**Cryogenic Engineering**
**Prof. M.D. Atrey**
**Department of Mechanical Engineering**
**Indian Institute of Science, Bombay**

**Module No. # 01**
**Lecture No. # 07**
**Material Properties at Low Temperature**

This is a seventh lecture on cryogenic engineering under the N P TE L program. What we are studying right now, is the properties of materials at low temperature. This topic we have been studying since last two lectures, and this is the third and last lecture covering this topic.

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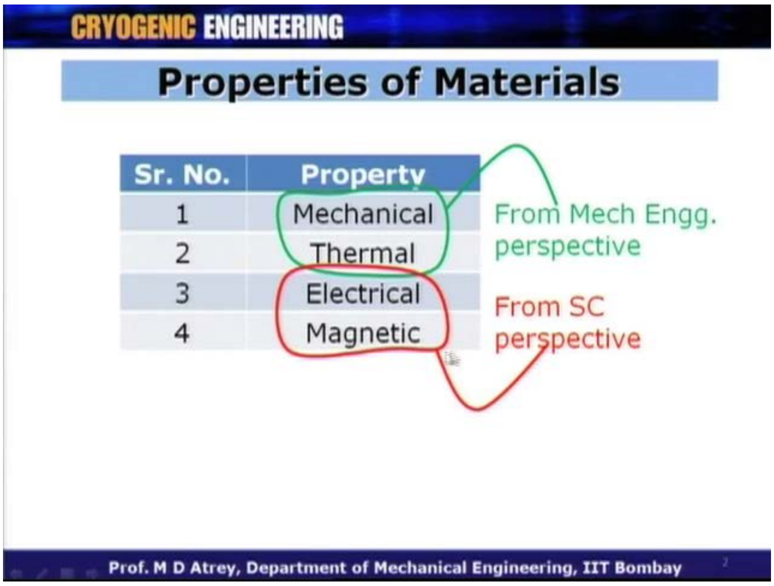


We have been covering various properties, under different subheadings mechanical properties at low temperature thermal properties of low temperature. The electrical properties at low temperature and finally the magnetic properties at low temperature. The first two properties, the mechanical and thermal properties are very very important for you. When I say you means students of mechanical engineering. At the same time electrical properties are also important, but this properties, the electrical properties and the magnetic properties.

I am going to cover under the section of super conductivity because super conductivity is a very important aspect of cryogenics. In fact, cryogenics is the cause and superconductive is effect. And here I will cover some basics of superconductivity, under the section of electrical and magnetic properties at low temperature or any material.

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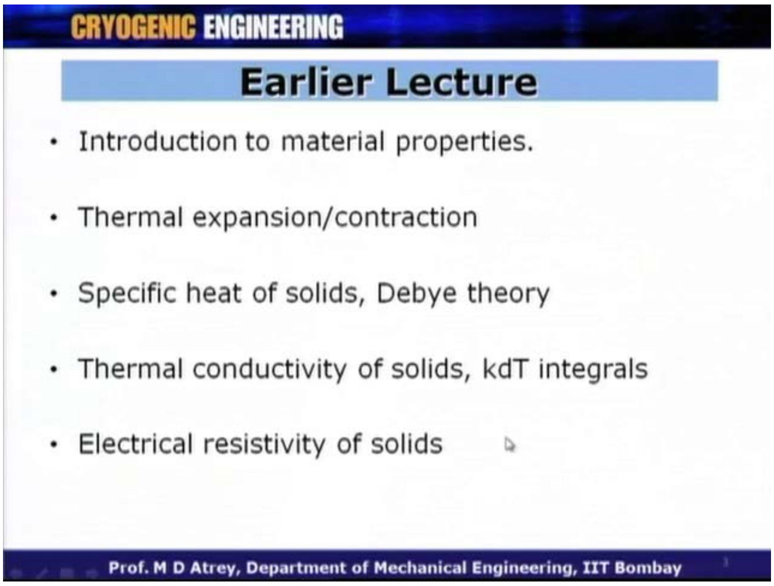


In the last lecture I emphasis more on the thermal properties. And before that lecture I have talk about mechanical properties. So, during the last lecture I introduce you to various metal properties, with reference more to the thermal properties. And what we cover under thermal properties were thermal expansion and contraction at low temperature. The specific heats of solids and we covered Debye theory we talk about Debye function. We talk about thermal conductivity of solids. And how the thermal conductivity were is at low temperature in addition to that. We talk about integral k d T that is k d T integrals which basically, text in to consideration.

The thermal conductivity variations with temperature especially at low temperature. And also we talk about electrical resistivity of solids at low temperature; this was what we covered during the last lecture.

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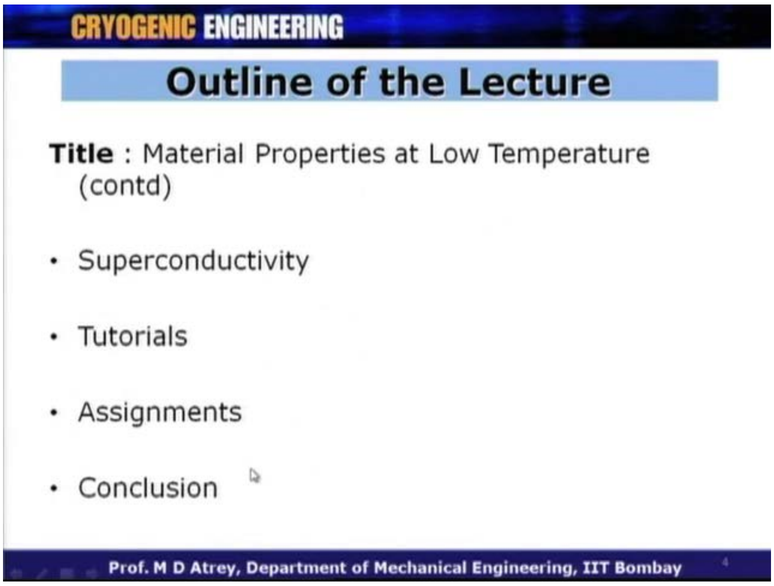


In the present lecture I am continue with the material properties at low temperature. But my focus here is basically, going to be superconductivity which is the phenomena which one comes across only at low temperature. And what it is how it happens what are the effect of all these things we can see and also I will show some video, which show some very peculiar effects at low temperature. Now, based on all the lectures what we have had under this topic. I am going to solve some problems under this tutorial section. I am going to solve around three to four problems on different properties how do calculate those properties at low temperature.

And finally, I would like to give you some assignments. And I will expect that all of you spend time and solve these assignments. And broadly and whatever, I have covered under the topic of properties of material at low temperature.

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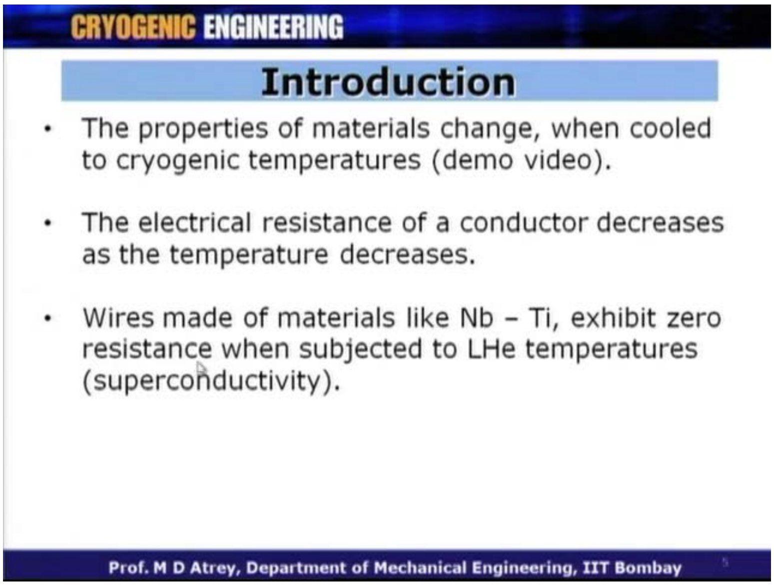


I will draw some conclusions covering all my total three lectures under this topic. As we all know we have seen a video, we shows that the properties of material change and change drastically when cooled to cryogenic temperatures. If you recall the video of liquid nitrogen and we had put some materials, like rubber like potato. We had put because those materials, were available to us we showed what happened to those materials at low temperature. The electrical resistance of a conductor decreases, as the temperature decreases. This is the noon fact and this is what leads to the phenomena called superconductivity.

The resistance decreases, and the material becomes more and more conductive electrically conductive. And finally, it become superconductive. For example, the wires made of materials like niobium titanium. This is the alloy niobium and titanium; it exhibits zero resistance when subjected to liquid helium temperatures. So, a material like this if it is subjected to very low temperature as well as, liquid helium temperature; that means, 4.2 Kelvin it becomes superconducting.

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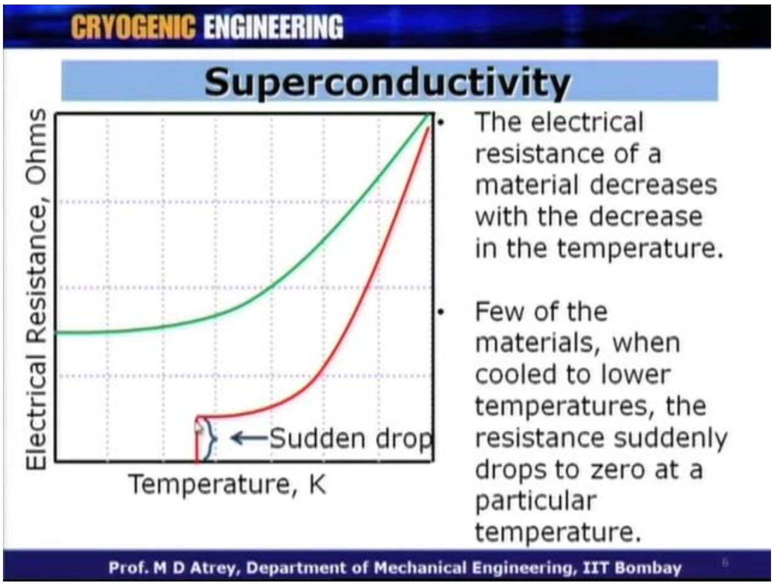


So, let us see a behavior of how the electrical resistance changes at low temperature. This particular graph shows, the electrical resistance of a material decreases with the decrease in the temperature. We can see a general behavior of material a general behavior of any material. That as you go on reducing temperature from let us say room temperature, and comedown to words let us say zero Kelvin, the resistance decreases and this is a general behavior. Now, some of the materials become superconducting. Few of the materials, when cooled to lower temperatures the resistance suddenly drops to zero at a particular temperature. This is what is shown by this particular graph.

So, here we can see that as soon as the materials starts, getting cooled at a particular temperature see if resistance decrease gradually. But at this particular the resistance suddenly, become equal to zero. And this particular temperature, what we call as critical temperature suddenly the resistance become zero and material become superconducting and at this point. This is the phenomena a, this is a behavior, which is shown by superconducting material. That as soon as hits the value of T c as soon as the temperature comes T c the material as become superconducting; that means, it is electrical resistance, as become equal to zero.

