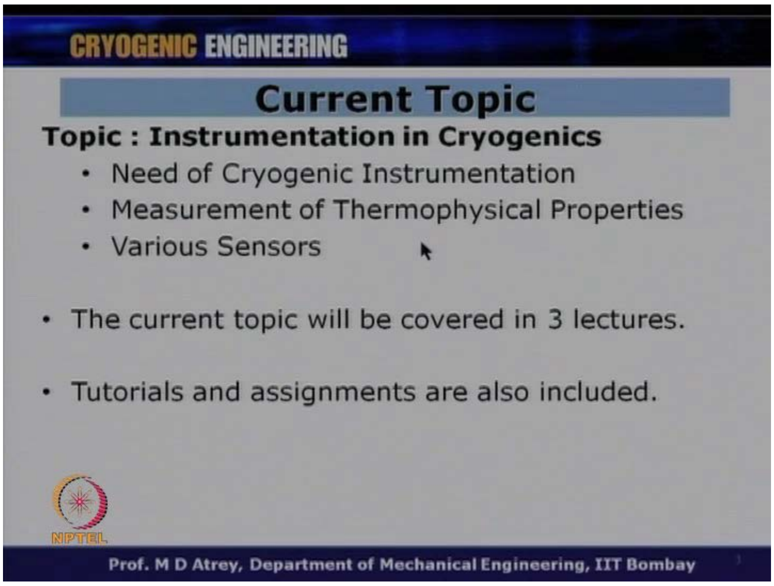

Going ahead from here, the current topic is focusing on instrumentation in cryogenics, specific instrumentation related to temperature; for example pressure and flow rates etcetera, we can do lot of instrumentation required in cryogenics. Under this topic, we will understand, what is there is the special need for cryogenic instrumentation, what is that is more demanded in cryogenic instrumentation. And then measurement of thermo physical properties, we will study a few properties, and how do we measure this properties at low temperature.

Then we can see if you sensors for measuring this thermo physical property as to how this sensors work, what are the sensors and thing like that. Then we will cover this topic in around 3 lectures, will just as upon various properties and the sensors and how do they work etcetera. And finally, we can have different tutorials and assignment, as we have been having under different topics till now.

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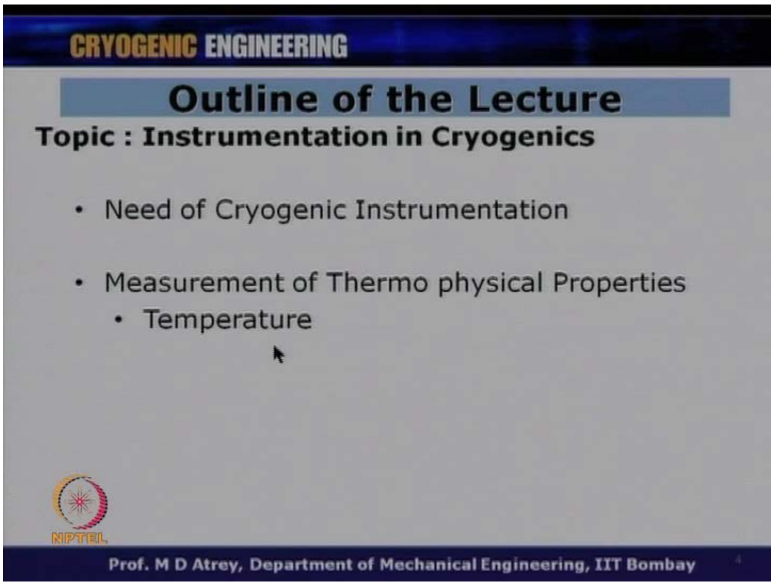

So, topic is therefore, instrumentation of the in cryogenics, let us understand the need of cryogenic instrumentation, what is the special need in cryogenic instrumentation as compared to what we do at for example room temperature, measurement of thermo physical properties and what are these properties, temperature that is what we cover in this particular lecture.

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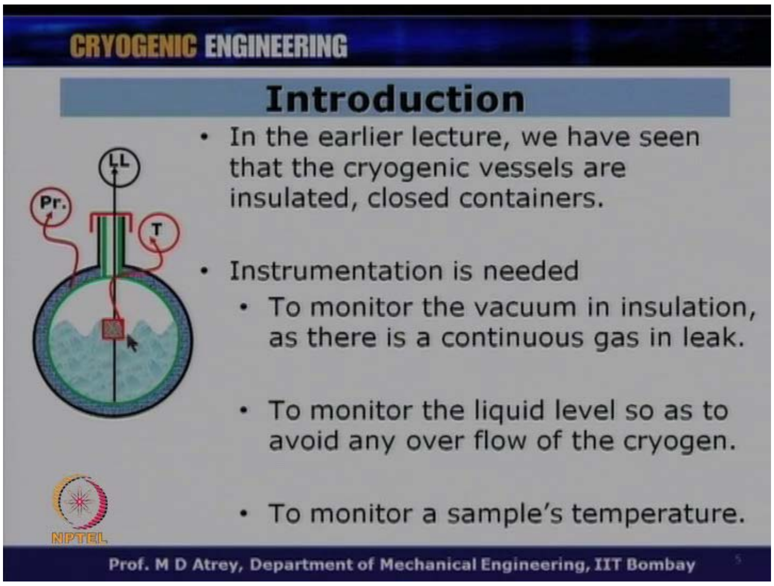

Introduction - In the earlier lecture, we have seen that the cryogenic vessels are insulated and they are closed containers. So, these are cryogenic vessel and you have got some cryogene in that; and you have got some insulation or vacuum around it. And in order to monitor particular experiment going on this close container, we require to have instrumentation, and it is needed to monitor the vacuum in insulation as there is a continuous gas in leak.

So, for example, there is the vacuum in between this inner vessel and the outer vessel. And we need to monitor this vacuum, because based on this vacuum or insulation the boil of of this cryogen will be dependent. So, let us say we have got a vacuum over here; we need to monitor this vacuum. And therefore, the pressure needs to be monitor or this should be some indicator, so as to know if this vacuum is coming down, as the vacuum is start coming down the radiation losses will convection losses will increase in this system and the boil of will be more and more.

So, basically we need to have some gauge in order to monitor if I have want to do instrumentation on this experimental cryostat in my laboratory I will worry about the vacuum that is produce between the inner and outer vessel here, also I would like to monitor the liquid level so as to avoid any over flow of the cryogen or if I have to monitor that if I got a sample of which I want to measure the temperature or I want to do some experiments to monitor the properties or to understand the properties at low temperature for example, conductivity of this material etcetera at low temperature this level of the cryogen let us say liquid nitrogen has to a monitor at a particular place.

As soon as this levels starts going down I will have to add in some liquid nitrogen or a cryogen or I should not add cryogen to a level, because of which it will starts coming out. So, it is very important that I monitor the liquid level of this cryogen that is put in this particular cryo container, and therefore, we will have to have some gauge which will monitor this liquid level. And also we have to monitor the samples temperature for example, and I have got a sample which is kept at this point, and I have to measure some property of this sample let us say conductivity or specific it capacity or shrinkage for example, whatever at low temperature, and therefore, I need to have this sample at different temperatures.

So, I need to have some sensor which is sitting on this sample so that I will know at what temperature the properties are being measured. So, there are various base and therefore, there are various property that could be monitored in a cryogenic experiment, but these are very small experiment that could be done in a laboratory scale, where in I would need to monitor the liquid label; I will lead to monitor the temperature of this sample with time, and accordingly I would also monitor the pressure or the vacuum that is being generated by a vacuum pump over here.

This will ensure that the boil of does not increase, this will ensure that whatever the properties I want to measure their measured at a particular temperature, and also the liquid level gauge will ensure that there the pre required amount of liquid that is always getting maintain in this cryostat. So, instrumentation is needed like this for various applications, some applications may not require for example, vacuum to be maintained, but some applications will required some other measurements to be done. And therefore, it is very important some application may require to see at rate the boil of is happening, the mass flow which is leaving this particular place needs monitored. So, there are various thing that needs to be monitored and therefore, a special instrumentation is require to be done at cryogenic temperatures.

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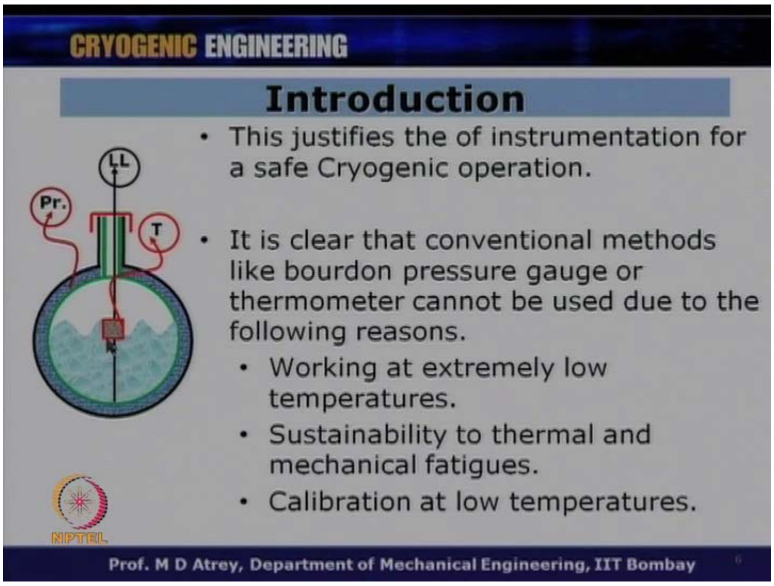

So, this justifies the need of instrumentation for a safe cryogenic operation, it is clear that conventional methods like bourdon pressure gauge or thermometer cannot be used due to following reasons. So, I cannot have a bourdon pressure gauge which is maintain to measure the vacuum over here, because I have got a negative pressure here; I have got a vacuum being generated at this point, also I cannot use thermometer with mercury at this point here. So, I need to worry about some other instrumentation mechanisms, some other sensors which will work at very low temperatures, and it will also satisfy other requirements at which are going to be very special at lower and lower temperatures. What are they?

This sensors have to work at extremely low temperatures; for example, I have got a mass flow measurement the mass flow is going to be measured at low temperature the boil of is going to be at lower and lower temperature. So, this sensors have to stand those low temperature, the liquid level sensor which is going to be kept inside the liquid has to stand that low temperature, it is very important because at low levels at low temperatures the material view under will undergo lot of changes, and therefore, sensors has to be correctly made in order to stand those low temperatures.

Also the sensor has to sustain it should have this sustainability to thermal and mechanical fatigues. So, after sometimes then the cryogen goes of it will come to room temperature, again when you put the cryogen the temperature will go down and therefore, the sensor has to stand this thermal and mechanical fatigue, as the temperature goes down it will shrink for example, or as the temperature comes to room temperature it will expand again, because change of temperature. So, this will happen many times and therefore, the sensor has to stand or sustain this thermal and mechanical fatigue.

Third important thing all these calibration have to be done at low temperature. So, whenever I develop a sensor if I want to measure the sensor temperature I want to measure the temperature to 1 Kelvin when I have to have a known 1 Kelvin source, the calibration has to be done with respect to this known standard 1 Kelvin, 1.2 Kelvin, 4.2 Kelvin whatever these sources have to be standardized. So, calibration at low is now to going to be very easy. So, liquid level sensor if I use it for water it will work in at different way, but if it going to be you know sensing the liquid level at 77 Kelvin or 4.2 Kelvin then I cannot use the sensor which is being use for water for example, because the sensor at 4.2 Kelvin will undergo completely different transformation, it will be working at low temperature the sensor will shrunk and again it requires to be calibrated at this temperature.

