Conduction and Convection Heat Transfer

Prof. S. K. Som
Prof. Suman Chakraborty
Department of Mechanical Engineering
Indian Institute of Technology- Kharagpur

Lecture 1

Now conduction, there are basically three modes of heat transfer conduction, convection and radiation. Incidentally, in this course conduction, convection heat transfer, radiation will not come into picture, conduction, convection. Now between these two modes conduction is the basic mode of heat transfer, convection is not an independent basic mode. It is artificially confide by as I will tell you in detail the concept of convection heat transfer.

Convection comes into picture when there is a flow it only occurs in case of heat transfer through fluid where the flow can take place and because of this flow the conduction phenomena is affected the basic mechanism of heat transfer. So, there for this affected convection that is flow affected conduction we define artificially as a different mode of heat transfer as convection though convection is not a basic or independent mode of heat transfer this particular thing you can write.

There are certain things you must write. There are things which you may not write or may write as note but this is very important thing though we tell two modes of heat transfer conduction, convection but basic mode of heat transfer is conduction and radiation which is altogether governed by different physics and which is not included in this course of conduction, convection heat transfer.

Now conduction is associated with a temperature difference I already told whenever there is a temperature difference between two points in special coordinates. The heat is transferred because of conduction so there for a temperature continuous change of temperature comes into picture and it flows in the direction of decreasing temperature that means in the direction of negative temperature gradient.

Let us think in this way that let us consider a direction of heat flow Q. Q is flowing in this direction and we describe this direction as x, as special coordinate. Well and heat is flowing in this direction means there is a change of continuous, change of temperature in these direction in any medium conduction can take place in any medium and conduction is the basic mode of heat transfer in solid, in fluid, in static fluid, in flowing fluid does not matter all these things I will be telling in deep with concept.

Now if we have a temperature field which is a function of x only, x is a space coordinate I gave in the direction of the heat flow and if I make inordinate T here I can show this like this T is a function of x. So, therefore, heat is flowing like this.

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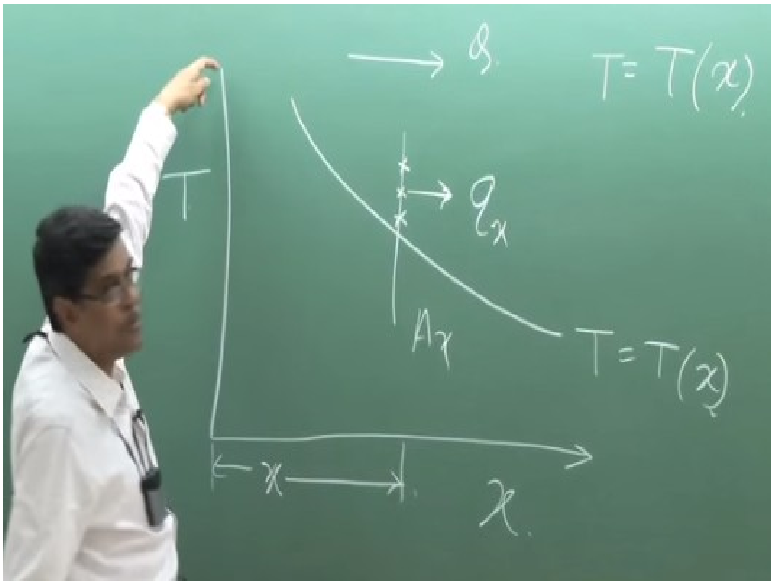

So, therefore heat is flowing like this. Now if I take a cross section at any distance x at Ax from the reference, origin or reference frame then what happens heat is flowing across this section now here one thing is very important when you define the heat we define its direction. Heat is flowing in one direction. Okay now why I have taken an area normal to the direction this is because in this connection we define a quantity heat flux.

Now one thing is true that what is the amount of heat that is flowing in a direction to know that we have to know an area over which we are interested, the heat transfer. Across which the heat transfer is taking place. If the area is more, more heat transfer, area is less, less heat transfer. So, an area is important so in this regard a heat flux is defined qx which is defined like this that if the total heat transfer through an area Ax, a finite area.

I prescribe a finite area Ax is Q, then Q/Ax limit Ax tends to zero.