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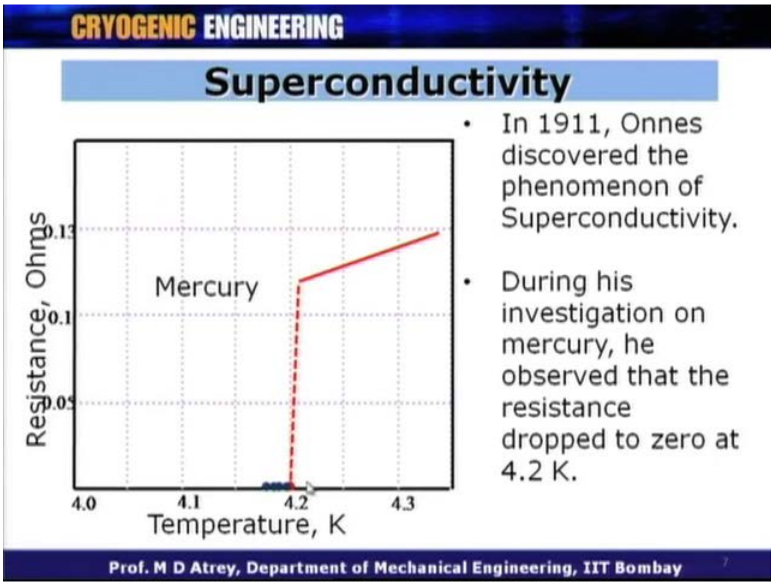


Now, in 1911 Kamerlingh onnes from Holland discovered the phenomena of superconductivity. And what we did is all shown here he use basically, mercury then. And when mercury is temperature was decreased at a particular temperature let say equal to 4.2 Kelvin temperature. It is resistance suddenly become, equal to zero suddenly kept down from this value to zero. And this is where he understood that some of the properties have drastically, change as for as mercury was considered. And then he say that mercury has become superconducting as, it is resistance become equal to zero at 4.2 Kelvin. During his investigation on mercury he observed that. The resistance dropped to zero at 4.2 Kelvin. So, T c of mercury can be called has 4.2 Kelvin.

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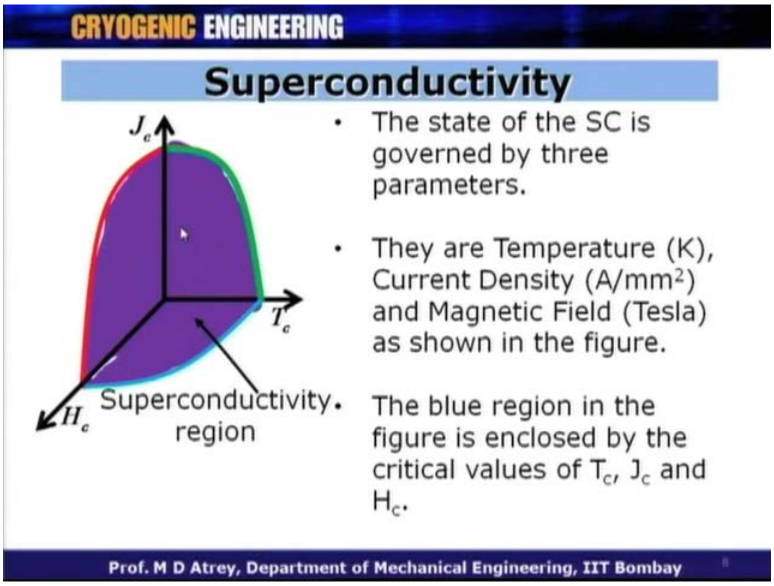


So, what is superconductivity? This particular graph in three dimension shows, that these are three excess. One is the temperature excess one is the current density excess, and one is the magnetic field excess. Pre say that the state of superconducting material is governed by three parameters. What are those three parameters? They are temperature current density and magnetic field as shown in this figure. So, the blue section what we show is the superconductivity region. As long as the material is in this blue section, in terms of all these three excess parameter that is temperature current density J c. And the magnetic field H c if they are in this region the material always remains in superconducting state.

However, if any of this parameter exceeds for example, a temperature goes beyond is T c or the current density exceeds this J c value or similarly. The magnetic field exceeds this H c value. There all the critical values if any material exceed, this value the material seizes to be a superconductive material, it will not show the superconductivity phenomena anymore. And therefore, superconductivity phenomena is shown as for as the temperature is less than T c. The current density is less then J c and the magnetic field is less than H c which are all the three critical parameters. So, that the, material remains in superconducting state.

So, here the blue region in the figure is enclosed by T c J c and H c. If I say that J c is equal to zero H c is equal to zero; that means, the material temperature has to be less than

T c in order that it remains in a superconducting state. So, when as to go on loading the temperature. So, that the material becomes superconducting material. So, this is a very important parameters, that it materially superconductivity the current density cannot exceed J c. As soon as one of the parameter is violated, the material sizes to be a superconducting material.

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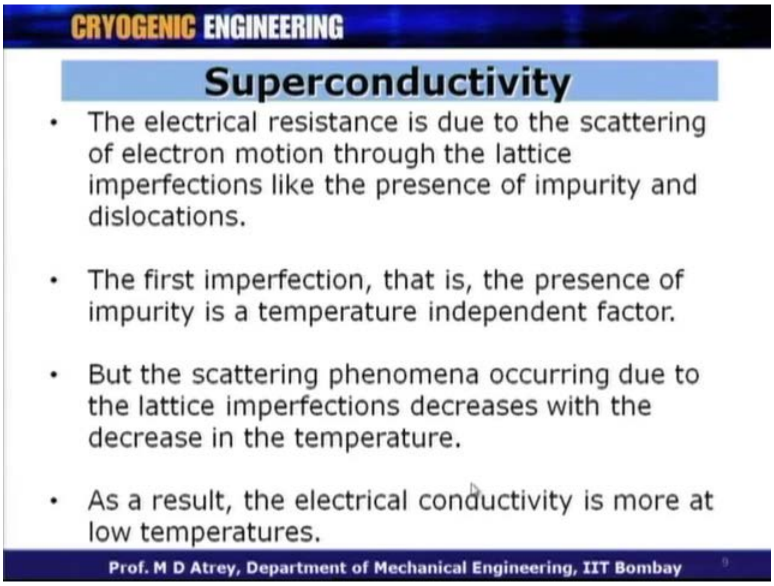


Now, why does this happen? Let us understand what are the reason that material become, superconductive in brief. The electrical resistance is due to the scattering of electron motion as you know every material as got free electrons. The resistance to the flow of electrons is basically, due to scattering that is inside the material. And that scattering is happening thorough the lattice imperfections. Because of the existence of lattice, imperfections like presence of impurity and dislocations. Electrons move in a material, but it will come across presence of impurity it will come across this location and the electrons may get scattered.

And this is what offers, the resistance to the flow of electrons. The first imperfection that is the presence of impurity is a temperature independent parameter. So, whatever impurity is present in the material presence all through irrespective of the temperature. While the scattering phenomena occurring due to the lattice imperfection decreases with the decrease in the temperature. What is it mean? At lore and low temperature the scattering phenomena is going to get lace and lace. And therefore, the resistance to the flow of the electrons is going to be lace and lace. This is what we Dermology shows that, at lore and low temperature because the scattering phenomena is going to be decreasing.

The resistance to the flow of the electrons is going to be decreasing. As a result the electrical conductivity when the resistance decreasing the electrical conductivity is more at low temperature this simple argument show that. At lore and low temperature electrical conductivity of the material increases. Now, why does the material becomes superconductivity? We understood the fact that conductivity increases electrical conductivity increases. But Bardeen Cooper and Schrieffer put fourth theory that not only the electrical conductivity increases. But some of the materials become superconducting at low temperature. And this is called as B C S theory named after Bardeen-Cooper-Schrieffer.

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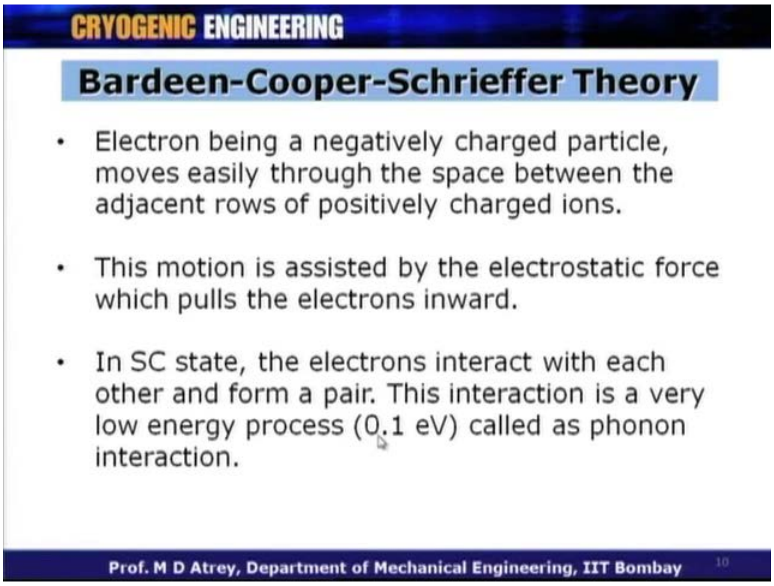


So, electrons being a negatively charged particle, they move easily through the space between the adjacent rows of positively charged ions. As in every material we have got positively charged ions, and the electrons close through the positively charged ions. This motion is assisted by electrostatics force which pulls the electrons forward. Because of the attractive force between the positively charge electro ions and the electrons which are basically, forming electron cloud. The electrons move by the electrostatic force which pull the electrons inward. However, in the superconducting state the electrons interact with each other and they form a pair. This is what happens?

At very low temperature below the critical temperature of any particular material. The two electrons come together and they form a pair. In fact, one electron pulls the other electron and that is why we call it. It becomes a pair. And this pairing is a low energy process basically an it is a stable process. Every low energy process is basically stabilize process. And therefore, formation of electron pair is a low energy process and this is called as phonon interaction. This is what put pair the B C S theory. So, as soon as the electrons form a pair the motion of the electrons is forward. The motion of the electrons is now, more and more conducting the electrons pair.