So, the sensor which are going to be working at low temperature has to satisfy all this conditions, and therefore, the sensor normally which have working in cryogenic conditions are very costly, this one has to keep it mind and therefore, there are not only very costly if you wanted calibrated for example, if you want to calibrated to very higher accuracy again your charge for that thing. So, accuracy requirement at low temperature also is a question mark, because the cost of the sensor will be accordingly decided. This requires a very special setup meant for cryogenic condition.

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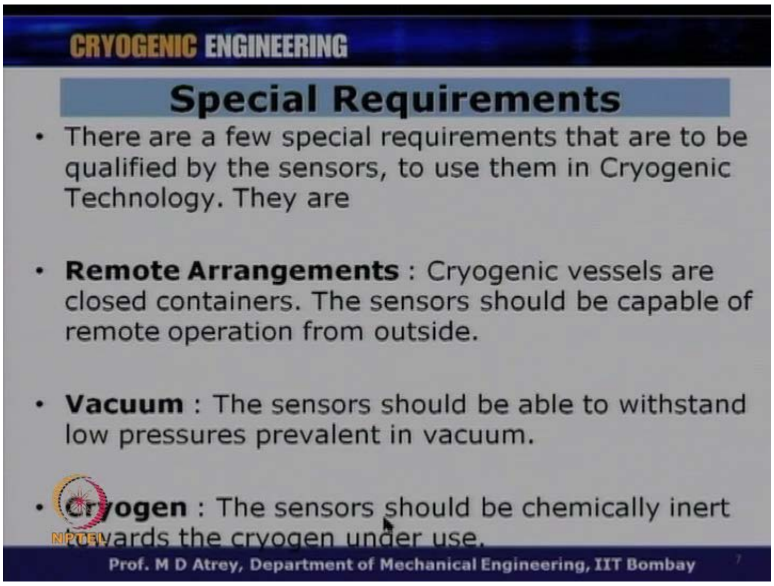

So, what are these special requirements for these sensors to be working at low temperature? There are a few special requirements that are to be qualified by the sensors to use them in cryogenic technology, they are remote arrangement; that means, the cryogenic vessels are closed containers. The sensors should be capable of remote operation from outside, because a sensor is going to be kept at low temperature, while the leads will come out, the wires will come out, and at room temperature you will have a display unit.

So, sensor actually working away from the actual you know measurement place, and therefore, it is kind of a remote arrangement and this remote arrangement should take care of all the wiring that should come out from inside to outside, it is a very important requirement. Vacuum the sensors should be able to withstand the low pressure prevalent in vacuum for example, some sensor may have to work vacuum especially the pressure measurement sensors. Or some sensors are working at low temperature and then also working a vacuum for example, a temperature sensor working in a cryocooler, the cryocooler will have vacuum all around it and the sensor also sees vacuum, and therefore, the sensor leads have to come from vacuum and it have to come outside. So, this also has to be taken care of while working in cryogenic or while working in vacuum atmosphere.

Is a very important requirement you have to have a very special kind of seals which seals vacuum from the atmosphere? So, you could to have some special seals for this purpose, cryogene the sensor should be chemically inert towards the cryogen under use. So, the sensor should not the material in sensor whatever is being used should not react with for example, liquid nitrogen, or there are other inert cryogenes basically, but some gas for example, liquid hydrocarbon should not interact with this sensor, otherwise you know we will have different chemical reaction therefore, the characteristic of sensor will completely change.

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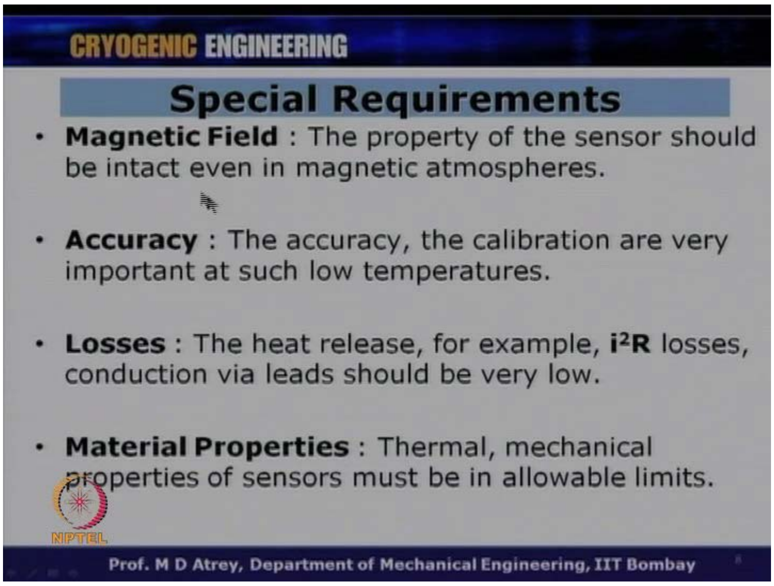

Sometime this sensors have to work in magnetic field and therefore, the property of the sensor should be intact even in magnetic field atmosphere, you have to see that the magnetic field for example, in M R I it will be there will be lot of magnetic field there is good magnetic field and the sensor property should not change and to the magnetic field for example, silicon dioxide cannot be used therefore, under the environment of magnetic field, but I have to use surnox for temperature measurement; very important deviation when I have to think about, then I go for a magnetic field envelopment.

Accuracy of course, is very important, the accuracy of the calibrations are very important at such low temperatures and one has to pay for this, the losses the heat release for example, I square R, because there are leads coming from the close containers to outside and therefore, some current will go inside, and therefore, some heat will be getting released because of the I square R losses, or conduction via leads because one end of the sensor is going to be at room temperature, the other end of the sensor is going to be at low temperature and therefore, some conduction may occur and that also can cause some errors in your measurements. So, the losses because of the conduction across the leads and I square R losses, you have to see that this losses are taken into account while calibration, these errors have to be taken into account basically.

And the material properties the thermal mechanical property of the sensor must be in the allowable limits, they should not be subjected to extra stresses, they should not be subjected to lot of thermal stress also, and therefore, this property also have to be taken into account when you design a sensor of cryogenic conditions. In fact, the cryogenic sensors therefore, we have to stand against all these odds which have normally not existent in room temperature or otherwise use in normal experiments. So, there are various thermo physical properties and this sensors have to stand all those requirements which we just defined.

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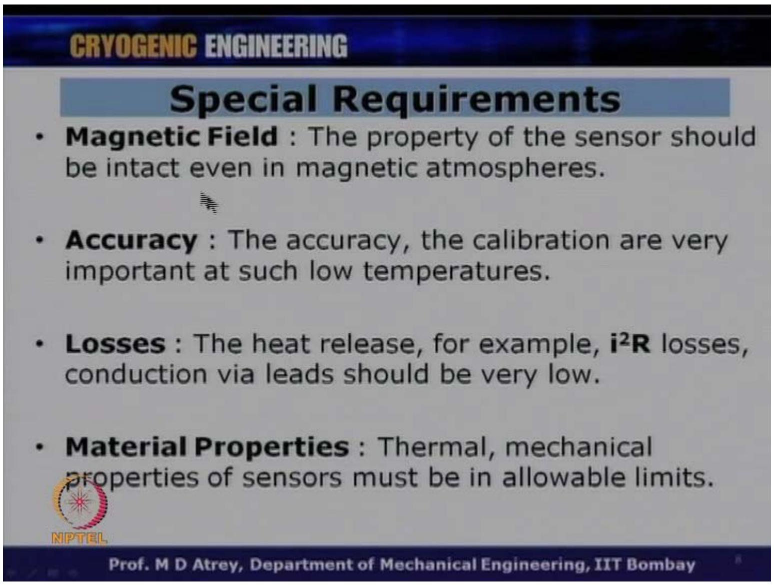

Now, let us see are these thermophilic physical properties which are required to be measured, there are various thermo physical properties that are measured or monitored in cryogenics they are temperature, liquid level, pressure, mass flow rate, viscosity and density, electric and thermal conductivity, in addition to that we can now specific capacity and thing like that, some property like magnetic susceptibility and thing like that, but out of which we are going to study mostly that are use in cryogenics will be temperature liquid level and pressures. This course we look at this three property measurements and in this particular lecture let us focus on temperature of measurement. In this topic only the first three properties are covered which are very important and normally that will be used mostly in the cryogenic operations.

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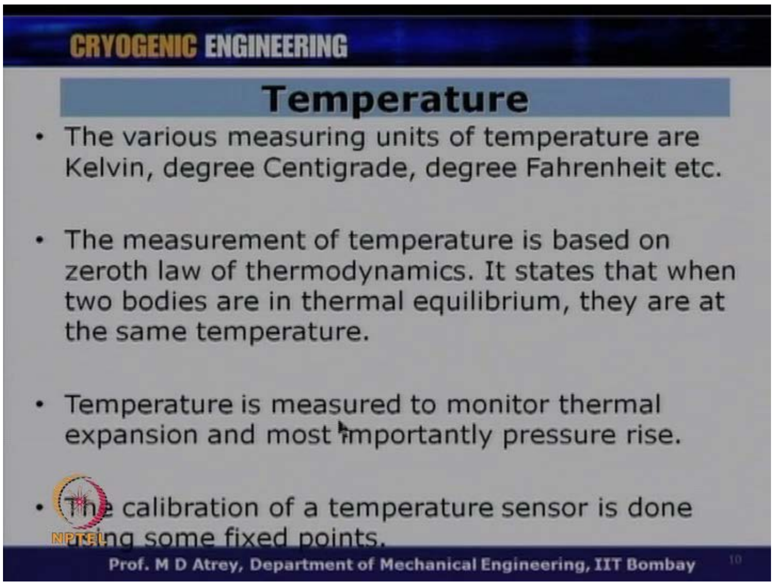

So, let us look at temperature, the various measuring units of temperatures are you know Kelvin degree centigrade, degree Fahrenheit, rank in etcetera, the measurement of temperature is based on 0th law of thermodynamics, it states that when two bodies are in thermal equilibrium they are at the same temperature; that means, I need to have some calibrated data in which the sensor to be calibrated will come in contact and then you can say that they are in thermal equilibrium and then with we say that they are at the same temperature. So, it is a very important that we keep two units in the good thermal equilibrium with each other and see to it that there in perfect thermal equilibrium and therefore, in this way we can calibrate a sensor at very low temperature.

Temperature is measured to monitor thermal expansion and most importantly rise. So, why do we require? Of course, we note we have to know the temperature by itself, but it can also an indirect based on a temperature you can monitor thermal expansion. As the same time we can see what is the pressure rise of a cryogene with increase in temperature. So, temperature is a indicate your lot of things actually in cryogenics.

The calibration of a temperature sensor is done using some fixed point this is a very important thing as I said. At room temperature above we have got various fixed points, but if you want to do calibration of a sensor at very low temperature we have to back some fixed point or conventionally fixed point, which are very known temperatures and this data is very important, we have to have the data regarding this fixed points.