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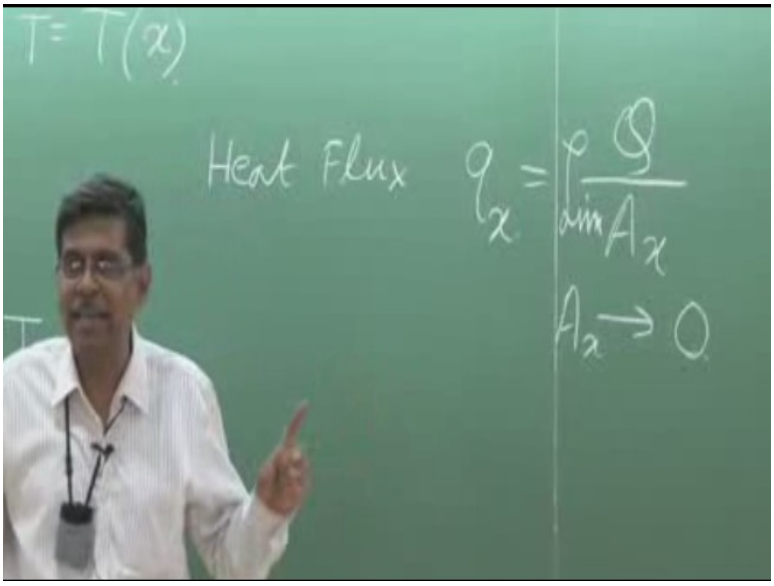

Now it is very fundamental and basic like the stress that heat transfer reduces to zero when A reduced to zero at a point. But their quotient I did not say finite value, limiting value and that is the heat flux that is the amount of heat per unite area and therefore this gets a definition at a point that means here we have heat flux at a point. So, therefore different point we have different heat flux, it may be constant may not be constant at all points on this area.

If it is constant, then simply we multiply the area with the heat flux against the total heat flux across the surface. But what is the difference with stress. Stress is a (()) (34:16). When you define stress force per unit area the area may be normal to the direction of force may be along the direction of the force. But while defining the heat, heat flux or heat transfer, it is used as a vectoring a particular direction and heat flux is defined divided by the area normal to the direction of heat flow.

You understand. So, heat flux is the heat transfer divided by the area. This x has to be normal to the direction of heat flow. So, heat flux (()) (34:58) takes the (()) (34:59) you have to know every physical quantity from his birth then step by step you will have concepts. Sometimes somebody starts giving the definition, conceptual definition from little step ahead it is nothing wrong. It depends upon the circumstances.

But when you teach somebody you start from this is the definition of heat flux which is defined at a point like a stress that is the heat flow per unit area normal to the direction of heat flow. If you this way define the heat flux then this heat flux, for example, here in the direction of x, qx can be written by an equation widely known, widely popular equation and we are grateful to the great mathematicians or physicist of France his name is Joseph Fourier who from his experimental observation told that this will be proportional.

This is a proportionality constant to the temperature gradient in the direction of heat flow. This temperature gradient is in the direction of heat flow qx and a minus sign is deliberately given because the heat is flowing along the negative temperature gradient to make the heat flux positive direction to be identified we give a minus sign and this is an analogy which all phenomenological equations or laws like electrical current flows along the negative potential gradient like mass transfer takes place along the negative concentration gradient.

So, therefore to identify the positive direction of the flux we give a minus sign so that the positive direction of the flux is associated with the negative gradient of the potential. Now the question comes that this is very simple case but in practice temperature may be a function of that, there may be a temperature variation in this direction also, why? If you consider this as y direction. If temperature is a function of x not of y.

If you consider this also as y direction then at all points temperature gradient will be same, heat flux will be same. Similarly, if it is not a function of z at all points will be same. But in practice temperature may be function of all this face coordinates with reference to a frame for example in Cartesian frame of reference, temperature may be a function of x, y and z and all this thing today what I am telling is at a particular instance.

So, time also will come an independent variable so it may change with time. Now we are thinking of special variation of temperature so at any instance we just concentrate at any instance. So, temperature may be a function of all the three space coordinates then in that case what happens that any point there will be a heat flux in this direction. There will be heat flux in this direction and there will be a heat flux in this direction at a point.

