Solid State Physics
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Lecture - 32
Electrical Properties of Metal

So, today we will learn about the Electrical or Electronic Properties of Solid.

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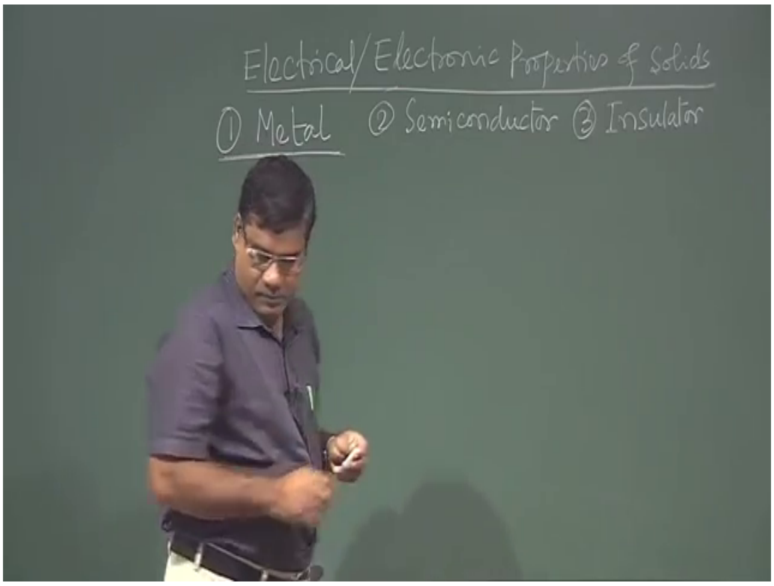

So, this is one of the very important properties of solid. So, depending on the electrical conductivity or resistivity solids can be divided into three categories, one is conductor or metal, another is semi conductor and third category is insulator.

So insulator is very highly resistance, it is resistivity is very high conductivity is very low whereas, metal are very high conductivity low resistivity and semi conductor is basically in between. So, it is conductivity is higher than metal, but lower than the insulator. So, we will try to find out the origin or reason behind such behavior of different materials.

So, today we will discuss about the metal conductor, what is the origin of this electrical behavior of this metal.

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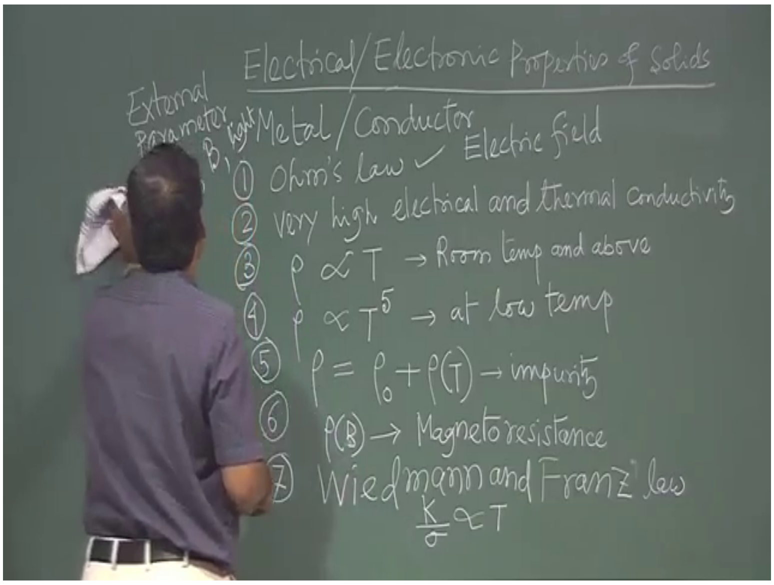

So, metal or conductor this is it obeys Ohms law. So, this the one important phenomenon that is it is obeys Ohms law right and it shows very high electrical as well as thermal conductivity. So, very high electrical and thermal conductivity and it is when we study in the proper of any solid. So, we use external parameter and apply on that material and see the response of that material to that parameter. So, what are the external parameter? External parameter one is temperature T.