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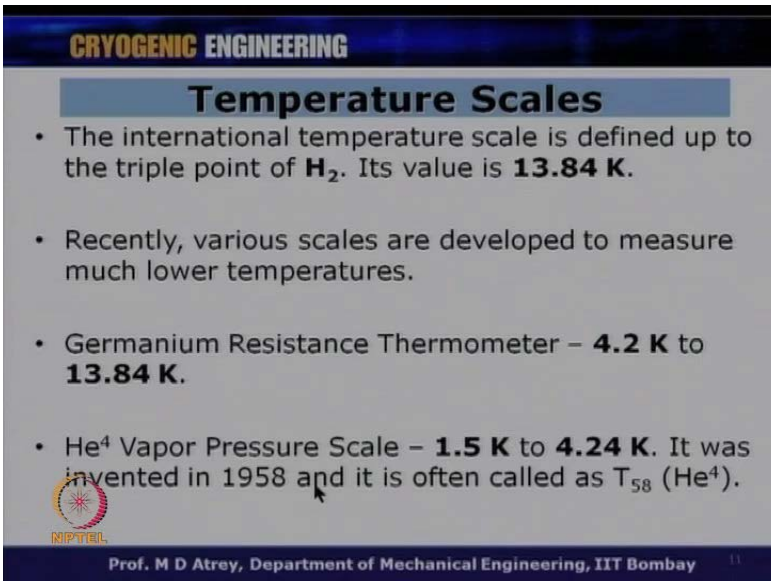

What are the fixed points? This fixed point use temperature scales. And the international temperature scales is defined up to a triple point of hydrogen for example, its value is 13.84 Kelvin. So, I know at a particular pressure above hydrogen I will get a triple point when the hydrogen gets solidified and that temperature is 13.84 this is a very define temperature. I know liquid nitrogen temperature, I know the 0 degree centigrade the ice temperature, I know the boiling point of water there all fixed points, but in lower temperature range we have got for example, the triple point of hydrogen as fixed point which is universally accepted. So, if I want to do measurement I can take this as a very important point and again this I can calibrate my sensor.

Recently various scales are developed to measure much lower temperature. So, if I want to go to 1 Kelvin below 1 Kelvin or below 10 Kelvin there are various fixed points which are again universally accepted for example, germanium resistance thermometer which normally give calibration from 4.2 Kelvin to 13.84 Kelvin. So, below hydrogen triple point we have got germanium resistance thermometer that also could be used as a function of resistance versus temperature. So, as soon as the temperature changes the resistance changes and we know the relation between this temperature and resistance therefore, we can calibrate sensors below 13.84 Kelvin up to 4.2 Kelvin using germanium resistance thermometer.

Then below that we have got helium vapor pressure helium 4 which is the isotope as you remember. So, we can characterize our sensor or calibrate our sensor from boiling point of helium till 1.5 Kelvin which is going to be at lower and lower pressures now below atmospheric pressures. And it was invented 1958 and this is normally called as T 58 scale or helium 4 scale which is develop in 1958. So, below 4.24 Kelvin up to 1.5 Kelvin I can use helium 4 vapor pressure; that means, how the vapor pressure of the helium where is below 4.24 Kelvin. So, there is the again a calibration curve with respect to vapor pressure curve versus temperature and that also can be used to calibrate sensors below 4.24 Kelvin.

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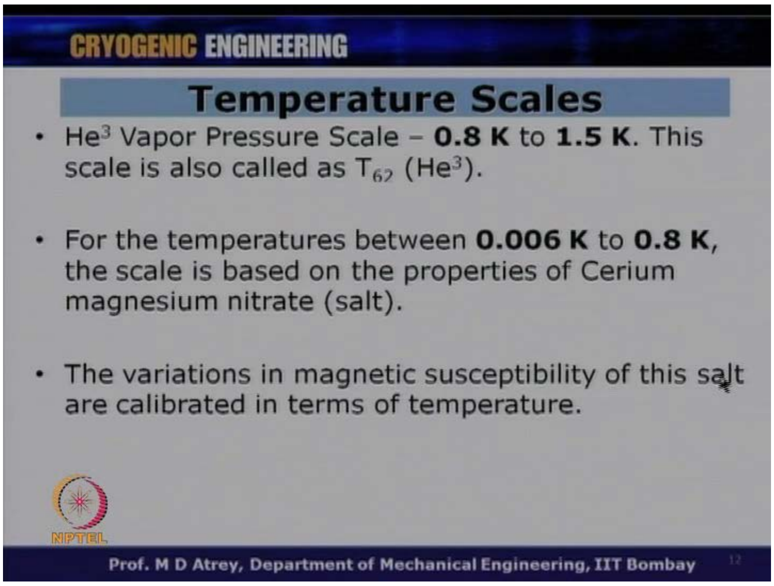

Then we got a helium 3 which is again isotope helium gas, and we got a vapor pressure of helium as a scale up to 0.8 Kelvin, so below 1.5 Kelvin up to 0.8 Kelvin we can use a helium 3 vapor pressure curve to calibrate and this scale is called as T 62 Kelvin, because it for invented in 1962.

For the temperatures between 0.006 Kelvin up to 0.8 Kelvin this scale is based on the properties of cerium magnesium nitrate the salt. So, you got a various properties of this salt that could be you know brotin and the temperatures in this range can be calibrated, and then below that the variation in magnetic susceptibility of this salt are calibrated in terms of temperature. In this temperature, what is basically calibrated is magnetic susceptibility of this salt. So, these are different temperatures skills that are used to calibrate different temperature sensors.

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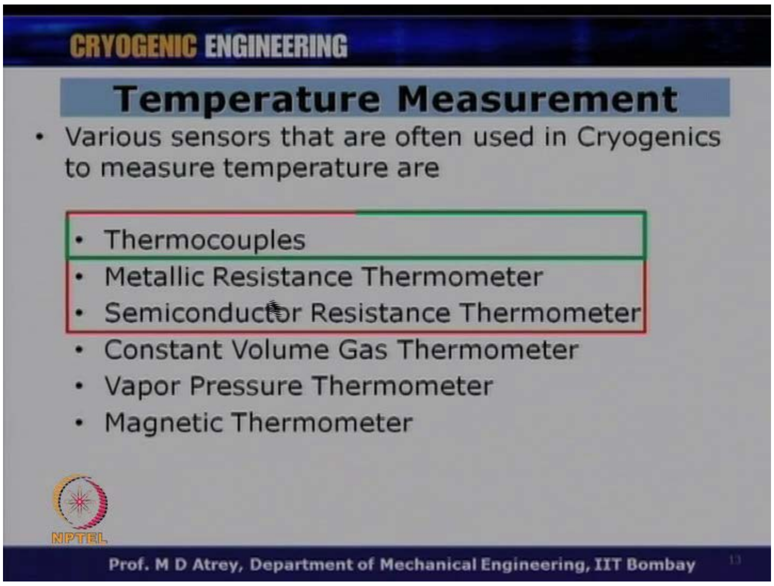

The temperature measurements various that are often used in cryogenics to measure temperature are thermocouples, metallic resistance thermometer, semiconductor resistance thermometers, constant volume gas thermometer, vapor pressure thermometer most of this you know thermocouple is mostly use at various application for high temperature as well as for low temperature. At low temperature again you have got magnetic thermometer which is what we just talked about. So, mostly thermocouples metallic resistance thermometers and semiconductor resistance thermometers will be used for normal applications in cryogenics. So, I am going to focus on these three parts and mostly we will talk about thermocouples in the present lecture. So, let us come to thermocouples now. So, how does it work? Consider two conducting wires of different materials for a thermocouple.

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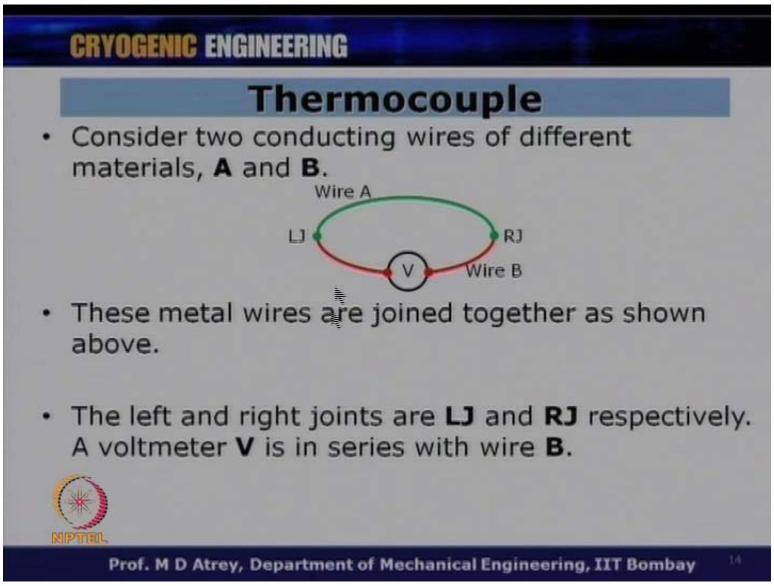

Now we got a material A and material B, so we can see a wire material a; and wire of material b, and you got a joint here let us called left joint and right joint. These metal wires are join together as shown above, the left and right joints respectively are L J and R J and; that means, if you connect metal A with metal B wire a and wire b at left joint and you have got a other connections we got a two different connections and we got a voltmeter across between A and B now.

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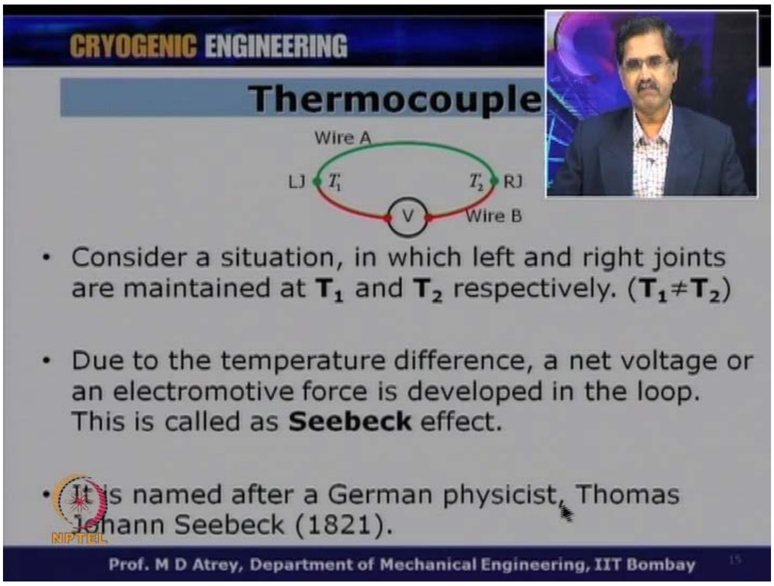

So, what happens? Consider a situation in which left and right joints are maintain at T 1 and T 2 respectively in such a way that T 1 is not equal to T 2. So, I have got a left joint at T 1 for example, and right joint I have kept A t 2 for example, such that T 1 is not equal to T 2.

If such a thing happens then due to the temperature difference a net voltage or an electro motive force EMF is developed in the loop and this is called as see beck effect, is most of you know. So, because of this similar metals join together and, because of the temperature different between T 1 and T 2 a voltage get generated EMF get generated. And this EMF is nothing but function of this two temperature difference T 1 minus T 2, now this is called as see beck effect, it is name after a German physicist Thomas Johann see beck in 1821 which is the old technology actually.