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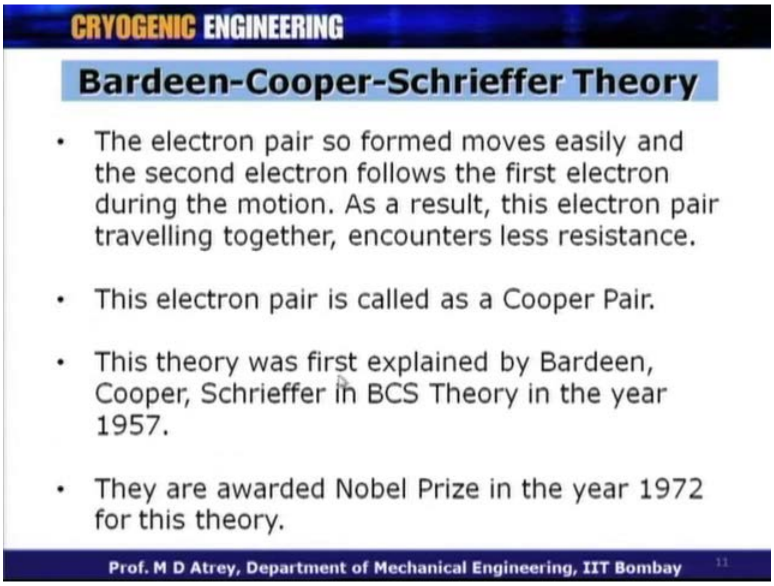


So, formed they moved easily and the second electron follows the first electron during the motion. As I said one of the electrons will pull the other electron and this results increase the motion of electrons. As a result, this electrons pair travelling together encounters less resistance. This is clear from this. This electron pair is called as cooper pair. This is the one of the highlight of the B C S theory. And this is what makes the material superconducting and therefore, it can carry more and more current in a superconducting state.

This theory was first explained by Bardeen, Cooper, Schrieffer in BCS theory in the year 1957. And for which they are awarded Nobel Prize in the year 1972 for this theory. This is some of the basics of the superconductivity and BCS theory there not going to go in the details of this theory. Now, here I understand how the material behaves at low temperature and how the relation for different material with respect to the magnetic field. And temperature as shown in this figure.

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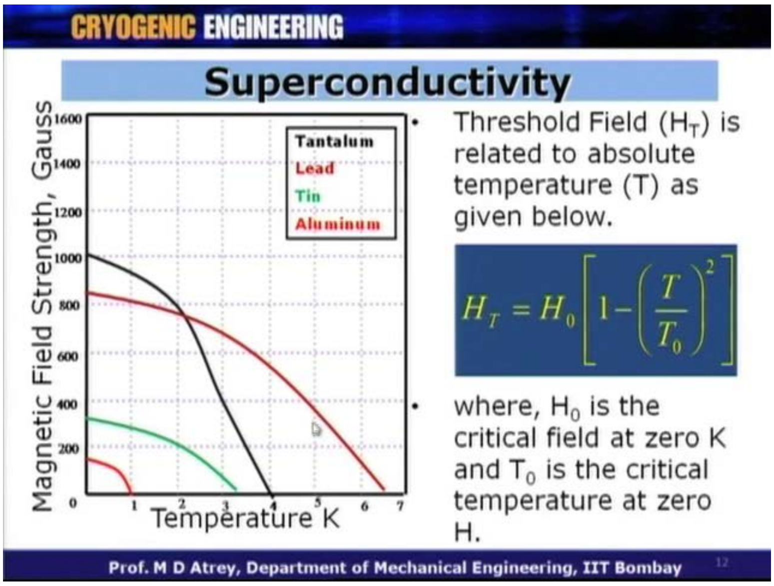


So, what we can see that on the y excess what you got to the magnetic fields strength on x excess what you got to the temperature. For different material likes, tantalum lead tin and aluminum. If you see for lead for example, at no magnetic field the T c is around 6.5. Similarly, for aluminum the T c is around 1. But as soon as you got a magnetic field the behavior is like this; that means, at this particular magnetic field the corresponding T c value is less than what it was earlier at 0 magnetic field. So, this basically gives a reason how the Magnetic field strength increases at loreing of temperature. At a particular T c value it as strength of only 0 magnetic field.

But as soon as the temperature decreases, below the T c value magnetic field strength increases and maximum value it at zero Kelvin. So, for every material the magnetic field strength is maximum at zero Kelvin. So, what is the relation between the threshold field H T and it is temperature this is the relationship. H T is equal to a 0 in the bracket 1 minus T upon T 0 square. So, H T is a field strength, at any temperature T while H 0 we can see H 0 is the cuticle field at zero Kelvin. So, a zero for different material is what it is on y excess ok. At zero Kelvin whatever, field is there is called as H 0 and T 0 is critical temperature at zero; that means, the critical temperature. T 0 is these values or what we called earlier at T c or circle temperature.

So, if I want to see what is H T value at T is equal to T 0. As you know this is the T 0 value. So, if I put at H T at is equal to T 0 if I put T 0 value here then 1 minus 1 and value of H T at T is equal to T 0 in the nothing, but zero which is what is shown on this figure. So, basically at H T is equal to zero the value of T is equal to T 0 which is what comes from this formula. If I want to find out what is the value of H T at any temperature let us a 5 Kelvin I just put this value T is equal to 5 over here. Corresponding T o value is around 6.5 and I know the value of H o which is around 850 for example. I can calculate what is the field strength at temperature equal to 5 Kelvin in that case.

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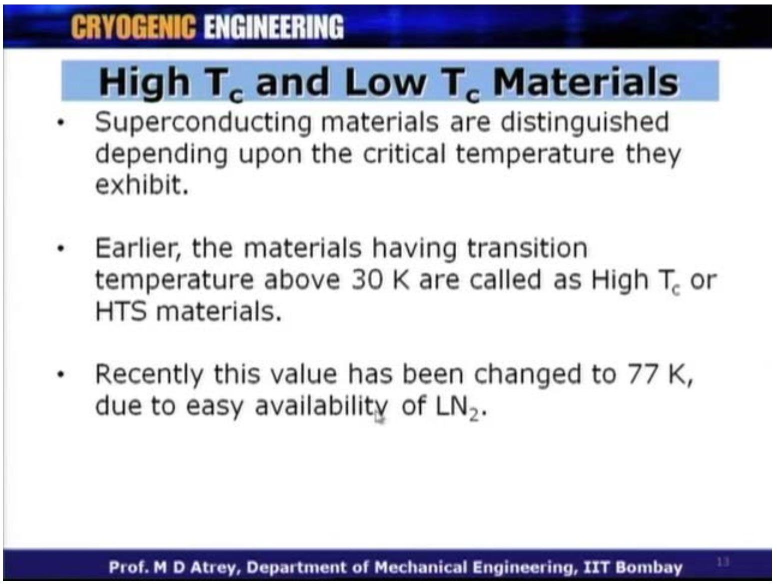


Now, there are different materials like high T c and low T c materials. Some show high critical temperature, while some material, show low critical temperature. So, superconducting materials are distinguished depending on the critical temperature they exhibit. Earlier this material having transition temperature above 30 Kelvin were called as high T c material. But now, this as been as 77 Kelvin because of LN 2 because availability of liquid nitrogen.

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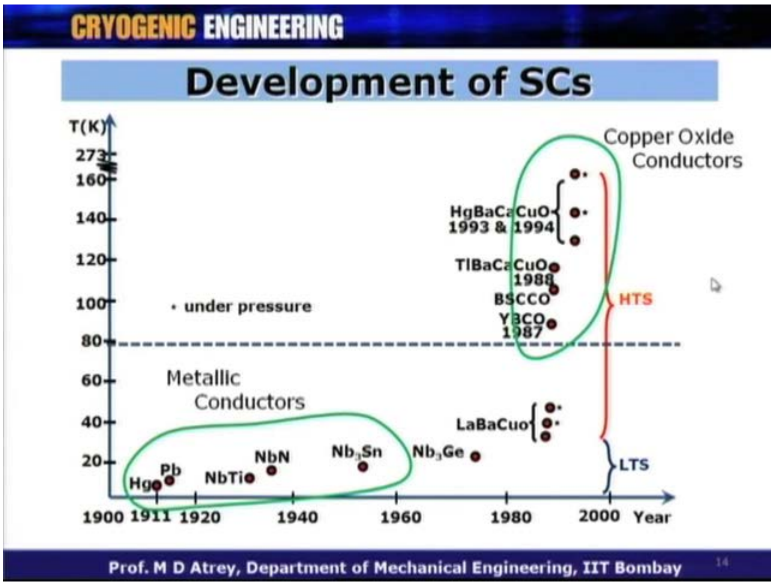


So, those materials which I got T c value above 77 Kelvin are nowadays called as high T c material. While below that particular temperature other materials are called as low T c material. What are these materials? Here you can see graph again on the x excess is equal to lot of material with the year with the discoveries, and on an excess what you see is there T c. You can see that Hg was discovered mercury was discovered a superconducting in 1911 by kamerlingh ones niobium. Titanium as it is around say one are 8 Kelvin which was discovered somewhere in 1930s.

Niobium tin was discovered later around 1950s. And these are all called as LTS that mean low T c material low T c superconducting material well what you have above those is high T c material. So, previously as we said previously this division line was 30 Kelvin, but nowadays it has become 77 Kelvin. So, all the material above these are normally, called as HTS material all the material c r called as low T c material all LTS material. The material to be talks about more at HTS, are normally the cooper oxide conductor by these are normally the metallic conductors.

And the material to be called as bismuth bis yttrium bis this is called as BSCCO and this is called Y B C O. These are the two highly use materials, high T c material in manufacturing of current lead something like that or the windings if you want have for high T cs superconducting magnetic material. These are basically high T c material HTS material or these are LTS material. Now, will see the phenomena of Meisner Effect this

Phenomena is shown by superconducting material. So, what is in this particular effect is at room temperature if a material is subjected to a magnetic flux.

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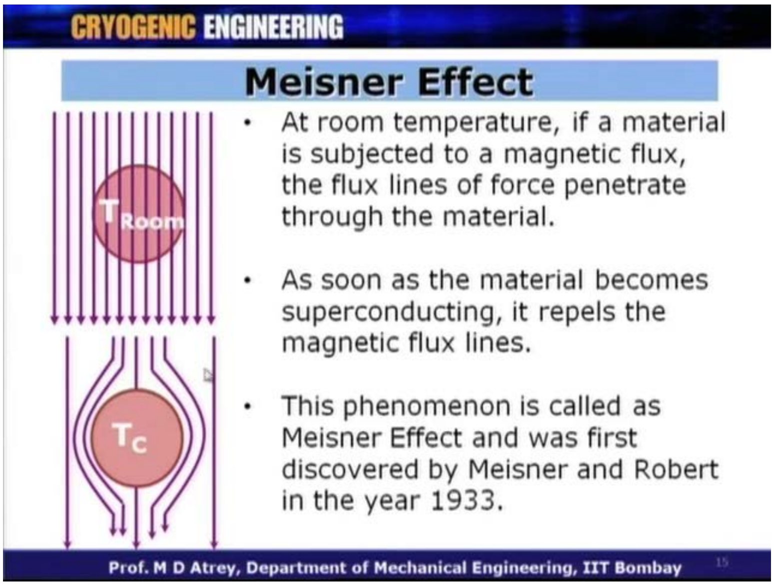


So, this is basically material at room temperature and if it is subjected to magnetic flux, the flux line of force penetrate, through the material I shown in this figure. However, I soon as this material become superconducting; that means, it is subjected to low temperature and the material becomes superconducting. It repels the magnetic flux lines. So, what happens to it behaves in a different way and it behaves like this. All the magnetic flux line, which were passing through the material earlier are no more passing through the materials.