So, behavior of a material with temperature so that can be observe to study that material and other one is electric field, we apply electric field on the material and see the response third parameter important parameter is magnetic field, what is the response of that material to magnetic field and fourth one is it is light. If you put light on the material what is the response of that material. So, to study behavior of metal in different aspect; it may be thermal, it may be electrical, it may be magnetic, it may be optical. So, we have to use this external parameter and apply on them and see; what is the behavior of that material in response to that external parameter. So, here this Ohm's law basically here we apply external parameter electric field right and electrical conductivity basically it comes from here.

So, for electrical conductivity one has to apply electric field or thermal conductivity one has to apply temperature external temperature, one has to apply or one has to vary the temperature and see the response of that material right. So, this resistivity of this material resistivity of this material metal basically it is behavior at low temperature and at above room temperature is different. So, generally above room temperature it is proportional to T, but at low temperature this is room temperature and above of course, this temperature it is decide it is not independent material, it depends on material and that critical temperature it depends on that material.

So, these are generally this happens it is not true for all material, but at low temperature generally it is varies with the power of 5 t to the power 5 and is at low temperature right. So, if metal is pure or metal is impure being some impurity in that material is there. So, depending on that this resistivity it is it generally it has two parts. So, this one part is independent of temperature one part is independent of temperature. So, all the time it is there internal to tell this internal resistivity and this is another part is there it depends on temperature. So, this type of resistivity of pure metal generally a for this if it is having impurity in that metal.

So, it is behaves like this, if it is not impurity is not there then it is rho T. So, this part comes from this basically impurity. So, so these are the experimental fact it is seen it is these type of behavior it is observed from metal and you know this response to this magnetic field of the metal that also it is there, it is called; so variation of resistivity with magnetic field, here variation of resistivity with temperature. So, similar type of variation of resistivity with a function of magnetic field that is also which it is it has response to the magnetic field and it is really called magneto resistance. So, magnetic due to magnetic field why distance changes what is the reason and how it defense on the magnetic field. So, that is basically in terms of magnetic magneto resistance of magnetic resistivity, we express them. Another important phenomenon metal source and that is called Wiedemann Franz’s law.

So, that is basically the ratio of the thermal conductivity and electrical conductivity, it is proportional to temperature T all the time, all the time this ratio is proportional to T. So, this equal to some constant into T, this of behavior all metal shows. So, these are the feature of metal. So, our task is here to find out the origin of these properties why it shows why is behaves like this, why it behaves how it behaves to electrical field temperature magnetic field right. So, this are the task we will explore in this lecture. So, let us see how you can explain this behavior. So, for that we have to know about electronic structure of the metal because electrical or electric property is basically, the it depends on the electronic state or electron electronic distribution in the metal. So, already we have mentioned earlier that metallic bond. In case of metal that metallic bond what we have see in basically alkali metal it is a ideal example.

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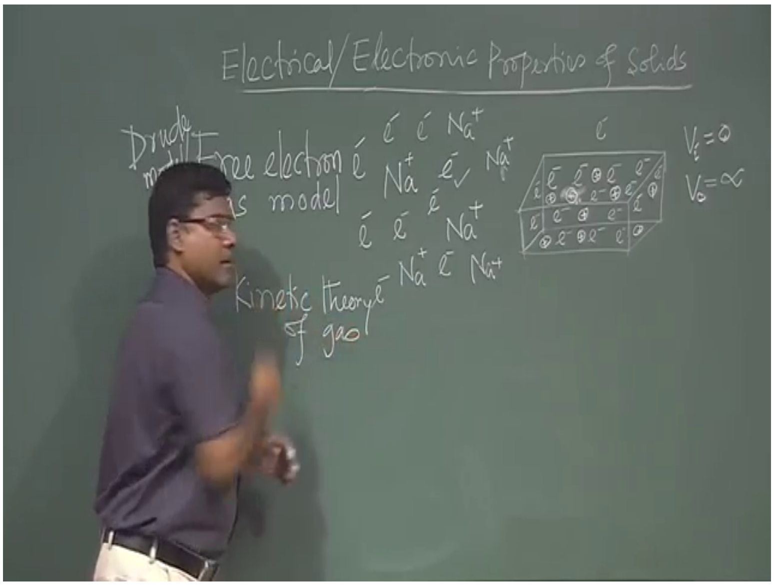

So, in case of sodium we have seen that, it is sodium ion sodium plus and one electron. So, this in metal they are in solid in crystalline form, now each sodium it gives one electron in the system right.