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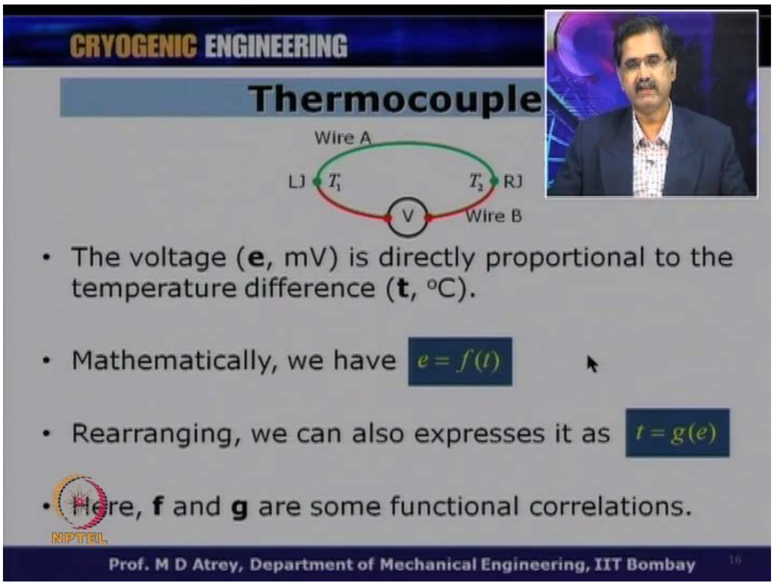

The voltage E is in normally in milli volts is directly proportional to the temperature difference. So, it is going to be proportional to T 1 minus T 2 which is denoted by a small T in degree centigrade, mathematically therefore, we can see that this E or the EMF which is generated is going to be function of this temperature difference. So, actually what you developed therefore, the calibration curve, you can have a voltage get a generated in millivolt as a function of this delta T or we can also call this as temperature difference as the function of E. I can relate now temperature difference as a function of whatever EMF get generated, because of the temperature difference T 1 minus T 2. Here f and g are some functional correlations, I can always developed some curve if I know various T values and corresponding to that T values I know various E values. So, I can find out a relation between T and e.

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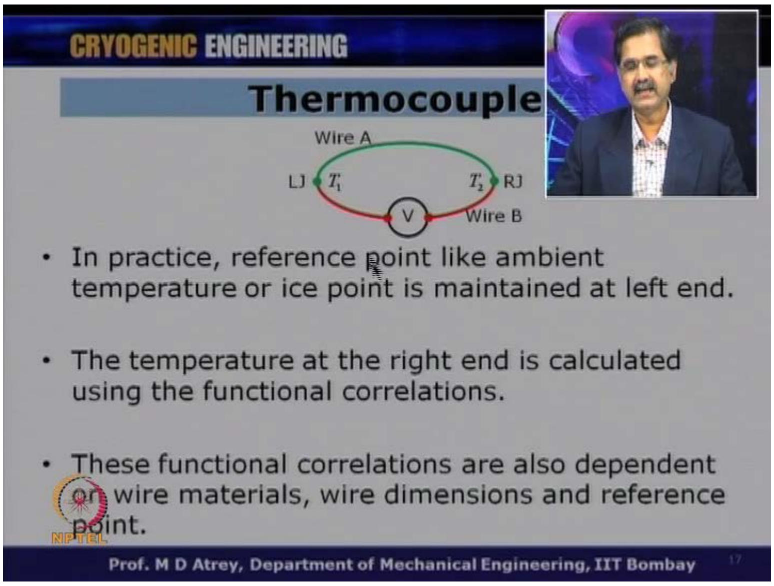

In practice so what do I do? I want to use this see beck effect now to measure temperatures. So, what do I do? I keep a reference point like ambient temperature or ice point is maintained at the left end, so I kept T 1 is a very standard value which I know, ambient temperature for example, 300 Kelvin or 0 degree centigrade if I put ice (( )) this point. If I keep T 1 as constant and if I want to measure now T 2 value of a particular you know cryo cooler for example, I will dip or I will touch that material for example, I can dip this in liquid nitrogen also which is 77 Kelvin.

So, depending on the difference between T 1 and T 2 I will get some EMF generated at this point, and this EMF is going to be directly dependent on T 1 minus T 2, and I will have this correlation in my hand which is basically coming out of some calibration technique and therefore, I will be able to relate this EMF generated to T 1 and T 2 of which I in I know T 1, because T 1 is kept constant and therefore, I can calculate the value of T 2 easily and this is the way a thermocouple works.

The temperature at the right end is calculated using functional correlation; these functional correlations are also dependent on wire material, wire dimensions and the reference points. So, depending on what I am using over here, what is the thickness of this wire? What is the length of this wires material of this wire? I will find out the relationship between that.

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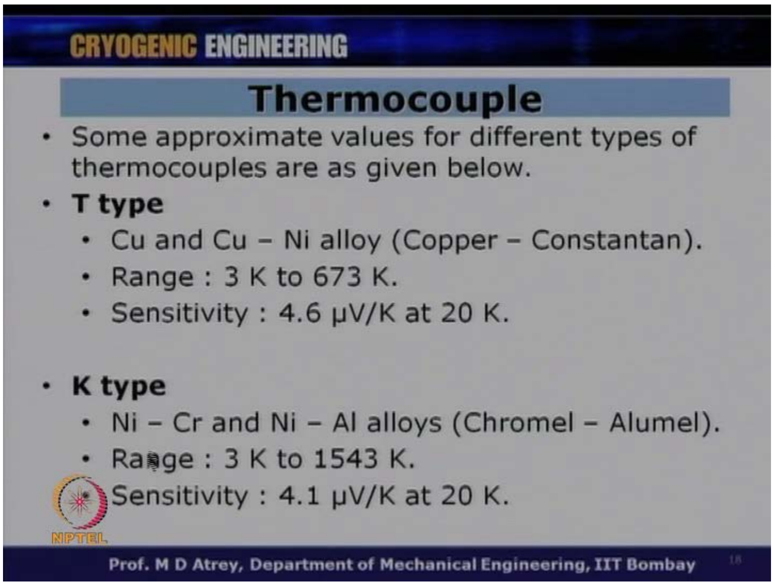

Some approximate values for different types of thermocouples are given below. There are various types of thermocouples, depending on the material that are used as different joints; there are T type thermocouples, K type thermocouple, p type thermocouples. So, when I talk about T type thermocouples they are basically copper and copper nickel alloy that is copper constantan, so one joint is copper; other material is copper nickel alloy which is constantan this is normally called as T type, it has got a range of calibration between 3 K to 673 Kelvin, so quiet a good range which covers from cryogenic to high temperature range, and sensitivity around 4.6 microvolt per Kelvin at 20 Kelvin. This will increase at higher and higher temperature, but at a low temperature it still had some sensitivity. So, you got a 4.6 microvolt variation per Kelvin at around 20 Kelvin.

Then we got a K type thermocouple, it is made up of nickel and chrome which is called as chromel, and nickel and aluminum which is alumel. So, we got a chromel aluminum or a K type thermocouple the two materials are chromel and alumel. Here the range is again from 3 K to very high temperature 1543 Kelvin K type and sensitivity around similar to what we have for T type 4.1 micro volt per Kelvin change at around 20 Kelvin. So, sensitivity also is not very small itself reasonably good sensitivity.

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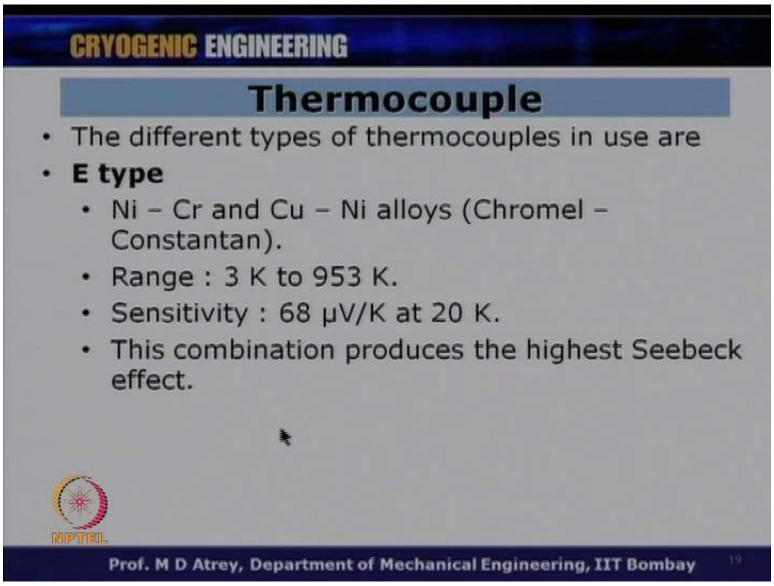

So, we have seen T type and K type thermocouple, and then we got a E type also which is also made of it is called as chromel constantan now, so we got a nickel chromium as one material a let say, and copper nickel which is constantan as a material b basically, so this is called as E type where we have got the chromel constantan thermocouple. It is again use for a range of 3 K to 9953 Kelvin, and sensitivity is around 62 microvolt per Kelvin at 20 Kelvin. So, we got a high sensitivity as compare to T and K type over here; so E type thermocouples are really acceptable.

I would just like to show you here a thermocouple which is over here, can you see this thermocouple, so this is a joint which you can see at this other end while this is a one joint I can say left joint and the right joint can be I can connect a voltmeter between this two and this voltmeter itself gets joint by you know at a room temperature joint basically, so you can have a material a as this red one; and you can material b as this yellow wire, one joint will be at ambient temperature and I can have a volt meter connected right over here. And the other joint could be the temperature if I want to measure whatever temperature I want to measure this temperature would come over here.

So, this is a simple thermocouple that you can see, you got a one joint here; you got a other joint here. And other joint will have ambient temperature we can have a voltmeter placed across this two lead wires. So, let us go back to… So, we have seen now T type, K type, and E type thermocouples, they got different sensitivity they got a different range of temperatures to be measured.

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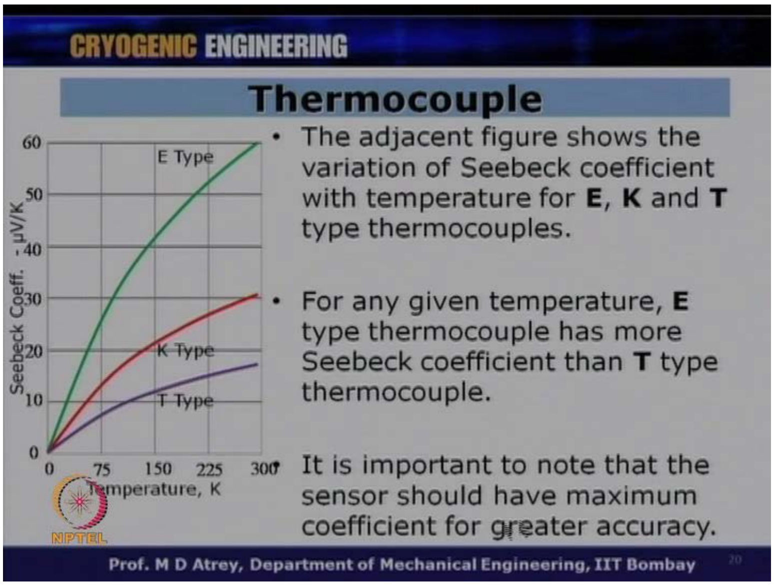

This combination produces the highest see beck effect as we can see for E type thermocouples; I can see the sensitivity or a see beck coefficient over here as compute to temperatures. The adjacent figure shows the variation of see beck coefficients with temperatures for E, K and T type thermocouples. So, you can see a E type thermocouple and you can see beck coefficient over here; and see beck coefficient is basically what is the voltage change that happens per Kelvin change over here. So, you can see E type, K type and T type and at any temperature you can see that E type has a very high sensitivity, high seebeck coefficients, which is microvolt per Kelvin. What is the micro belt changes that happen per Kelvin? So, adjacent figure shows the variation of seebeck coefficient with temperature of E, K and T type thermocouples; for any given temperature E type thermocouple has more seebeck coefficient than T type thermocouple that is what we see. It is important to note that the sensor should have maximum coefficient for greater accuracy therefore, it is very important to that this works mostly the E type will be preferred in that case.