And there going outside the material and because there repair by the because of the superconducting material. Now, this phenomena or this effect is what is called as Meisner Effect and was discovered first discovered by Miesner and Robert in the year 1933. So, the phenomena in which the magnetic flux, is repelled as soon as the material becomes superconducting is now use for various end application. What I am going to show your right now, is the small video to show this effect.

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So, that you understand this effect in a better way. In this video now, what you saying is a part to parts, one is the magnate which is N D F E B neodymium ion boron. This standard magnate and what you see here is basically, is superconducting material. So, the base of these, what you are seeing here is a YBCO material having a t c o around 95 Kelvin. And what you see around that is plastic container basically, is the plastic container and superconducting material from the base of this material. So, what I am going to do is put this YBCO container on the magnet and as you can see it is sitting perfectly alright. This is at room temperature. So, you can understand that YBCO is not in superconducting state right now.

Now, what we are going to do is. We want to see basically, how it is behave this as soon as it becomes superconducting. So, what should I do in order to make it superconducting I can pour liquid nitrogen inside this. The liquid nitrogen will bring it is temperature down to 77 Kelvin. And as I said the T c of this particular material around 95 Kelvin; that means, defiantly at 77 Kelvin it will become a superconducting material. Now, let us see how it is behave it show the Miesner Effect on the material we start repelling the magnetic flux line.

So, let us bring it near to this now, what we can see suddenly is a whatever flux lines, were passing through the YBCO material it is not letting it pass now through it. And because now putting the pressure on it, it is creating a back pose and magnetic stain to go away. Because YBC is stain to repel this magnetic plus line to pass through it. This effect basically shows that, as soon as the material becomes superconducting it repels the Magnetic flux. Now, this leads to the application of Miesner Effect which is the magnetic levitation train or Maglev.

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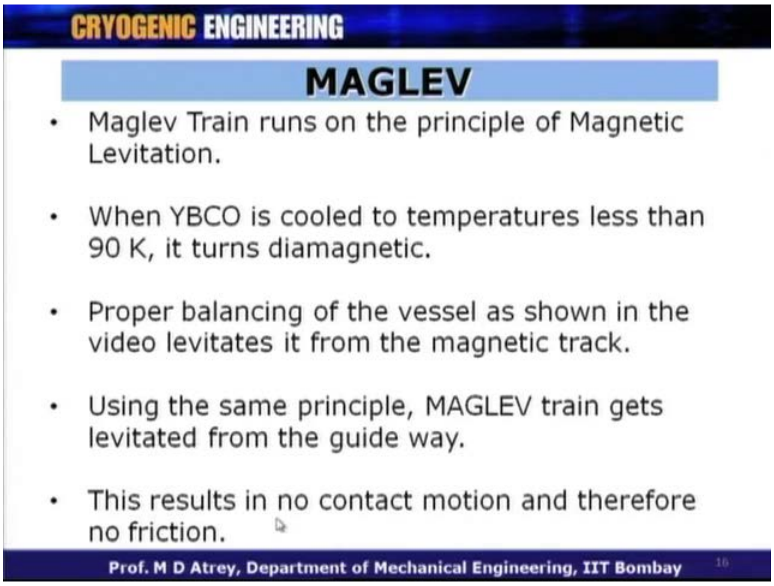


So, Maglev train runs on the principle of Magnetic Levitation. When YBCO is cooled to temperature less than 90 Kelvin it turns diamagnetic. The proper balancing of the vessel as shown in the video levitates it from the magnetic track. Now, this is what we see using the same principle maglev train gets levitated from the guide way. This results in no contact motion and therefore, no friction now, the same principle what we saw in Miesner effect I will show in a application in the terms of Maglev.

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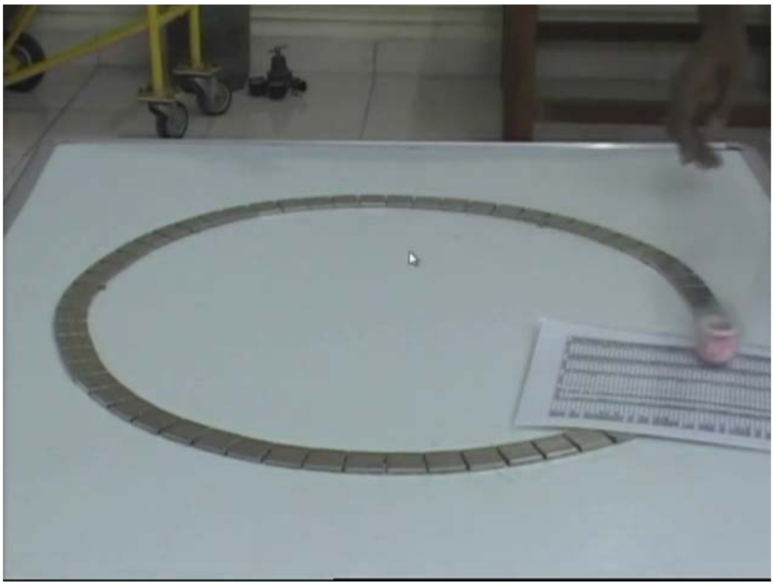

So, in this video now, what you see is a the N D F E B magnets basically, are late down as track. So, got magnetic track you can say that. The train should move on this you must tell in this in some kind of toys earlier. Now, what I am going to show here is how the levitation text plus. So, the YBCO magnet container what we saw earlier is kept here and it is now, the liquid nitrogen put in that. And it is already kept over there on the track we some kind of material in-between. So, let us a train is already standing on the track over here. As soon as now, the material become superconducting it will starting floating because the magnetic flux lines are now, repelling and which kind of produces force. And therefore, material starts floating on the trains sorry floating on the rails over here.

So, what are you getting from here? You are getting a lift thus this particular train or material is floating or levitating on the rails, which means there is a lift which the train obtained and if you give a push to this now, it is a kind of a propulsive force. Because of will the train will starting moving. So, basically now, you can see that the propulsive force is given by some kind of engine. Let us a talk about that, but the levitation basically, makes the train float on the train on the rails. Now, it will seek to be a superconducting material with passage of time because nitrogen will get evaporated.

As soon as the material sizes to be a superconducting material it will become in normal material. And the Miesner field come to stand still this is what happens right now. As soon as temperature of YBCO more than 90 or 95 Kelvin the material is no more in a superconducting state and now, it as shutdown. So, this particular kind of motion does not result in a any contact. And therefore, the friction would be absolutely, minimum and this is principle of magnetically limited train.

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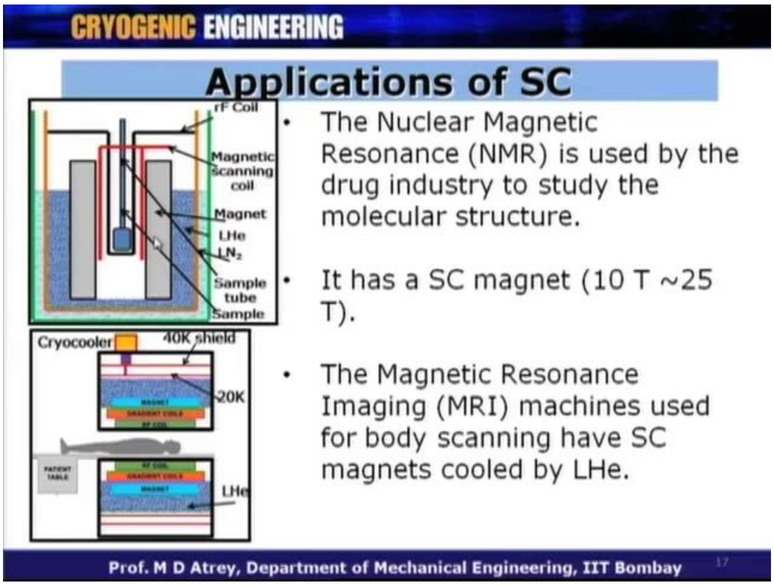


Now, the similar applications are therefore, superconductivity and possibly we have discuss, that in the first lecture. And one of them is a NMR nuclear magnetic resonance NMR apparatus which is the magnate over here and it is kept dip in liquid helium. And liquid helium is surrounded by liquid nitrogen. So, this is what it become superconducting magnate at low temperature it results in nuclear magnetic resonance. One can do NMR of any sample which is kept sat the center of this magnate.

And similarly, what you have is a MRI magnate also is kept dip in liquid helium surrounded by liquid nitrogen or a Cryocooler cooled sheets. So, that the body scanning could be done as one can see the internal details of body here in this case. And one can say the internal material details in the case of NMR these are very, very well known usages of superconducting magnate as we saw earlier. All the winding in this case are made of niobium titanium and niobium tin and depending on the magnetic filed strength.

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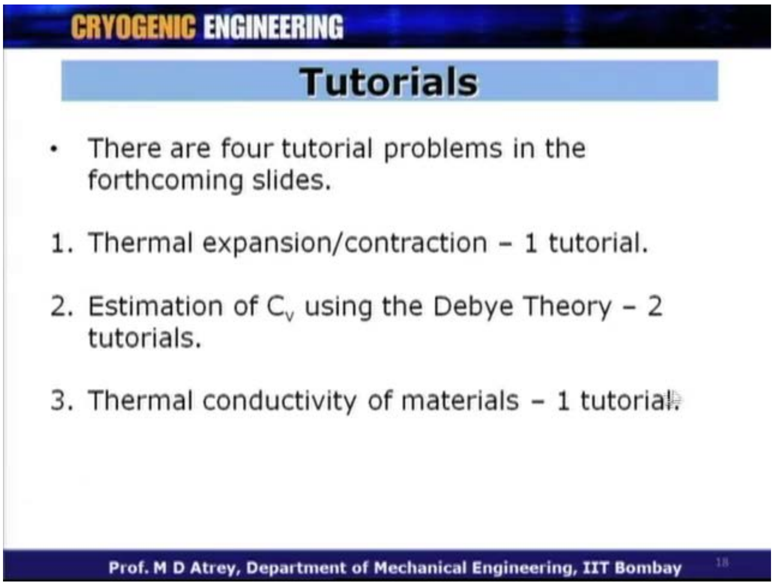


Now, what I am going to do in this remaining time is to solve some problems, under this tutorial section. We have seen various properties still now, and each property has got some way to calculate the property variation at low temperature. Now, in these Tutorials I want to solve some other problems, that we can calculate these properties at low temperature. I am going to have four Tutorial problems one is on a Thermal expansion and contraction. So, one Tutorial on that then we have got a estimation of specific capacity using Debye theory we got two Tutorial on that. And finally, we got Thermal conductivity materials at low temperature. We can calculate the value k or the loss due to k at low temperature and because one to till on that ok.