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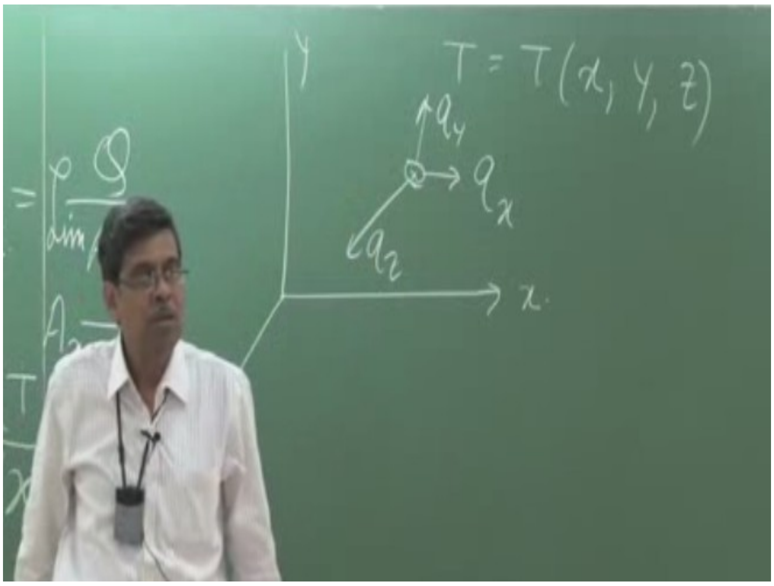

That means these are the respective heat flow per unit area normal to that directions. They are limiting value as the area ten to zero and in that case q is represented as a vector qx where i, j, k are the unit vector along x, y, z directions with respect to a Cartesian frame. Well q is represented as a vector in that case this law given by scientist Fourier can be written in a generalized format q is equal to -K grad T, that is gradient of t where grad T is given by

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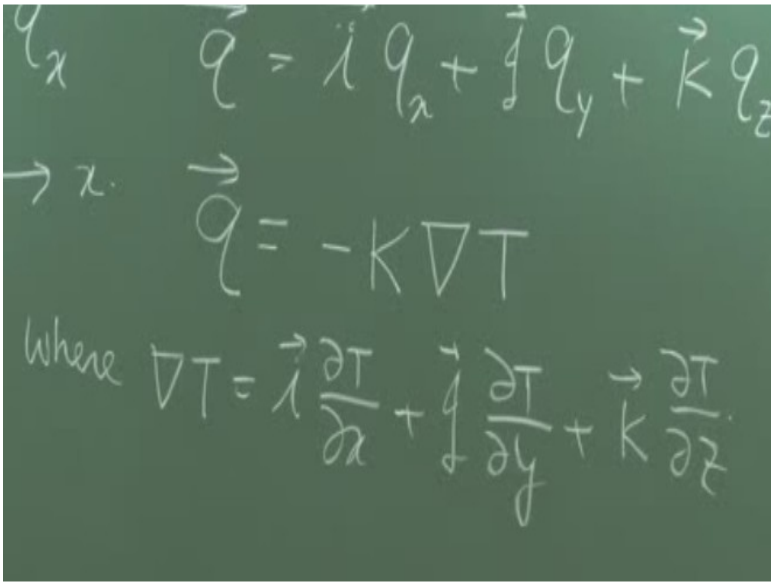

So, that qx becomes - k then dt, dx because they are partial notation, partial derivatives has to be given so in that case qx is minus k because t is a function of

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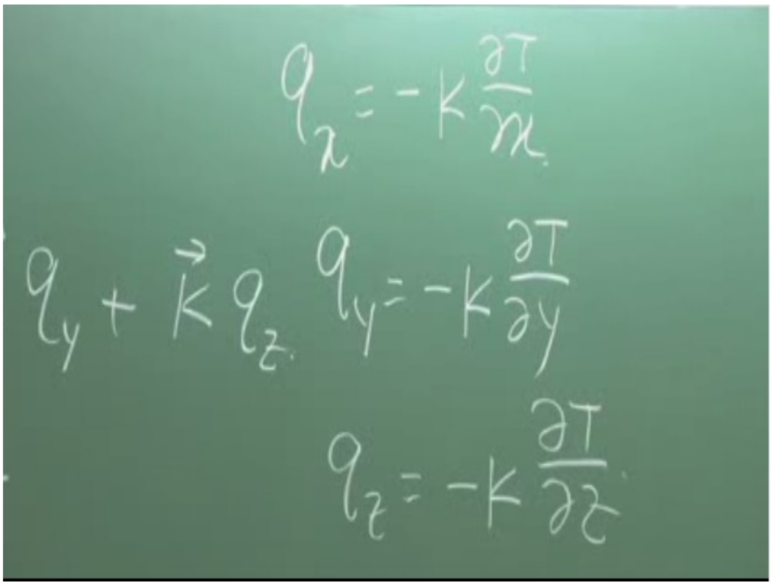

And this law q is -K grad T this law is known as according to the name of the scientist Fourier's Law of heat conduction and this forms the foundation, pillar of the conduction and the convection heat transfer that is the Fourier's Law of heat conduction that is q is equal to -K grad T.