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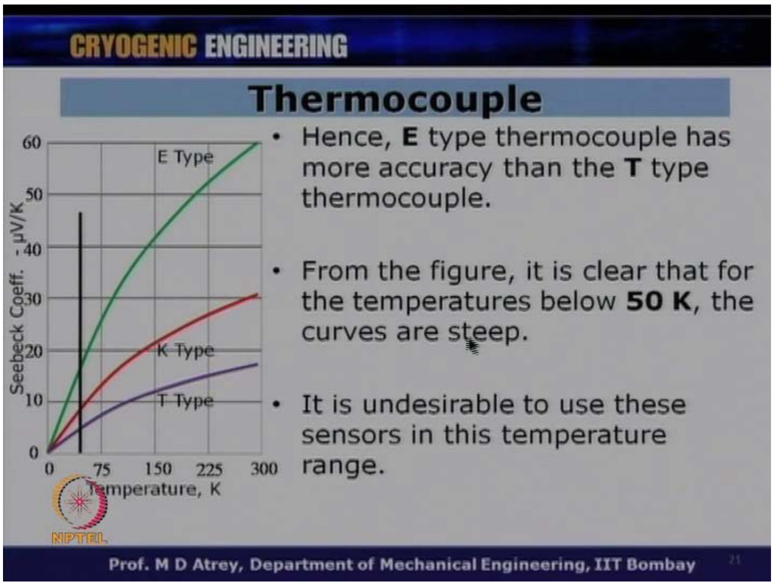

Hence, E type thermocouples has more accuracy than the T type thermocouple, from the figure it is clear that temperatures below 50 Kelvin if I come below 50 Kelvin the microvolt per Kelvin is going to be less and less and therefore, normally thermocouples will be used let us say above 50 Kelvin temperatures. Of course, one can come down over here, but the sensitivity less and less and therefore, you will have to increase this microvolt, you have to amplify the output or the E m f to a greater level in this case. So, here normally will have thermocouples measurement to be done normally up to 50 Kelvin. It is undesirable to use this sensors in this temperature in, so below 50 Kelvin I will not normally use thermocouples, because the will be no questionable and therefore, the accuracy will be questionable.

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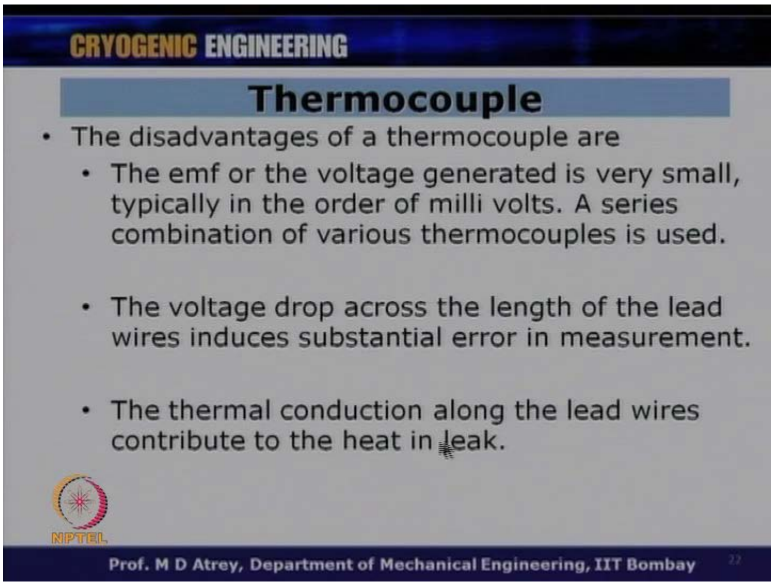

Now, what are the disadvantages with thermocouples? There are some disadvantages the EMF or the voltage generated is very small typically in the order of milli volts, a series combination of various thermocouple is therefore used, so if I want to increase that milli volt to some volt I let to amplify it and therefore, I will to use series of thermocouples to increase this milli volt to some measurable voltage level. So, one can have some errors in this you need to have some amplifier circuit also. The voltage drop across the length of the lead wires induces substantial error, there are some errors measurement as we say because we got a long wire which is coming over here and therefore, there is could be some voltage drop across it that also will cause some errors in the thermocouple temperature measurement.

The thermal conduction along the lead wires contribute the heat in leak also, so you got a some, because at the lower temperature other side; and higher temperature on the other side there will be some temperature conduction thermal conduction that will be happening that also we will cause some error of measurement. And one has to take this error into account while use in thermocouple for temperature measurement.

So, after thermocouple just now we have seen how do thermocouple work, and how it is use in cryogenic conditions? We got a next sensor which is resistance temperature detector or normally called as RTD, which is most prevalently used to measure temperatures at very low temperatures let us up to 30 Kelvin temperature. It is very commonly used it overcomes most of the disadvantages that the thermocouple normally will have and therefore, RTDs are very popular in cryogenic temperature measurements.

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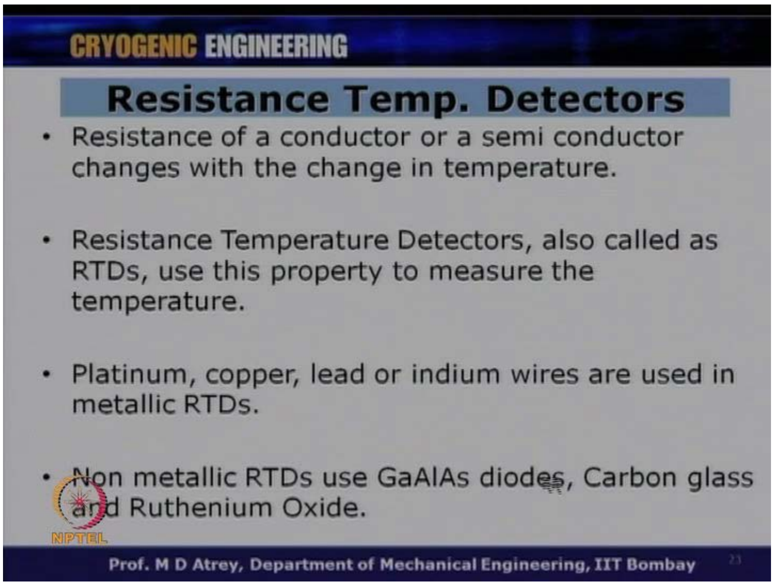

Resistance of a conductor or a semi-conductor changes with the change in temperature, so basically this is the relationship between the resistance and the temperature which be known to us so the calibration becomes simple, resistance temperatures detectors also called as RTDs use this property; that means, the relationship between resistance and the temperature to measure the temperature. So, one should calibrate the change in resistance that occurs with the loading of temperature. If this standard calibration is known if this relationship is known with us we can formulate also in equation. And against the change in resistance we can find out what is the temperature that is correspondingly exist over there.

Platinum, copper, lead or indium wires are used in metallic RTDs, so the resistances of this particular materials change with temperature and this change of temperature is going to be related to the changes that occur in resistance of this particular materials. Non-metallic RTDs use GaAlAs gallium alluminium arsenic diodes, carbon glass and ruthenium oxide, so this are the non-metals that also could be used whose resistances change with lowering of temperature. The resistance change also can be calibrated across with changes that happen with temperature, so they all they also can be used to work at low temperatures.

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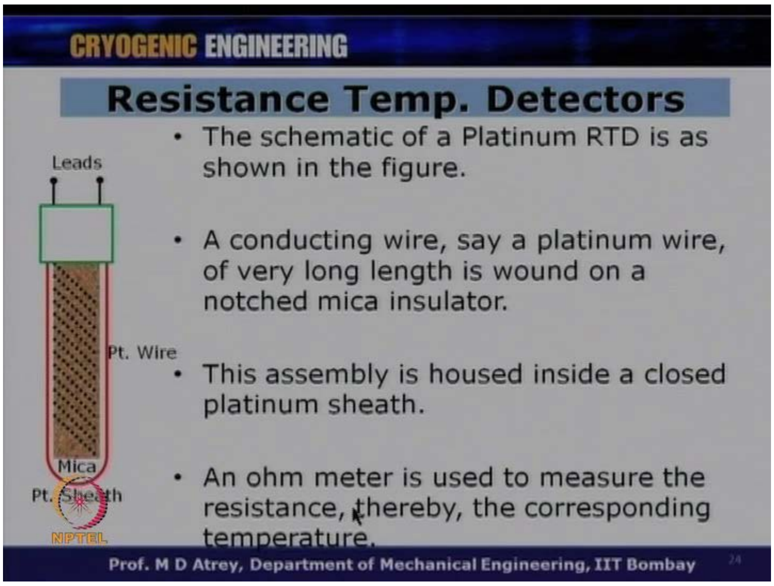

So, this is how sensor would look, a typical sensor RTD sensor a normally I am talking over here platinum sensor, because it is what mostly will be used cryogenic application, this cause also little less lets around 1000 rupees per small sensor, which may not be calibrated or which you have calibrated sometimes and the calibration of this actually simple. The schematic of platinum RTD is as shown in the figure, a conducting wire say a platinum wire in this case of very long length is wound on a notched mica insulator. So, we can see a mica insulator over here, and this mica insulator has got notch made around across which runs this platinum wire. And this platinum wire is now the entire thing is going to be actually covered under this platinum sheet; this assembly is housed inside a closed platinum sheath.

So, if I want to measure particular temperature this sensor will be exposes to that temperature this entire thing is sensor, and corresponding to this temperature it resistance will change which will be measured from this leads, very simple application very this sensor has to be in thermal contact with whatever temperature you want to measure for example, liquid nitrogen I can just deep this sensor in liquid nitrogen corresponding to this I will get some ohms associated with this temperature. Normally around 21 to 23 ohms, what we will see at liquid nitrogen or 77 to 80 Kelvin temperatures, and ohm meter is used to measure the resistance thereby the corresponding temperature.

So, depending on the temperature to which this platinum seas or exposed I will get some ohm across this leads, which are kept at room temperature. So, I will have a long leads which may come out and therefore, I will measure the resistances across this platinum wire which seas the particular temperature to be measured.