So, we have many sodium atoms in the crystal. So, we have many electrons. So, these electrons are basically they can move throughout the crystal throughout the solid right. So, the sodium atoms hold it like a crystal due to metallic bond. So, that metallic bond is basically this as a whole this electrons can move in the crystal and that so, electrons is negative charge and this ions these are positive charge. So, these are as if these are heavy positive charge is there, and now this electrons moving around them. So, it is so, a particular electron is not attest with the one ion. So, they are sharing this they are they are sharing with all the ions. So, that is basically as if whole this whole electrons are hold by this whole sodium ions; so this bonding.

So, holding each other not individually one ion one electron as a whole, whole electrons and as a whole ions. So, they have some weak interaction electrostatic interaction and that type of holding is basically all metallic bonding. So, that is we have mentioned earlier. So, now, to explain all the properties whatever I have mentioned this response to electric field magnetic field temperature. So, this one has to take model and then test on that model we have to assume we have to speculate and based on that model we have to derive relations and that relation whether it can satisfy the experimental result or not that one has to check. If it satisfies, then we demand that the assumptions in the model for that model are correct. So, to explain all this things this one model very famous model was taken that is free electron gas model.

So, this model is basically given by Drude, this model was given by Drude that is why it is called Drude model or free electron model. So, this also called Drude model or free electron model, and Franz was having some continuation also to this model. So, what is that model? So, that we will try to explain; we have a piece of metal now it is made of either sodium or this copper or silver gold whatever it is. So, it is considered that the since these electron are very weakly interacting with the ions.

So, in this model these weak interactions is ignored and consider that in this metal this electrons are free although sodium say you can just take as a example sodium so that ion positive ions are there. So, you can number will be right. So, both are there electrons and ions, ions are fixed in the side right as lattice structure according to the lattice structure they are fixed in the sides right, now this electrons they are free there is no attraction interaction with this ions.

So, that is ignored and now in a piece of metal now we have free electrons. So, they can move anywhere, but restriction is that this electron cannot go out from the metal. So, because it we have not seen any electron emission at room temperature right if we increase the temperature for any material metal. So, electrons emit. So, there is a thermal emission, but. So, (Refer Time: 25:43) a in normal temperature the electrons are not allowed to go out and they do not go. So, it is assumed that the potential energy of electron inside the metal it is constant and it is low and outside of the on the metal of on the surface of the metal and outside. So, this potential energy of a electron if one electron is here, potential energy of that electron is very high compared to the electron inside the metal.

So, it is assumed that the potential energy outside is like infinity is very high and inside of the material metal this potential energy is very low. So, potential energy inside the metal is very low. So, that is considered as a the zero potential energy of this electrons inside metal is 0 and outside metal outside metal just on the surface and outside of the metal this potential energy is very high. So, it is taken as a say infinity. So, it is like a just potential box you know. So, these electrons are in a potential box. So, inside it is potential is 0, but it cannot cross the surface like the potential barrier very high barrier it cannot go out from that box, but in that box it is free to move in all directions it has no potential energy is very is considered as a 0. So, this is the model free electron model or Drude model.

So, all metal is considered that the it has a free electrons, it has a lot of free electrons and it behaves just like gas, gas of atoms molecules right. So, forever the kinetic theory of gas, that will be applicable to this electron free electron gas. So, it is also assumption that is this free electron that it will just behave like gas. So, whatever the theory is applicable for gas. So, that will be applicable for this electron gas in case of metal. So, this is also another assumption.