Here the constant k is a property of a system and it is known as thermal conductivity. Well this is known as thermal conductivity. So, k thermal conductivity. K is known as thermal conductivity and for an isotropic material k is same for all directions x, y, z. It is independent of the direction of the coordinate axis as you know and in that case k depends only on temperature.

K is thermal conductivity and it is a property and for isotropic material it is independent of the direction of the axis and in that case, it is purely a scalar quantity, scalar constant which is a function of temperature only for isotropic material in this class we will discuss the things almost for isotropic materials and this thermal conductivity in a broad sense is known as transport property relating to heat transfer.

So, the property which relates the transfer or flux of quantity with the potential, with it is potential causing that flux is known as transport property. Like viscosity which relay stress with the rate of strain, diffusivity who relate the mass transfer with the gradient of concentration. Here the rate of strain is difficult at the first moment where the gradient is coming because of the rate of strain is defined in terms of gradient of velocity from the kinematics of fluid flow.

Well, so therefore this is known as in broad sense, transport coefficient related to heat transfer, thermal conductivity. Now the unit of thermal conductivity is very simple because heat flux divided by the temperature gradient.

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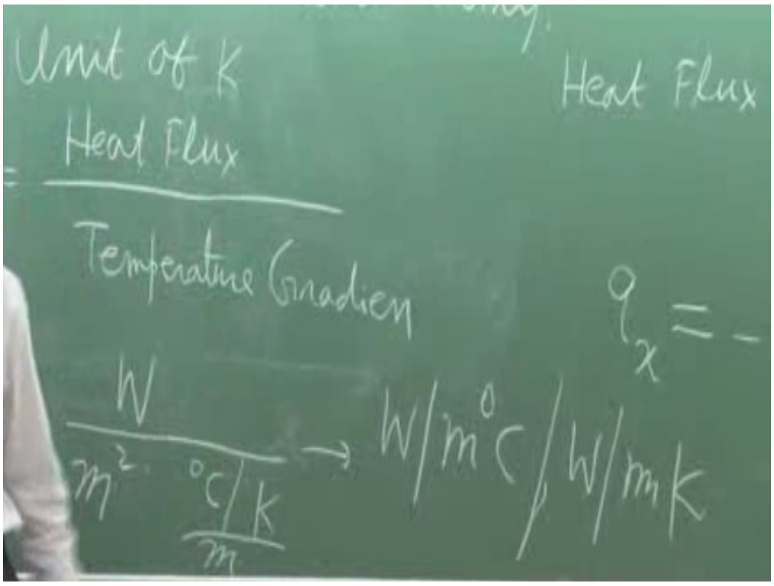

The thermal conductivity unit will be heat flux divided by temperature gradient. Now in SI heat flux is defined as unit of k. Heat flux is defined as heat flow per unit area watt per meter square. And what is temperature gradient? it is degree Celsius or Kelvin. Any one of these two divided by meter. So, therefore, the unit is watt per meter degree Celsius or watt per meter Kelvin.

This K is not thermal conductivity, it is Kelvin and Kelvin is unit is not written in terms of degree Kelvin whether it is a change in the Kelvin or it is the absolute Kelvin, you understand. If you change the temperature from 460 Kelvin to 480 Kelvin, what is the change in temperature in Kelvin? 20 Kelvin. And what is the temperature of the body? 460 Kelvin, not degree. Okay. So, therefore, it is written as Kelvin. So, this is degree Celsius. So, this is the unit either this or this.

Time left is less. So, before I finish this I will tell you this part I will extend after wards that the cause of thermal conductivity or thermal conductance in different material. As you see here the thermal conductivity is a property which allows the heat to flow for a given temperature gradient more is the thermal conductivity, more is the heat flux. Now this property of thermal conductivity is due to what?

Is attributed to certain molecular level physics because any microscopic property whether it parameter rather, whether it is a property or anything else we define through the molecular activities. Now the cause of this thermal conductivity in case of fluids comprising liquid and gases are different from that of solids. In liquid and gases, the heat is conducted by the energy transfer between the molecules because of its collision.