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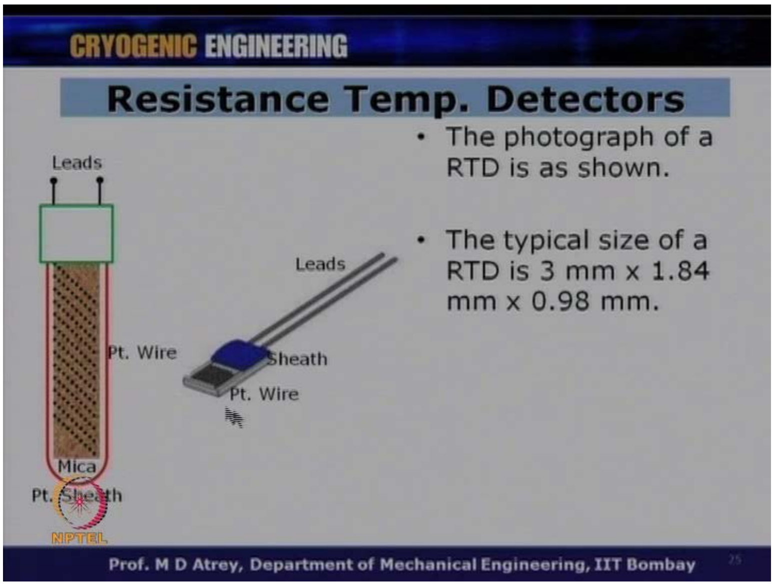

A simple operation, the photograph at the RTDs as shown over here you can see the sheath the platinum sensor and the long leads, now I shown you schematic and show you the sensor also which we have here with me, so you can see I got this sensor and I will just take this sensor out normally should handle this sensor with care. You can see these two wires or the leads coming out of this and inside this platinum wire which runs through the mica sheath there is the platinum sheath there is the sheath also.

So, normally what you can see is some kind of square over here and having two or three leads coming out, and this leads then you can connect wires to this leads so that you can have a temperature measurement to be done at room temperature. So, you see here platinum wire at the other end you can see the sheath also and the lead coming out of this. So, simple K T 100 what you can see a platinum sensor un RTD or here. So, let us come back to over slide. So exactly its look like what I am showing here in the slide, so you got a leads to leads you got a PT wire, which is what you just saw, and you got a sheath also which is come covering this platinum wire, so that you know this is not get accidently, you should not thinker with this PT wire, which will changer resistance and accordingly you can have errors in measurement. So, a photograph RTD is as shown over here; the typical size of a RTD is 3 milli meter into 1.84 into 0.9.98.

So, you can see that the length wise little longer, width and height is just milli meter actually very small one, so what is most important is that this particular sensor should be kept in thermal contact with temperature you want to maintain, so if you can have a platen surface so that you can have a maximum area of contact, so that the two are in good thermal equilibrium which is very important (( )) thermo couple for example, or also in RTD to the surface temperature of is you want to measure is very important, they should normally be in having some kind of a grees we call as thermal grees so that the resistance is minimize between this two measurement. There in good thermal equilibrium with each other. So, these are very important things of actual experimental cryogenics techniques.

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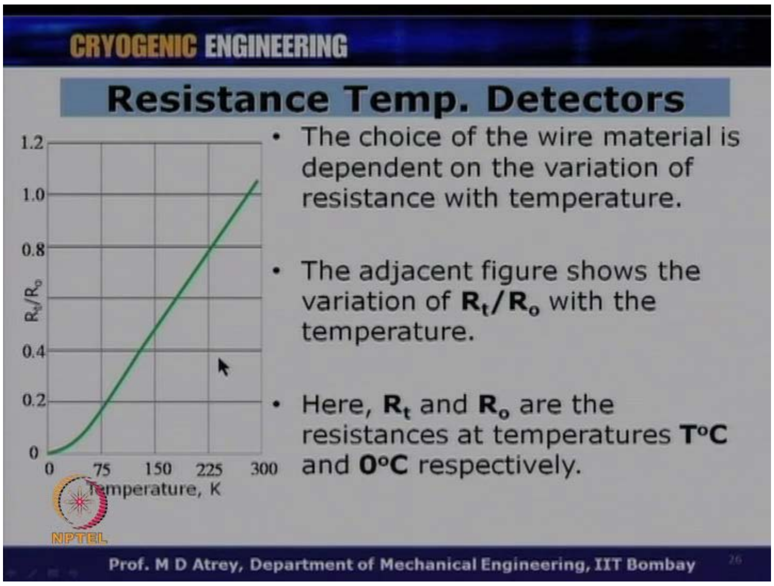

So, here we have got a curve between the resistance variation with temperature, and this resistance measurement is actually R T by R o; that means, the resistance temperature T divided by resistance at 0 degree centigrade. So, the choice of the wire material is dependent on the variation of resistance with temperature, the adjacent figure shows the variation of R t by R o are R 0 with the temperature. So, you can see that the temperature variation or non-dimensionalize resistance R T by R o with temperature as you low the temperature the R t values starts coming down, R o is a constant temperature constant resistance.

Here R t and R o are the resistance at temperature T degree centigrade and 0 degree centigrade respectively. So, R 0 are R o is a constant while R T is going to vary if I lower the temperature the resistance R T will start coming down. And you can see this is as good a linear variation up to a particular temperature and this becomes non-linear at temperature at let us below 50 Kelvin, so having a linear relationship is always better and I can actually a fix a y is equal to m x plus c kind of curve which is linear variation from let us say 50 Kelvin up to 300 Kelvin that is my cryogenic temperature region.

So, is very good for calibration if I major the temperature for example, at if I want to calibrate I can put it liquid nitrogen and I can get it resistance and I can resistance at 300 Kelvin, if I get this two value I can just join them by central line by s line and I can extend this line further to 50 Kelvin, and I can have a equation of a calibration curve for a given R T d, this is the very important and therefore, simple calibrations just deep at it liquid nitrogen get the value at 77 Kelvin, get the value of resistance at 300 Kelvin have this two points an extended line further, and I can depend on this curve up to 50 Kelvin with a good accuracy of around 1 Kelvin, this is a normal process of celebration of R T d or a PT 100. If you want to do further if you want to go very close and we can do want to improve the accuracy there I will go for small intermediate points also.

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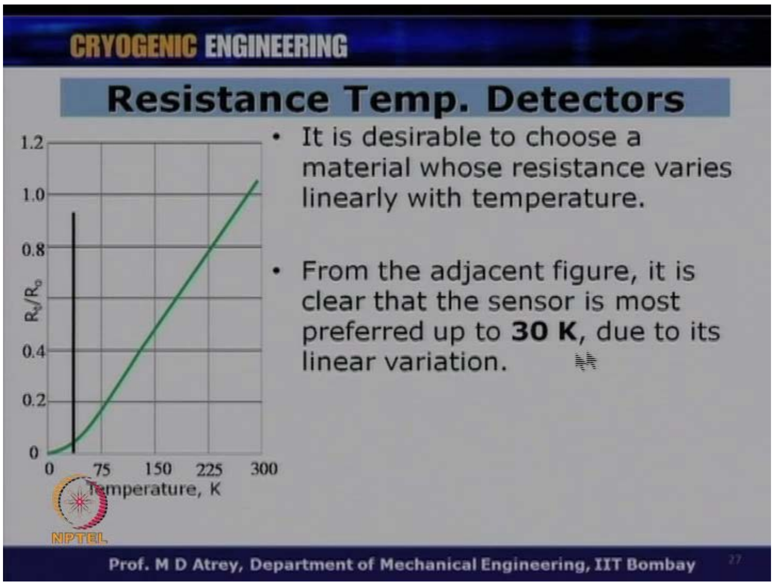

It is desirable to choose a material whose resistance varies linearly with temperature, and that is why PT platinum is preferred, because there is a linear variation of a resistance with temperature, but you can have otherwise variation, but then I have to vary about all the intermediate point at different temperatures, from the adjacent figure it is clear that the sensor is most preferred up to 30 Kelvin, so one can go up to 30 Kelvin infect up to 50 Kelvin 40 Kelvin as I said the curve is linear and they you have to have some other values below and up to 30 Kelvin. Below 30 Kelvin I will not use PT 100 unless I got fairly good accurate celebration done up to 20 Kelvin.

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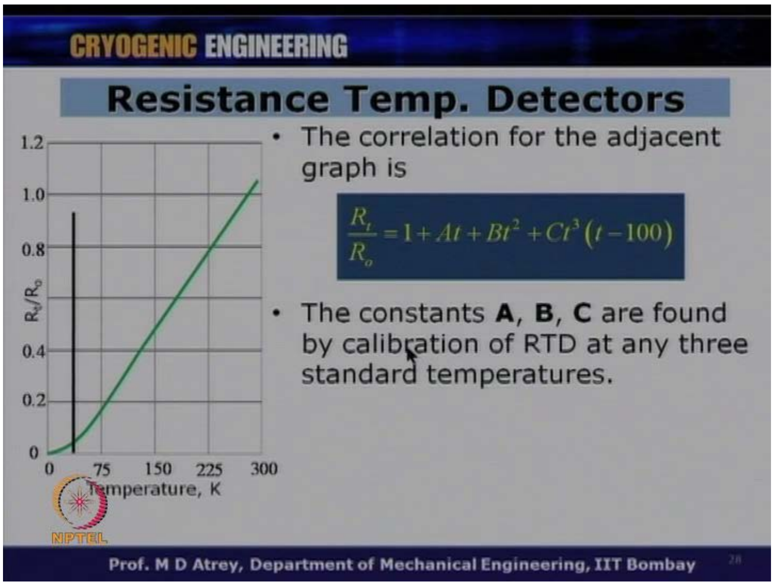

So, 30 Kelvin as I say thus that variation is acceptable, the correlations for the adjacent graph is R T by R 0 is equal to 1 plus A t plus B t square plus C t cube plus into t minus 100. I mean you van have this curve fit up to 30 Kelvin, I would have a have only 1 plus 80 curve up to let say 50 Kelvin, because there is clear linear variation that is happening up to 50, but if I want to have a calibration up to 25 Kelvin or 20 Kelvin or 30 Kelvin I will have to go for a B t square and C t cube and this kind of this is the temperature which I C at particular temperature.

So, I can fix of a curve and this can be fear to the you know whatever software you are using, so the moment you a measure this value of T or resistance I can get the value of temperature done, I can get the value of temperature immediately, the constants a b c d are found by calibration of RTD at any three standard temperatures. So, I can have 100; I can have 300 Kelvin; I can have 273 Kelvin, it is 0 degree centigrade I can have 77 Kelvin this are my three points based on which I can get a b c, but I need to have one more point below over here which is below you know I should have some source which will definitely give me 20 Kelvin, 25 Kelvin so that my curve is fairly accurate. This can be you can cryocooler also, now if I want to the sensitivity of this so this is sensitivity curve with temperature.

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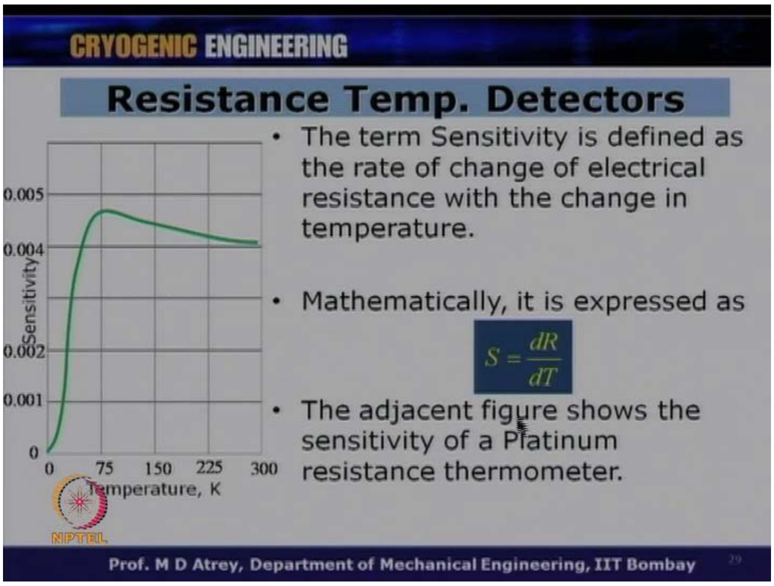

The term sensitivity is defined as the rate of change of electrical resistances with the change in temperature, mathematically it is expressed as s is equal to dR by dT, so how my resistance change happens with change in temperature, so you can see that resistance change is fairly high up to let say to 50 Kelvin temperature then it comes down, so that is y the sensitivity is very high let say up to 30 Kelvin and below which the sensitivity decreases, the adjacent figure shows the sensitivity of platinum resistance thermometer.