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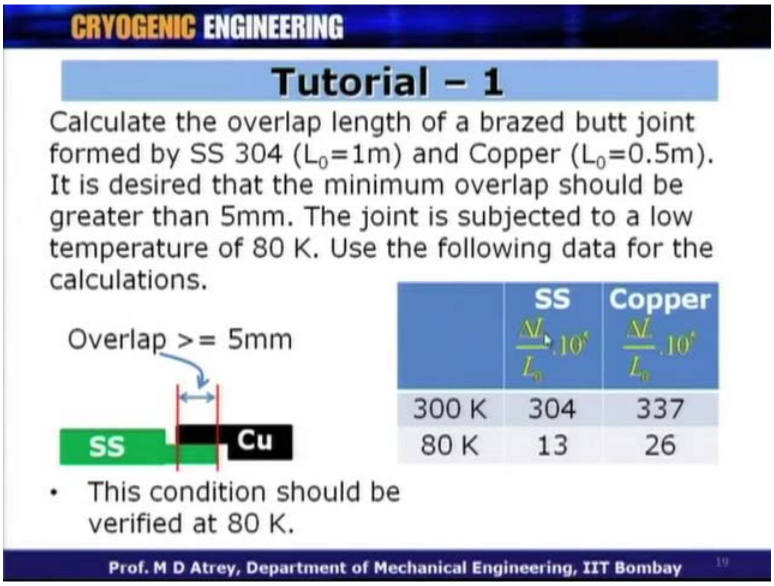


So, Tutorial number one the problem statement is calculate the overlap length of a brazed butt joint. You know the brazed butt joint formed by two materials one is SS 304 and the other one is cooper. The SS length of l naught or length at 0 Kelvin is given as 1 meter well cooper length is 0.5 meter. Now, it is desired that the minimum overlap in a butt joint, what we have is a overlap minimum overlap should be greater than 5 millimeter. The joint is subjected to low temperature of 80 Kelvin following data could be used. The problem statement says that you make a joint and joint is made that naturally, at room temperature which is at 300 Kelvin.

However, this joint is going to be subjected during operation to a temperature of 80 Kelvin. And therefore, what we know is the shrinkage will happen. The statement also, says that the overlap should be of these to material should be greater than 5 millimeter at low temperature. Because the shrinkage would happen that low temperature and overlap will decrease at low temperature. And therefore, what should be the overlap at room temperature in effect that is basically the questions. So, what you can see here is a problem statement that, at 80 Kelvin condition this is the SS material this is the cooper material. Both the leans are given as 1 meter and 0.5 meter respectively.

What is the problem? The problem is that at 80 Kelvin this overlap of material of the butt should be more than equal to 5 millimeter. So, it should basically more than 5 millimeters. So, that it has got good strength.The data is given at 300 Kelvin and 80

Kelvin. So, Del L by L zero, we have seen this behavior of mean linear thermal expansion the values for SS and the value of cooper are given as this. At 300 Kelvin it is 304 at 80 Kelvin it is 13 and at cooper for cooper it is 337 and 26. So, what we are going do basically is calculate shrinkage of SS at 80 Kelvin. Calculate shrinkage of cooper at 80 Kelvin. And then based on that based on the relative shrinkages, we should calculate what should be the overlap at room temperature.

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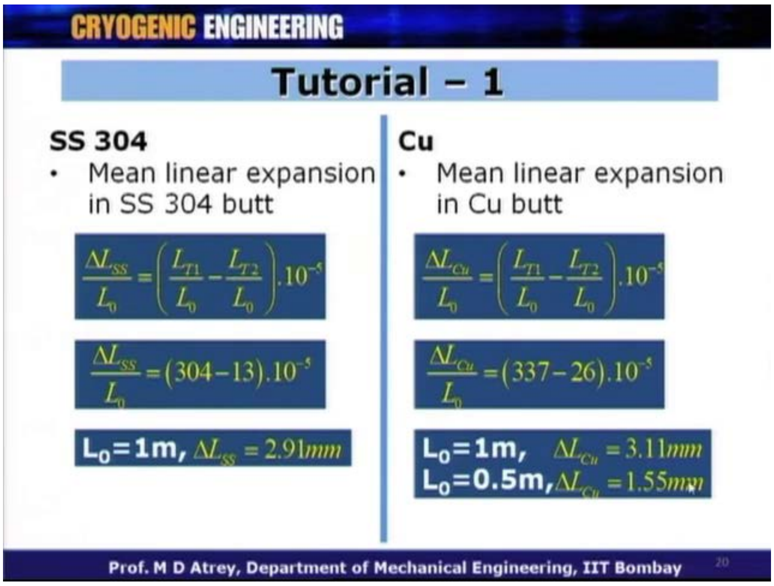


Let is divided to two parts one for SS 304 and one for the cooper. Getting the values from data it is the main linear expansion in SS 304 butt is del L by L zero is L T1 by L 0 minus L T2 by L 0 10 to the power of minus 5. This is what we get this is what we have seen. If I put the values of L T1 by L 0 at T 1 temperature, which is in this case, is 300 Kelvin and T 2 temperature which is in this case is 80 Kelvin. If I put those values what I get Del L SS by L 0 is equal to 304 minus 13 3 0 is the value 80 100 Kelvin 13 is value at 80 Kelvin. If I take L 0 as one meter which is what the problem says delta L SS will be 2.91 millimeter.

The material is going to be subjected form 300 Kelvin to 80 Kelvin for a length of one meter the shrinkage would be 2.91 millimeter. As for as SS 304 is considered for cooper if you do the similar calculation we have got del L C u by L 0 is equal to L T1 by l zero minus L T2 by L 0 L, T1 by L 0. For cooper is 337 at 300 Kelvin L T2 by L 0 of cooper is 26 at 80 Kelvin. But these values were main for L 0 equal to 1 meter. So, L 0 equal to 1 meter Del L Co is going to be 3.11 millimeter.

While if the length is only 0.5 meter it will be half of that and for Del L C u will be 1.55 millimeter. What is that mean the shrinkage of cooper will be 1.55 millimeter when the shrinkage of SS will be 2.91 millimeter when the joint is subjected to 80 Kelvin. Now, problem says that overlap should be more than or equal to 5 millimeter. So, have to take the worst of these shrinkages which is 2.91. If I take that worst of the shrinkages I should be able to calculate what should be (( )) overlap at room temperature being.

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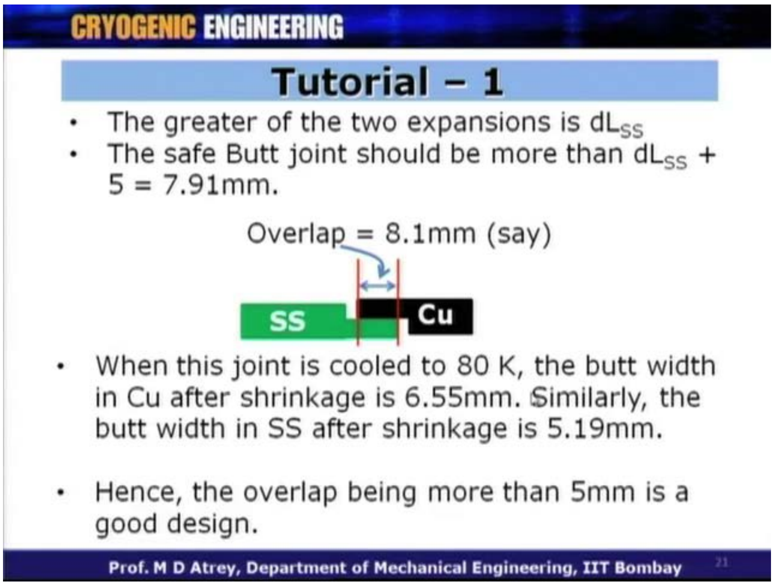


So, the greatest of the of the two expansion is shrinkage of dL ss still. So, the safe butt joint should be more than dL SS which is shrinkage of SS plus 5 millimeter that is 7.91 millimeter. If I take this as 8.1 for example, which is more than 7.91 than butt width in cooper after shrinkage is 6.55 millimeter. Similarly, butt width in SS after that will be 8.1 minus 2.91; I think as 5.1 millimeter which means that the overlap is going to be more than 5 millimeter. And it can stand required strength at 80 Kelvin. So, basically the problem is to calculate the shrinkages of these two materials.

And see that at 80 Kelvin the joint does not failed; that means, the overlap is basically, more than the minimum value of 5 millimeter. This is very practical problem I am shure you will understand from here, what are different parameters that have to be consider wild designing such a joint at low temperature.

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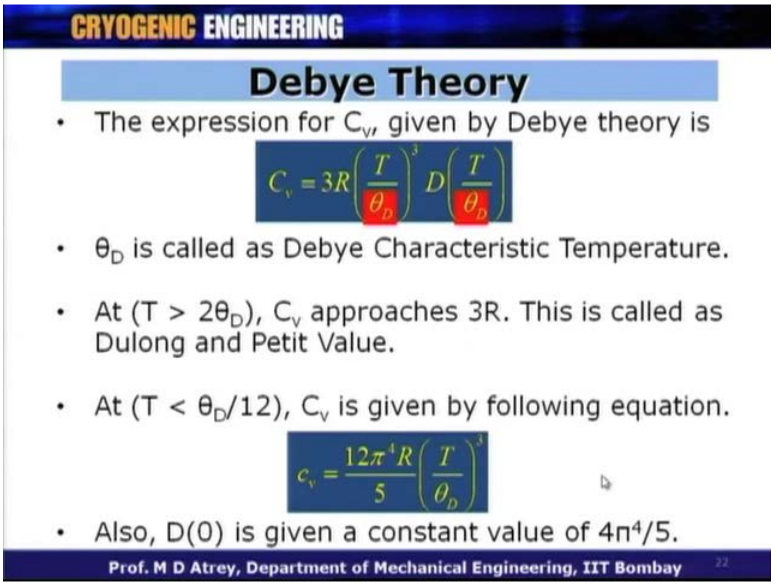


Hence, the overlap being more than 5 millimeter is a good design. Second problem is Debye theory we know in Debye theory we got in expression for the value of specificate capacity. So, C v is equal to 3R T by theta D cube in to a Debye function represented by D of T by theta D. The theta D is basically Debye characteristic temperature which is known and it is a characteristic temperature of every material. Also we know from earlier lecture that add the temperature which is more than two times theta D C v approaches 3R value which is this coefficient over here. This is called as Dulong and petit value. And very low temperature that is T less than theta D by 12, C v is given by following equation it reaches this value. Now, we see the problem based on both these extreme cases. At D T is equal to 0 the constant value is 4 pi to power 4 by value 4 by 5.