Molecules are always in a state of ceaseless motion as you know and this motion comprises translational motion also the rotational and vibrational motion about its own axis and because of which all molecules have kinetic energy. When a molecule is activated to raise its temperature, it is kinetic energy is actually increased and because of random collision between the molecules, it transfers the kinetic energy to the neighbouring molecules which gain kinetic energy from the upstream molecules which collides.

And there is a random collision in all directions and because of this collision when this kinetic energy is transferred the conceive this the heat transfer. So, therefore, a fluid liquid or gases I mean high thermal conductivity means the collisions for this molecules of these fluids at a given state, property is more compared to the other. So, there for this energy transfer due to the collision is the mode of heat conduction in liquids and gases and conductivity arises out that the property.

In solids, it is little different, this is because in solid as you know the basic difference with the liquid and gases is that in solid the molecules are closely packed mean three path is extremely small and the cohesive forces are very strong. The OUFC in the viscosity affect in case of liquid and gases are different. Similar way, here is not the collision rather it is attributed by two phenomena one is the flow of free electrons and another is the propagation of lattice vibrational waves.

What is flow or free electrons? Flow of free electrons take place in case of metals. In metals, the molecular arrangement is such that there are free and or valence electrons you have read in chemistry that which form a cloud in the periphery of the atom. They are not within the atom and they share with the other atom of other element for in the reaction. This cloud of electron is known as free or valence electron which are there in all metals which take part in conducting the electrical current, flow of this free electrons from the electron cloud and at the same time they take part in flow of, enhancing the flow of heat due to conduction.

So, therefore, for this reason a metal is a good conductor of both heat and electricity and the lattice vibration wave part is suppressed there. But there are highly ordered crystalline nonmetallic substances where the lattice vibrational part becomes prominent. What is this? So, in those types of solids nonmetallic solids the molecules are arranged in an order, in an array a set type of thing which is known as lattice probably you know these things.

I am not going into details of this and there the molecules start vibrating in a very synchronicity as a whole there is a lattice vibration which is propagated within the material and that is known as lattice vibrational waves. You do not have to know much in depth of it because this is not our course, this is for your information.

And for those highly crystalline nonmetallic solids specially for I am telling examples diamond, graphite, silicon, quartz is lattice vibrational law it propagates and that propagation makes the major contribution not the free electron to the conduction of heat and sometimes this becomes so high that these nonmetallic solids exhibits more thermal conductivity than the metals but electrical conductivity, they are very poor.

They are bad electrical conductor but good heat conductor and that is why they are used for cooling of electronic component and they are known as semiconductors. Now with this I will just show some for your ranges of thermal conductivity of materials for your information this is nothing great you just have a look the range of thermal conductivity of the materials. So, you see just have a look only this is the range of thermal conductivity I do not know whether you can see from the back.

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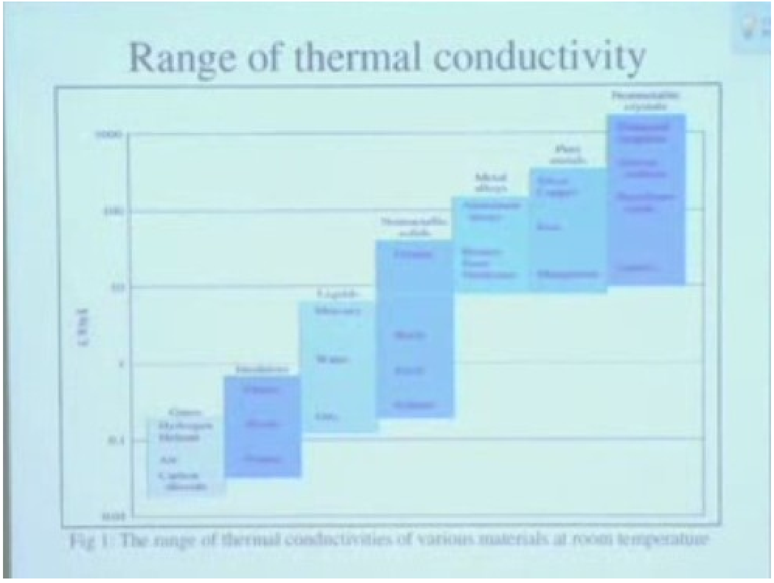

You see this is the thermal conductivity axis watts per meter k. This is point one, this is one, this ten, this is hundred, this is thousand and you see hydrogen, helium, air, carbon dioxide gases they are within that range point one to point zero five like that a little bit point six. Then comes the insulators fiber, wood, then this is foam. Then comes the liquid mercury, water, oils. They are in the range of six, seven, eight that is between one to ten and for some oil little bit of one.