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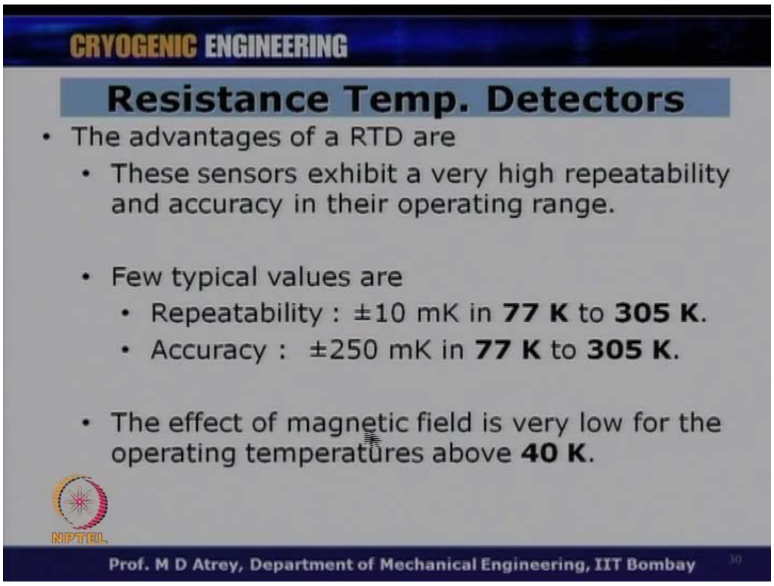

The advantages of a RTD are these sensor exhibit a very high repeatability and accuracy in their operating range, few typical values for this sensor are the repeatability plus minus 10 milli Kelvin in 77 Kelvin; 305 Kelvin which is fairly expectable in over normal measurement of temperature, unless if you want go deep down I am in less than milli Kelvin region then will have to have a very good calibration done or you let go for a other senses like silicon diors etcetera, but then for which we will pay very high amount. The accuracy is plus minus 250 milli Kelvin again in this temperature range which is also acceptable to me infect form is plus minus 0.2 0.3 or 0.5 Kelvin acceptable actually.

The effect of magnetic field is very low for the operating temperature above 40 Kelvin. So, this is acceptable even if the sensor was magnetic field environment there are no not much errors that is going to be the calibration will holds could basically and therefore, this a very important thing; however, in cryogenic condition most of the environment are having a magnetic field and therefore, PT 100 is well suited above 40 Kelvin its acceptable in a magnetic field environment acceptable in a magnetic field environment.

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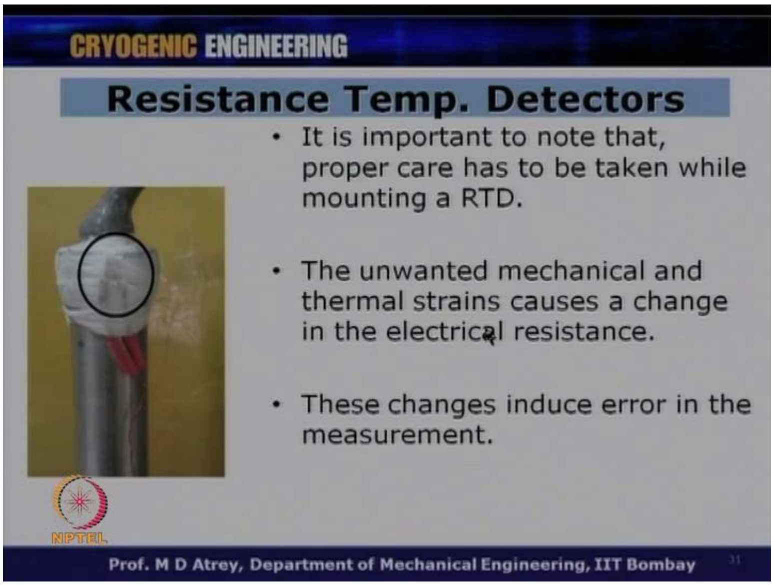

It is important to note that proper care has to be taken while mounting a RTD, I had just told you that RTD mounting is very important and here you can see that I have got a sensor setting over here, and I got leads of this sensor which is running too, and over that I have put some Teflon wire so to ensure that at Teflon the PT 100 is kept in proper thermal contact over here, normally this also not allowed, but I have to see that this holds you know this gets struts to that space over here. Otherwise I should not infect put pressure on this sensor, because putting the pressure on the sensor also can change the sensor characteristics.

So, you can just example how the RTD has been put in place over here, the unwanted mechanical and thermal strains causes a change in the electrical resistance, so this actual example of what we should and do also all the we have done over here, so we should not have you know tight we should not trace this sensor again we should not put forced on this, because of the calibration can sometimes get change. These changes induce error in the measurement. So, I should ensure that there is mechanical strain or thermal strain that is caused on the placement of an RTD or the surface temperature to be measured.

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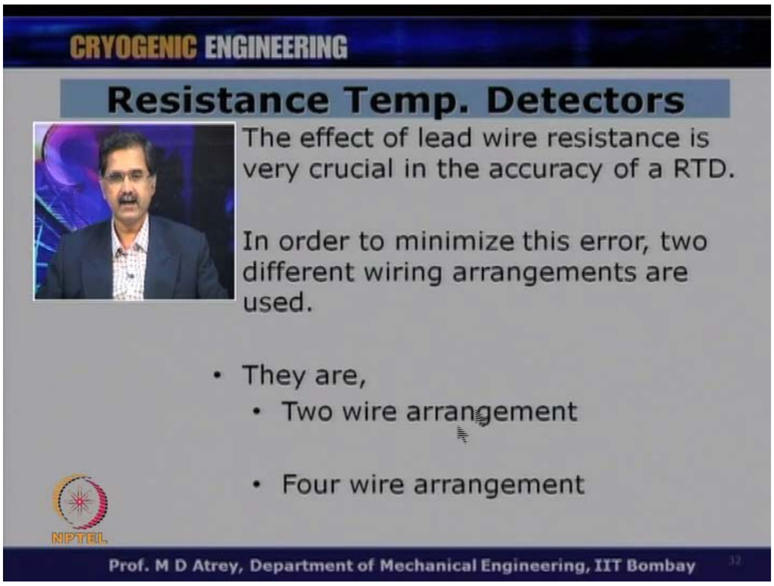

The effect of lead wire resistance is very crucial, the very important thing is the lead wires or off very long length and therefore, it will have its own resistance again. And therefore, the effect of lead wire resistance is very crucial in the accuracy of a R T d, in order to minimize this error two different wiring arrangements are used, this is very important that if you want to do very accurate measurement I have to worry about the lead resistance, because this wire leads are very high, and higher the links higher is going to be the resistance of this wire, and this resistance we figure in measured voltage a resistance across the RTD and therefore, one has to minimize this error and therefore, what we see is very important. So, there are different arrangements and this arrangements therefore, are called one is called two wire arrangement. And other one is called as four wire arrangement.

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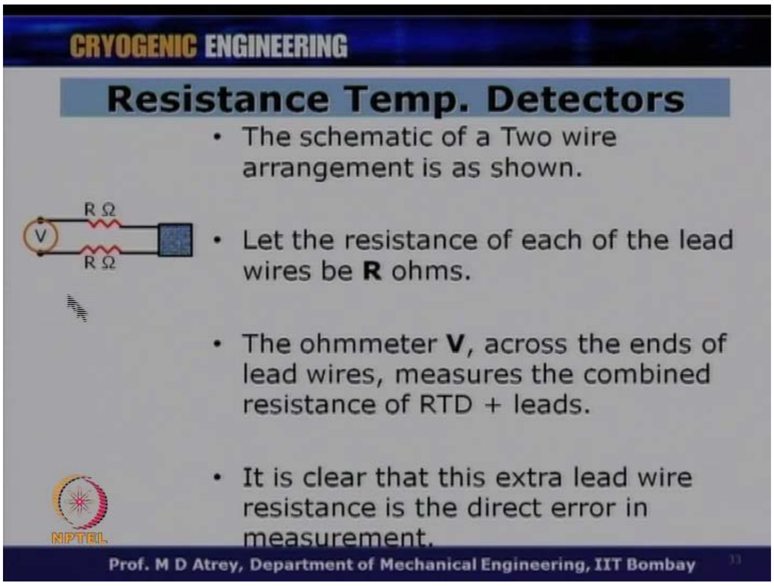

Let us see now a two wire measurement, the schematic of a two wire arrangement is as shown over here, so this is my PT 100; and this is the lead and this corresponding resistance of the lead wires, so the longer the length it will have a longer resistance, and the voltage I am going to measure actually is going to be basically, because of the resistance change that will occur at low temperature which what this senses is, but addition to that I will have this resistance are on this side and this resistance are on other sides also will figure up in this voltage measurement, because lead wires which bring this voltage to room temperature also will have own resistance. And that we also come in to this voltage measurement and therefore, this voltage measurement will have error. It will not talk about the voltage change that is going to occur a low temperature only.

Let the resistance of each of the lead wire be R ohms the ohmmeter V across the ends of lead wires measures the combined resistance of RTD plus leads. So, my volt meter is going to measure the voltage change that is because of temperature change over here; plus the resistance that occurs over here. It is clear that this extra lead wire resistance is the direct error in measurement. So, I will have to vary about this also that can I take this are into account.

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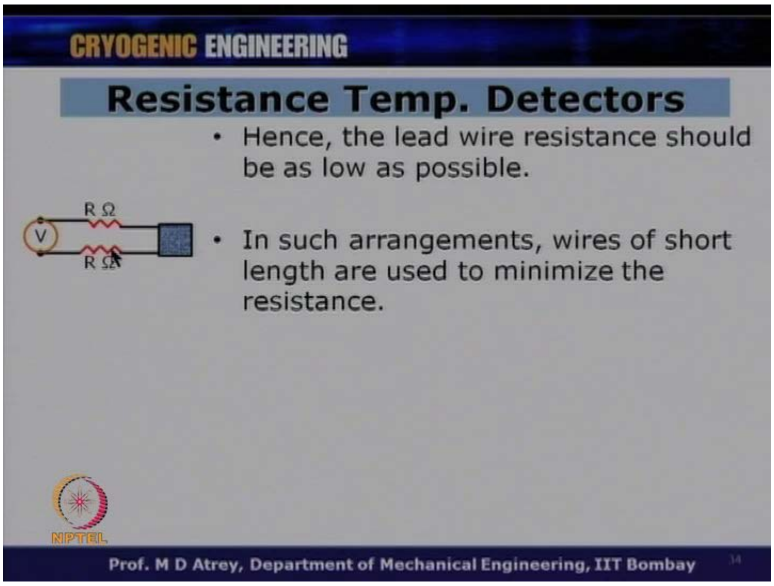

Hence the lead wire resistance should be as low as possible, so if my measurement has to a very accurate I will have to vary about this lead wire resistance also, and while calibrating, then I will have to take care of I will have take this into account. So, this is going to be a crucial arrangement if my measurement has to be very accurate. In such arrangements, the wires of short lengths are used to minimize the resistance. So, normally what should do? We should have minimum length wire so that the resistance in that case also going to be minimum.