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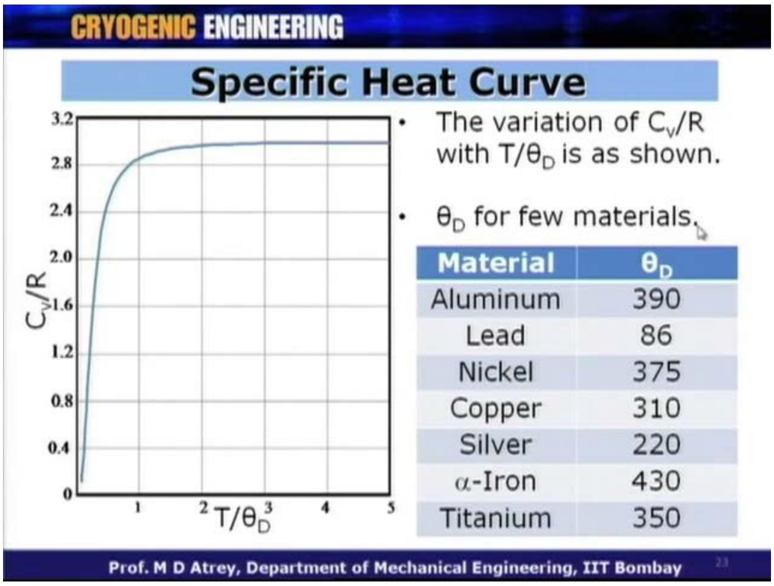


So, these particular carve shows C v by R variation against T by theta D values. So, this variation of C v by R once a T theta d is cubic at low temperature and it constant at high temperature as we have seen earlier. We know that theta T values for various materials and there has given over here in the table.

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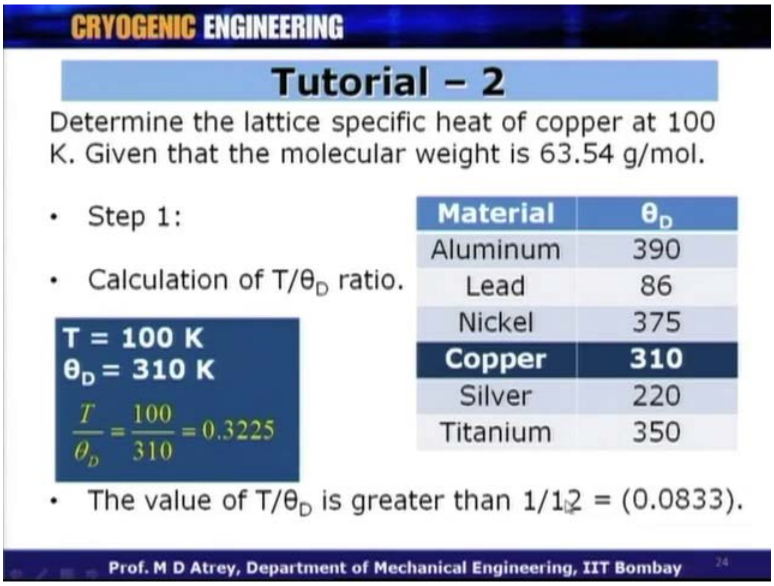


Now, based on this wills of the second tutorial determine the lattice specific heat of cooper at 100 Kelvin. So, calculate the value of C v at 100 Kelvin for cooper given that the molecular weight of copper is 63.54 gram per mole. The step one for this basically to get the value of T by theta D. So, T is known to us which is 100 Kelvin and theta D is a characteristic Debye temperature for cooper which from this table you can see that the theta D value for cooper is 300 and 10. So, T by theta D for cooper is 100 upon 300 and 10 which is 0.3225. This value of T by theta D is greater than 1 by 12 of T by theta D and therefore, what we can say now, we can basically refers to this particular graph.

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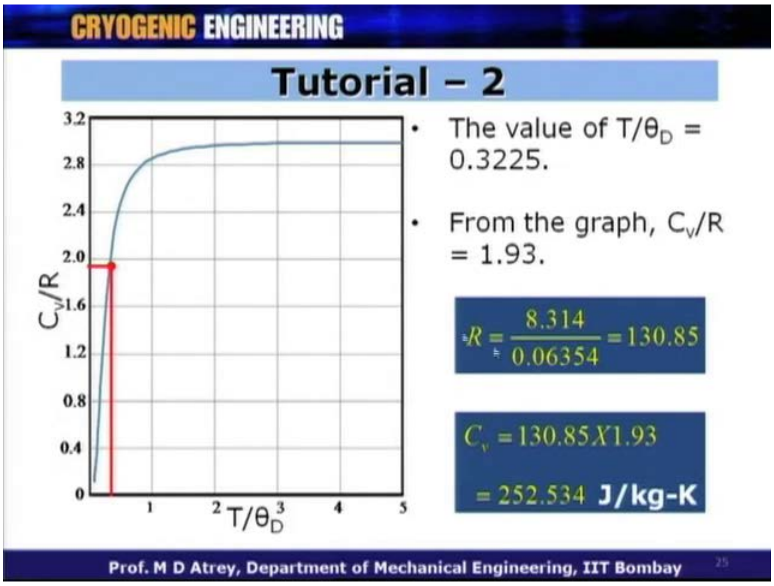


So, 40 theta T by theta D to be 0.3225 I will to locate the value of in here and get correspondingly the value of C v by R. So, from the graph what you see is a corresponding to 0.3225 of T by theta D and I get the value of C v by R which is equal to 1.93. Once I know C v by R I just multiply it by R in to get R what I do universal gas constant divided by the weight which is given which is 63.54 grams per mole. And which gives, me the value of R to be 130.85 which is the specific gas constant. So, the value of C b therefore, equal to 1.93 into 130.85 and what you get ultimate leaser 252.534 joul per kg Kelvin.

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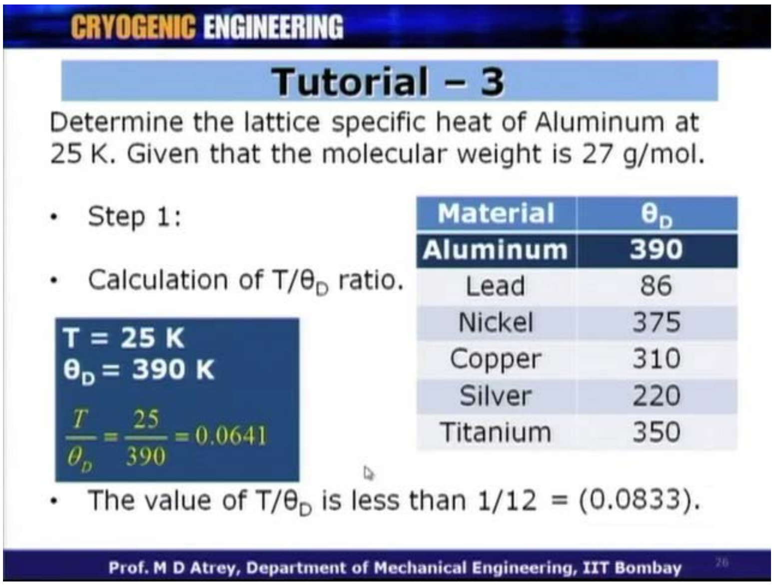


So, the C v of cooper at T is equal to 100 Kelvin is 252 joul per kg Kelvin. Naturally, C v of cooper 300 is much higher another temperature is reducing the value of C v is decreasing. Extreme in the same I go to tutorial three where the problem statement is determine the lattice specific heat of aluminum at 25 Kelvin. Given that the molecule weight is 27 grams per mole. So, here I am talking about aluminum and I want to calculate the value of specific heat at 25 Kelvin it is a very low temperature. The data is given to me in terms, of it is molecule weight which is the standard property again going by step one I am going to calculate the T by theta D.

So, what is T by theta D ratio? For which I have to know what is the theta T value are the Debye temperature for aluminum which is 390. The Debye temperature for aluminum is 390. And therefore, T by theta D is going to be 25 upon 390 which is 0.0641. Now, this T by theta D is less than 1 by 12 of theta D. So, 1 by 12 of theta D is basically 0.0833. So, T y theta D in this case of aluminum is 0.0641 and if this T by theta D is less than 1 by 12 that is 0.0833. So, this 0.0641 is less than 1 by 12; that means, we can apply is simple formula to calculate the value of C v in this case.

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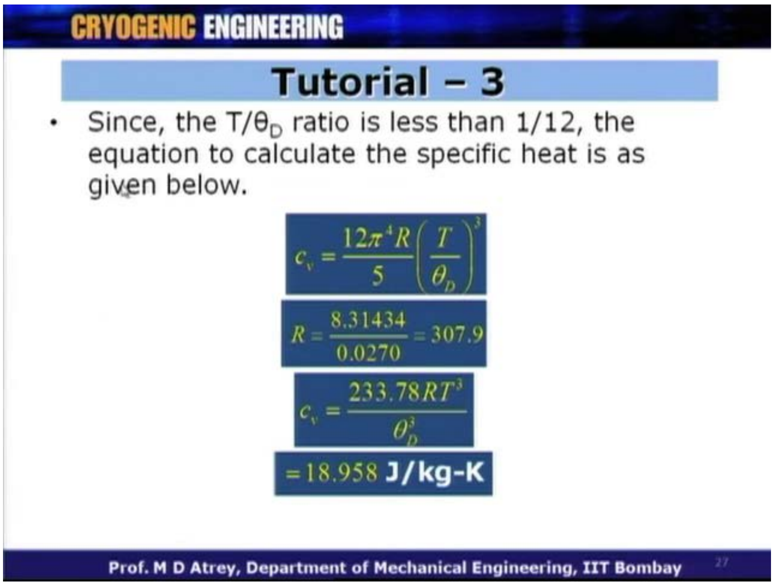


Since, that T bye theta D ratio is less than 1 by 12, the equation to calculate the specific heat is also given below. Now, with this equation I can calculate the value of C v which is completely T by theta D dependent. We know the temperature T is 25 Kelvin in this case and T by theta D value is known to us if you put those value. For corresponding R is universal gas 8.314 divided by the grams per mole for aluminum what you get is the specific gas constant which is 307.9 for aluminum. Putting those values over here what you get ultimately, is a value of C v which is 18.958 joul for kg Kelvin.

So, what you see here is the value of C v is drastically lace at 25 Kelvin in this case of aluminum. In the earlier problem what we saw first for cooper which was a correspondingly very high value and at 25 Kelvin aluminum shows a very low value. We have studied two examples, to calculate the specific heat at low temperature for one for cooper one for aluminum. In one case we refer to the graph in the other case we have calculated based on a available formula at low temperature.

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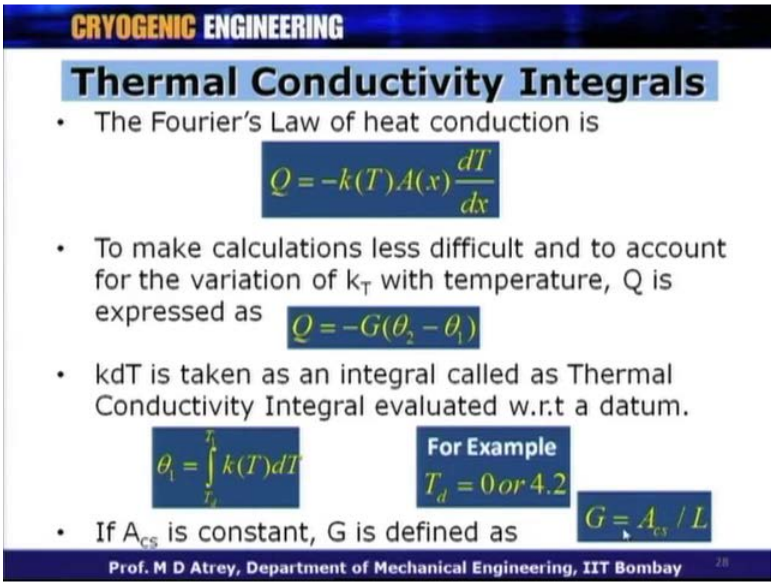


The next tutorial will be on thermal conductivity integrals. Just you revise that the Fouriers law of heat conduction is as you know. Q is equal to minus k into a into d T by d x. While k is a strong function of temperature in this case at cryogenic temperature to make calculation less difficult and to account for the variation of the k T with temperature, Q is expressed as Q is equal to minus G into theta 2 minus theta 1. We have seen this earlier; here k d T is taken as an integral called thermal conductivity integral which text into account variation of k with temperature.