The nonmetallic solids, some oxides rock they lie in this range it is the 50 we have been below one. Then the alloys aluminum alloys, bronze, steel, nichrome. These alloys fall within this range hundred, little more than hundred or below hundred. Then comes pure metals copper is one of the very good heat conductor whose thermal conductivity is somewhere near four hundred.

And you see those nonmetallic highly ordered crystalline materials that solid that is diamond, graphite, silicon, cobalt their thermal conductivity even up to thousand watts per meter k. This shows such high thermal conductivity.

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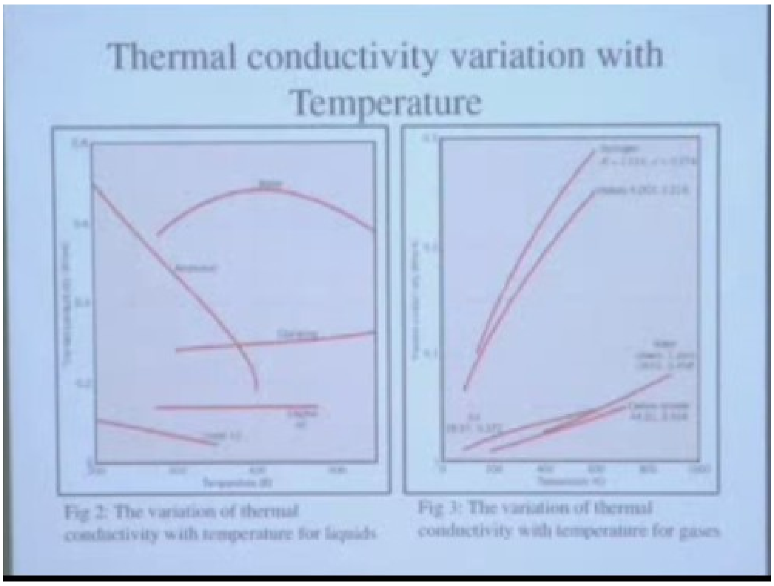

Next, this is some representative figure of thermal sorry, representative figure of thermal conductivity variation with temperature this is for liquids ammonia there is a strong decreasing trend this is for gases, for hydrogen and helium there is a strong increase, strong influence of temperature in increasing the thermal conductivity whereas for air the thermal conductivity is less influenced by temperature then it is water and carbon dioxide.

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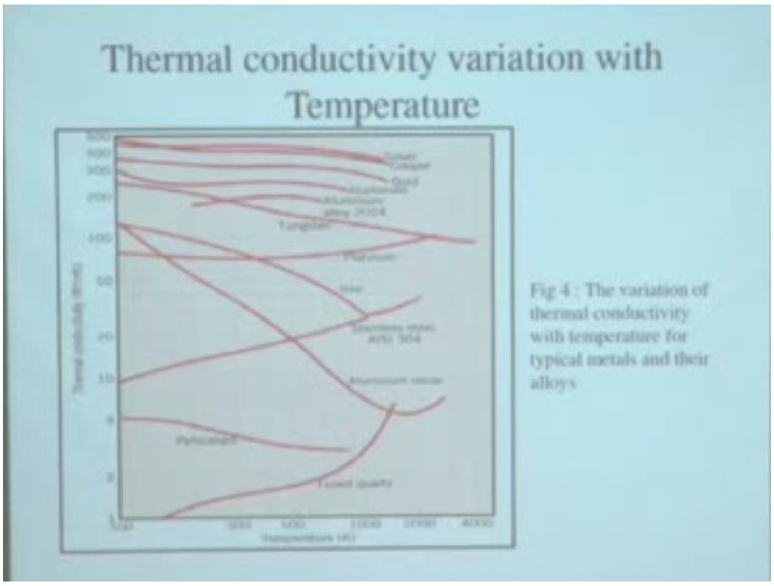

Next is these are just for your understanding for solids you see the thermal conductivity of different solids are there, not much of a difference for some solids there is a sharp decreasing trends for silver, copper, aluminum these are very important. The influence is not very mark with the temperature the thermal conductivity change. So, these are certain information that how do thermal conductivity varies with the temperature. Okay. Thank you for this class.