So, now, in case of gas you know this when they are moving and they collide with each other. So, there will be distribution of velocity of gas, there will be distribution of energy of the gas right. So, here if I consider that energy of this of electron gas for each electron it will have only kinetic energy, it means velocity is v like from that kinetic theory one can. So, this kinetic energy happened is correct.

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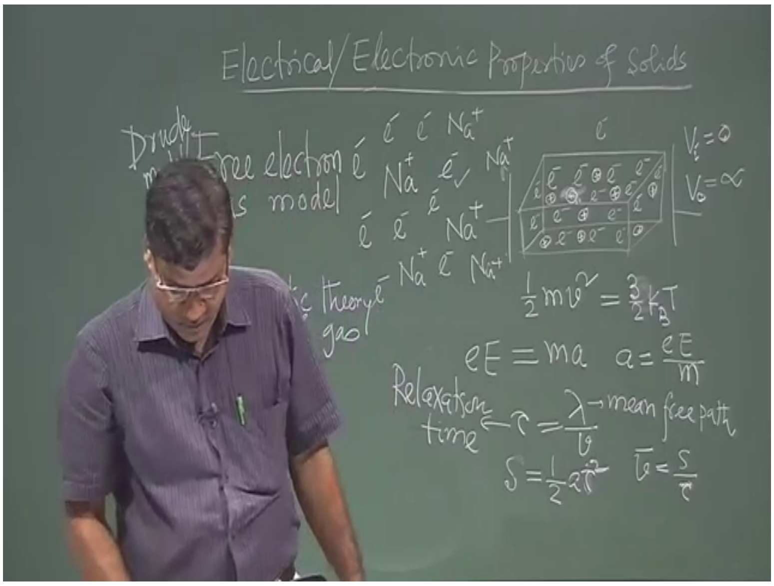

So, that is a energy of each electron and comparative theory one can write that this energy is basically 3 by 2 K B T Boltzmann constant and this is temperature. So, from kinetic theory, we can apply on this electron gas and you write this right. So, now if we apply electric fields then what will happen? if I apply electric field, they now they before they apply electrical they are free they are moving in all directions now when I will apply electrical field. So, I am applying in a particular direction right.

So, now they will move in that direction right. So, why they will move because force is acting on this electromotive force right. So, that electromotive force because of electromotive force now that electron will fill force if electric field is E and charge is small e. So, this will be the force acting on a electron. So, because of this force it will move it will be accelerated while force is acting on a on a particle. So, it will be accelerated right. So, then to find out one can apply Newton's law. So, this we can equate with mass into acceleration right. So, from this one can find out the acceleration a equal to e E by m. So, m is mass of electron and capital E is electric field right now because of this force they will move they will when they will move.

So, there will be some collision although it is collision is very less in number, but it has some collision. So, that we express in terms of mean free path lambda right and if it is moving with velocity v, so, then time this lambda by T that is a velocity. So, now, by velocity that is T. So, this lambda is called mean free path means path between two successive collision right. So, after one collision, it starts fresh movement fresh velocity and it goes to the goes travel lambda distance and then gets another collision. So, this distance is basically it is lambda and it is called mean free path, because it is average one it is for all the collision for all electrons it starts same. So, this is the one has to average and this. So, this is the time during this time it does not collide. So, this tau is called relaxation time it is called relaxation time. So, basically due to this force there will be acceleration and this acceleration a.

So, due to this force it will travel say distance S, if it is acceleration a and if your constant start from zero velocity and moving. So, then we can write a (Refer Time: 36:12) to the distance a T square. So, at time T what will be the distance? So, this time let us take this time tau relaxation time.

So, it will travel this distance right; so velocity. So, this now this velocity whatever now I am talking is the drift velocity, this is the drift velocity and that velocity is one can velocity drift velocity one can write that s the distance travelled by time tau. So, this velocity is drift velocity. So, S is known a is this tau is this. So, now, in terms of this other parameters one can find the drift velocity. So, drift velocity one can find out.

So, I think I will continue this class in next class. So here let me stop.

Thank you for your attention.