And if I am talking about temperatures, I will talk about range of temperature and the theta 1 and theta 2 are basically, 41 92 respectively. Both of them should have the same days of T d here. So, theta one is nothing, but integral k d T from some datum temperature T d up to T 1. And this datum temperature could be from standard books it could be 0 Kelvin or 4.2 Kelvin. Here the A c s is constant, a cross section area constant and the G is defined by A c s by length.

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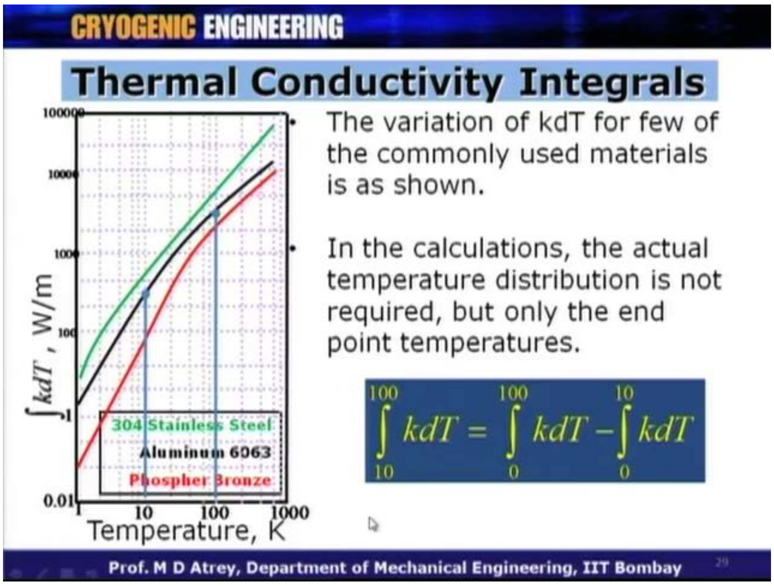


So, what you see is a graphical variation of integral k d T in a graphical form with temperature on the x excess. For different material stainless, steel aluminum and phosphor bronze. And the variation of k d T for few of the commonly material shown over the here. In the calculation the actual temperature distribution is not required. So, if I know might T 1 is going to vary from 100 Kelvin to 20 Kelvin 100 Kelvin to 10 Kelvin. I have to just see the end values integral k d T at 100 Kelvin in integral k d T at a 10 Kelvin. And different of these two will give me integral k d T between 100 and 10 Kelvin.

So, the formula is if I want to calculate integral k d T between 10 Kelvin and 100 Kelvin. I should get the value of integral k d T at 100 Kelvin which is basically, taking zero as a base minus integral k d T art 10 Kelvin again, the base remaining same at 0 Kelvin. If I get a difference of these two values is nothing, but integral k d T 10 to 100 Kelvin. This is what I want to use if I want to calculate the lost to thermal conductivity or loss to conduction or heat transfer due to conduction. If the, material is subjected at 1 and from 100 Kelvin and the other temperature at the other and is around 10 Kelvin.

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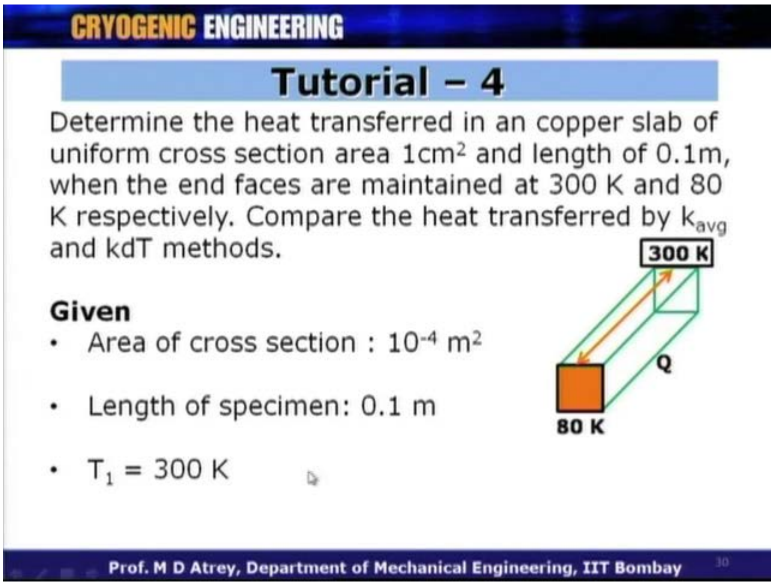


So, my next tutorial is based on this function. The problem statement is determine the heat transferred in an cooper slab of uniform section of area 1 centimeter square and length of 0.1 meter. To the L is equal to 0.1 meter while a, is equal to 1 centimeter square, when the end faces are maintained at 300 Kelvin and 80 Kelvin. So, one end of the cooper slab it has 300 Kelvin the other end is subjected to 80 Kelvin respectively. Compare the heat transferred by k average and k d T methods. So, k average is basically, taking average of the k value at 300 Kelvin and k value at 100 Kelvin, while k d T takes into consideration. The K variation between 300 Kelvin and 80 Kelvin at all the points.

So, let us compare this two heat transfers, obtained using K average method and integral k d T method. So, what is given to us is a cooper slab one end of the cooper slab it a 300 Kelvin. The other end is (( )) 80 Kelvin naturally, will be heat transformer high temperature low temperature. In this case which is equal to cube what is given to us is area of cross section a is 10 to the power minus 4 meter square which is nothing, but 1 centimeter square. And the length of specimen is 0.1 meter, T 1 is equal to 300 Kelvin wild T 2 is equal to 80 Kelvin.

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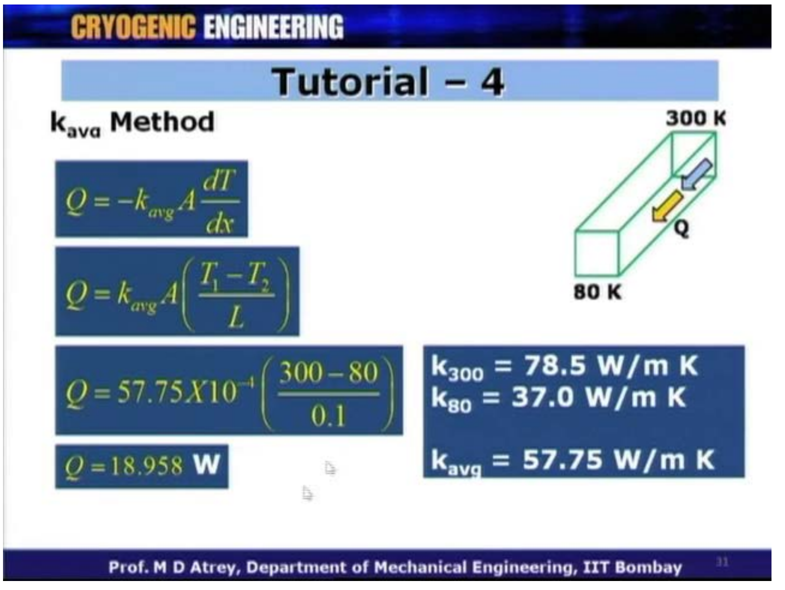


So, let us first go back K average method in which I will take the average value of the thermal conductivity, between three 100 Kelvin and 80 Kelvin. So, what is k 300 is 78.5 as for as cooper is considered 78.5 at 300 Kelvin. And K at 80 Kelvin is 37 watt per meter Kelvin. If you take the average of this two, the K average value is going to be 57.75 watt per meter Kelvin how do I calculate Q in this case, Q is equal to minus k into A into d T by d x. The value of k is taken as K average in this case. I put the values over here, what I get ultimately is 57.75 into 10 to the power minus 4 which is a, and this is K T 1 minus T 2 which is nothing, but d T 300 minus 80 divided by the length which is 0.1 meter. And the Q calculated in this way based on K average is 18.958 watts. This is based on the K average method.

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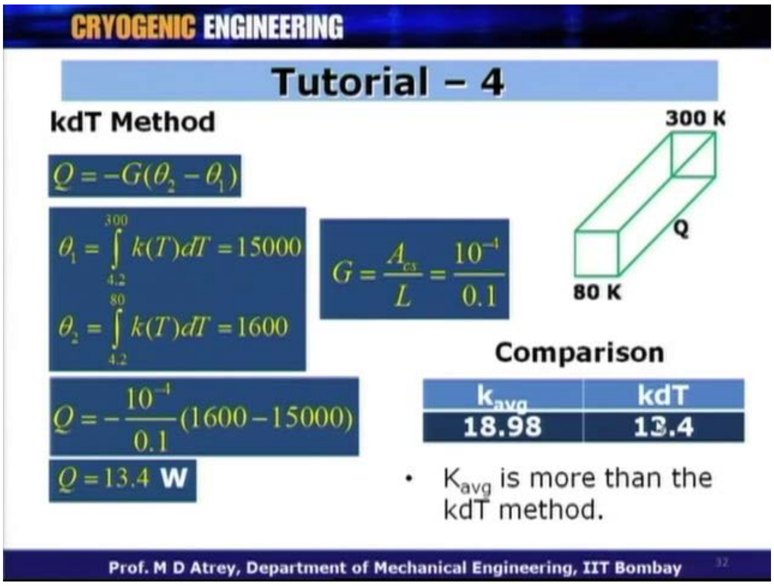


If I want to now calculate the same thing by using integral k d T method or a k d T method, what I should know? Now, Q is equal to minus G into theta 2 minus theta 1. On the base line here is in case, 4.2 to 300 k d T is 15000 for cooper, while theta 2 at 80 Kelvin taking base at 4.2 Kelvin is nothing, but 1600. G is equal to A c s upon L which is 10 to the power minus 4 upon 0.1. And the Q if I put all these values over here I get the value of Q to be equal to 13.4 watts which means, that if I camper the two values.

Based on K average I got 18.98 watts well best on k d T method I got 13.4 watts. That means, my calculation based on K average is quoit higher. As consider to what it is which is realistic picture taking all the property variations, in this temperature region of 300 to 80 Kelvin region which is just 13.4 watts. And this is what I should use for actual calculations. So, K average is basically predicting more heat transfer as compeer to the, realistic heat transfer predicted by integral k d T method.