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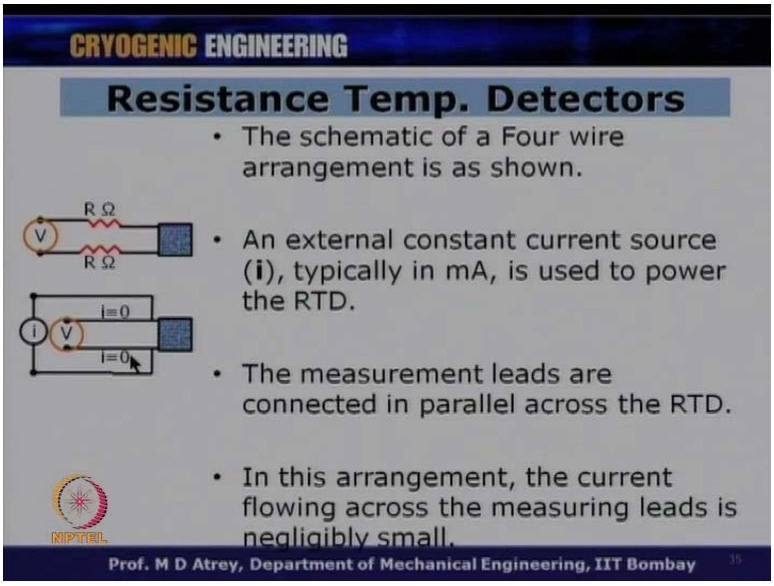

But how to overcome this? I can overcome these by having a schematic of a four wire arrangement as shown; I can haven four wire arrangements instead of a two wire arrangement over here. So, as shown here I got four leads now 1, 2, 3 and 4, one is pass in the current and other one in parallel to this to measure the voltage across the sensor only, and external constant current source I typically in milli amps is used the power the RTD, in this case I got a same source this only sense the current; and these only sense the voltage, and therefore, this voltage measurement will have some resistance figuring in their; however, in this case I got a different source to send the current in and different measurement to measure the voltage or resistance across the sensor, so this to arrangements are different this there for called as two wire in which the source the current and the voltage measurement or the resist the measurement is then by the same and the same place, while in this case there are different things.

So, external constant current source typically in milli amps is used to power the RTD. The measurement leads are connected in parallel across the RTD. So, here I am measuring the voltage across parallel to this, in this arrangement the current flowing across the measuring leads is negligibly small. When I am doing the voltage measurement here the current flowing through this arrangement is going to be negligibly small, because I am doing volt meter measurements.

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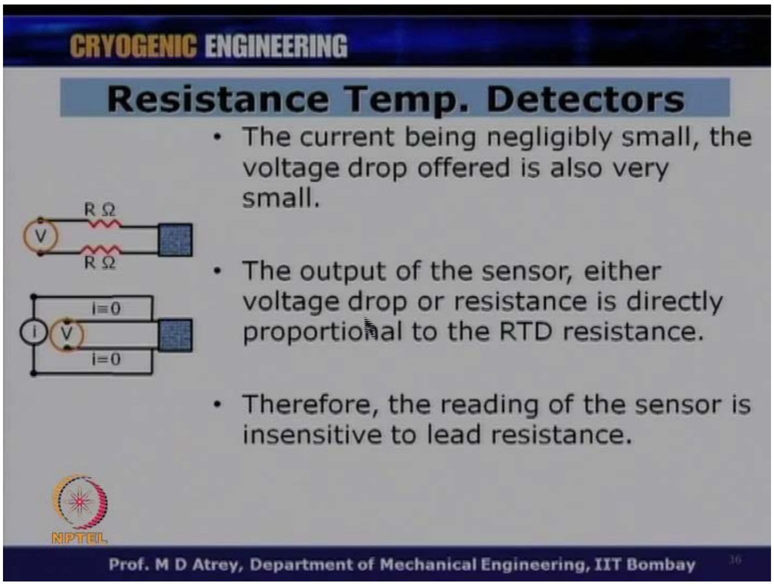

So, here is going to be different then the two wire arrangement that we just showed, the current being negligibly small the voltage drop offered is also very small, so I is actually very close to equal to 0 and therefore, there is no resistance drop or voltage drop across this leads, this is completely taken care of while this is this cannot be taken care of over here, because I got a current source also in the same circuit.

The output of the sensor either voltage drop or resistance is directly proportional to the R T d resistance, so in this case whatever voltage I see whatever resistance I see is going to be the resistance across the sensor itself, and it has got nothing to do with the resistance across this leads because the current flowing this to this leads is going to be equal to almost equal to 0 is negligible. So always if I want to do very accurate measurement, I will always preferred to have a four wire measurement, then having a two wire measurement, and this is the way a two wire and the four wire measurements work therefore, the reading of the sensor is insensitive in this case to lead resistance, in a four wire measurement the reading of the sensor is going to be insensitive. Now, I can use a very long length also basically in this case provided by the long length is attached directly across the sensor and it is then attached to the voltage. Or a volt meter or a ohm meter.

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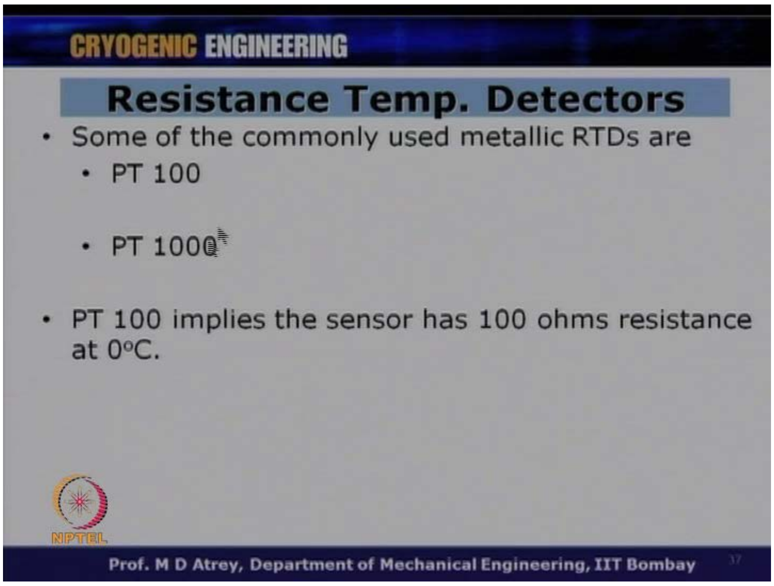

So, some of the commonly used metallic RTDs are PT 100, a platinum 100, PT 1000 also could be used. There is PT 500 also now-a-days, which are available in the market.

What is it mean? PT 100 implies the sensor has 100 ohm resistance at 0 degree centigrade, that is why the PT 100 name comes, so PT 1000 will that that the same definition will have 1000 ohm resistance at 0 degree centigrade, so you can have a more you know sensitivity; you can have a good scale in between if I use PT 1000 compare to PT 100, but if there are calibrated it does not make any difference.

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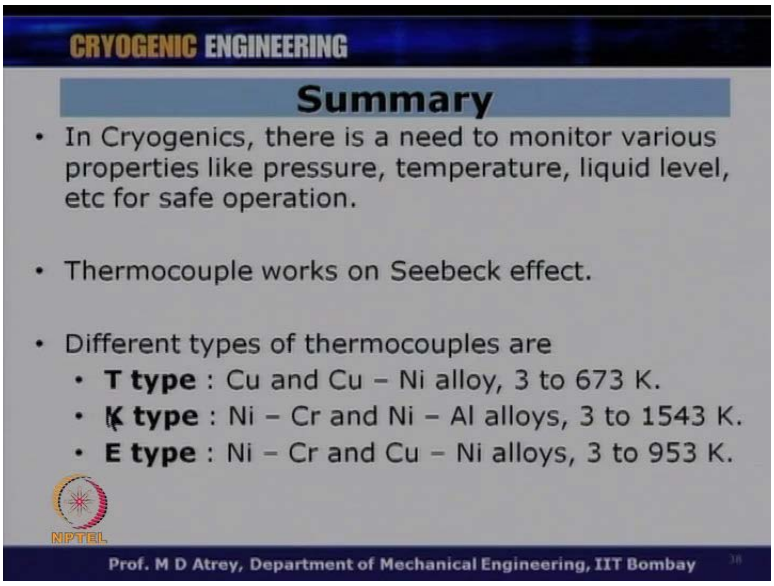

So, the summary of the temperature measurements a related to thermocouple and RTDs is in cryogenics there is need to monitor various properties like pressure, temperature, liquid level etcetera, for safe operation thermocouple works on see back effect which is what we saw, the voltage change occur because of the materials a and b and the temperature difference T 1 and T 2 between the two junction, different types of the thermocouples what we saw are T type which has got copper and copper nickel alloy as a two metals working between three to 673 Kelvin, then we got a K type which is Cromwell aluminum, there is copper constant, copper Cromwell alluminium, nickel chromium, nickel alluminium between 3 to 1543. And then we got a E type which is nickel chromium and cupronickel, so you got a constantan alloys you are here which is working between 3 to 953 is got a T type, K type, and E type thermocouples normally being used in cryogenics.

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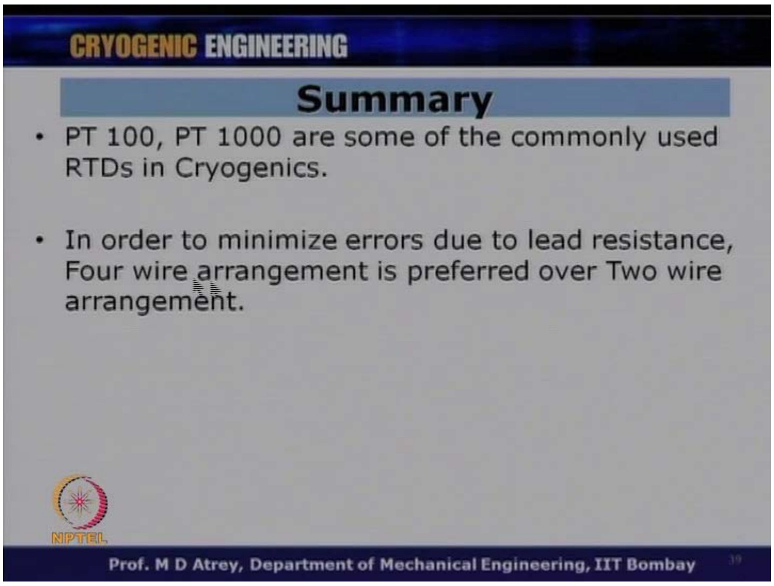

Then we got a platinum 100s or a PT 100s and PT 1000s as RTDs are some of the commonly use RTDs in cryogenics; and in order to minimize errors due to lead resistance, which we just saw. Four wire arrangements is preferred over two wire arrangement, which is we just saw the schematic of four wire arrangement over a two wire measurement. Thank you very much.