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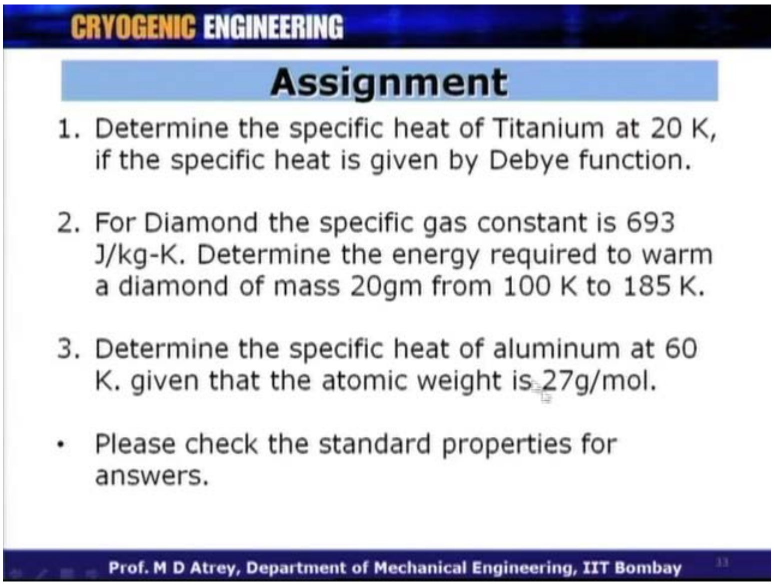


So, we just saw several tutorial best on those, I am going to give assignment, which you can see, calculation of specific heat. Calculation specific gas constant is given determine the energy required to warm it calculation of q over here. Then specific heat of aluminum has been given at 60 Kelvin when has to calculation specific heat over here.

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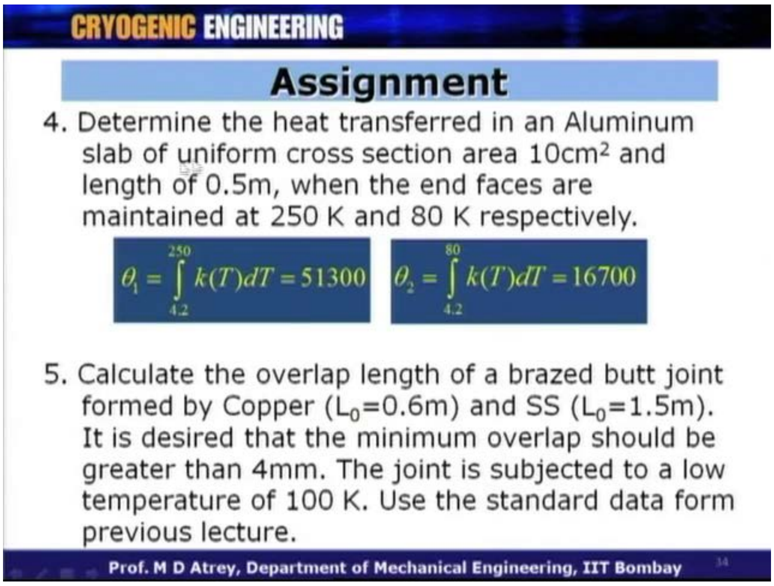


So, based on whatever problem we have solved in the tutorials, you have to solve these assignments. And this is calculation of the heat transfer which we just saw and her again and here just know what we did calculation shrinkages. So, that the overlap length is always maintained. So, please go through the assignments, and solve these problems and for all these problems use the standard data. That is available both in the literature and has given in my earlier lectures.

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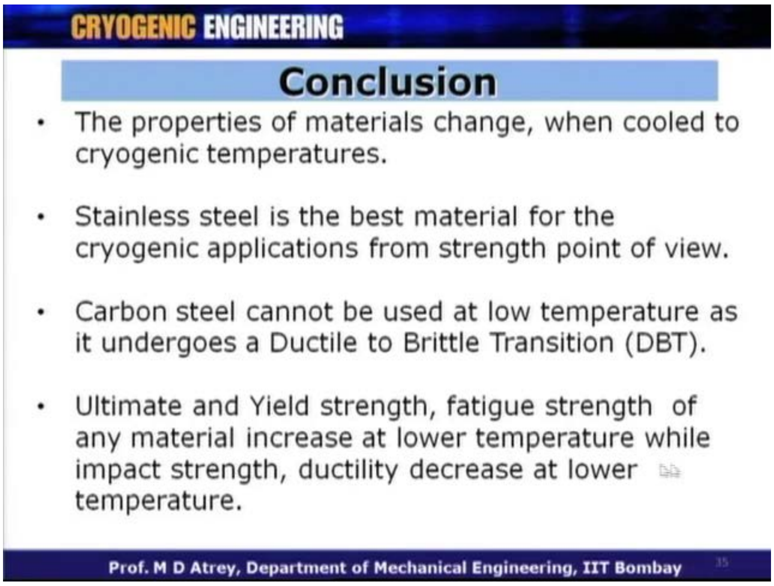


Just to conclude what we have done till know. We know that the properties of the material change, when pull to low temperatures or cryogenic temperature. We have found that stainless steel is the best material for the cryogenic application from strength point of view. If the strength, is a requirement when you should go for stainless steel only. Carbon steel cannot be use at low temperature as it undergoes a D B T transition or ductile to brittle transition Ultimate strength and yield strength, fatigue strength of material increase at low temperature while impact strength, ductility decrease at low temperature.

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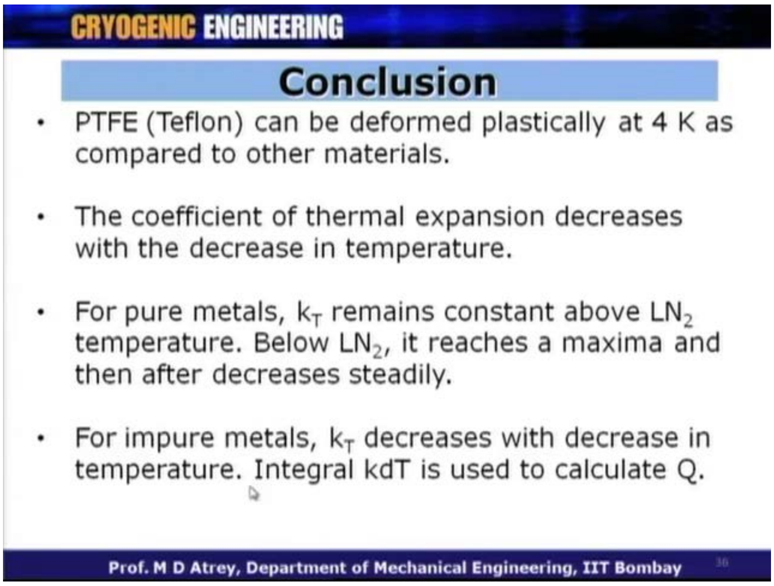


P T F E or (Teflon) which a non-metal can be deformed plastically at 4 Kelvin, as compared to other materials. And therefore, Teflon is preferred in cryogenic. The coefficient of thermal expansion lambda decreases with decrease in temperature. For pure metals, k T remains constant thermal conductivity remains constant above LN 2 temperature which is 77 Kelvin. Below this temperature it reaches a maxima and then decreases steadily this is what we see saw in the last lecture.

For impure metals k T decrease with decrease in temperature. While as we just saw in problem integral k d T is used to calculate the heat transfer at low temperature. We also, saw that the electrical conductivity of metallic conductors increases low temperature. That is what leads to superconductivity also; we saw that k e electrical conductivity and thermal conductivity are correlated by Wiedemann-Franz Law. Basically, k t by k e is just a function of temperature.

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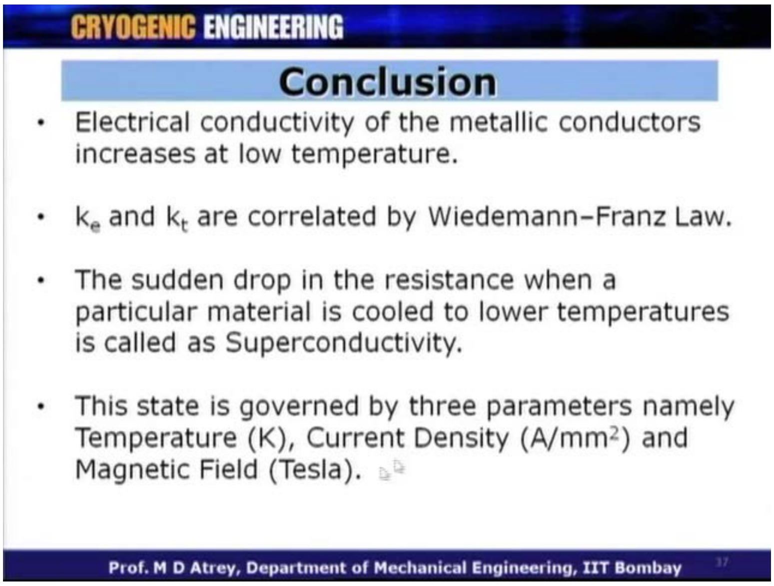


The sudden drop in the resistance, when a particular material is cooled to low temperatures is called as superconductivity. This is what the phenomena we studied in this lecture. This state is governed by three parameters namely, temperature current density and magnetic field.

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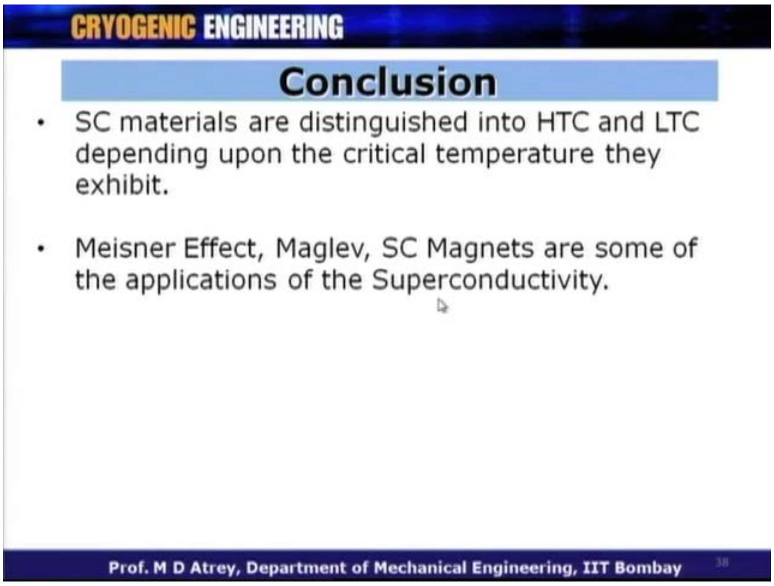


The superconducting materials are, distinguished in to high HTC material and low LTC material depending on the critical temperatures they exhibit. We also saw that Miesner

Effect, Maglev, superconducting magnets are some of the applications of the superconductivity.

Thank you very much.