Solid State Physics
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Lecture - 33
Electrical Properties of Metal (Contd.)

So, will continue our discussion, these based on the free electron gas model, we have seen that when we will apply electric field.

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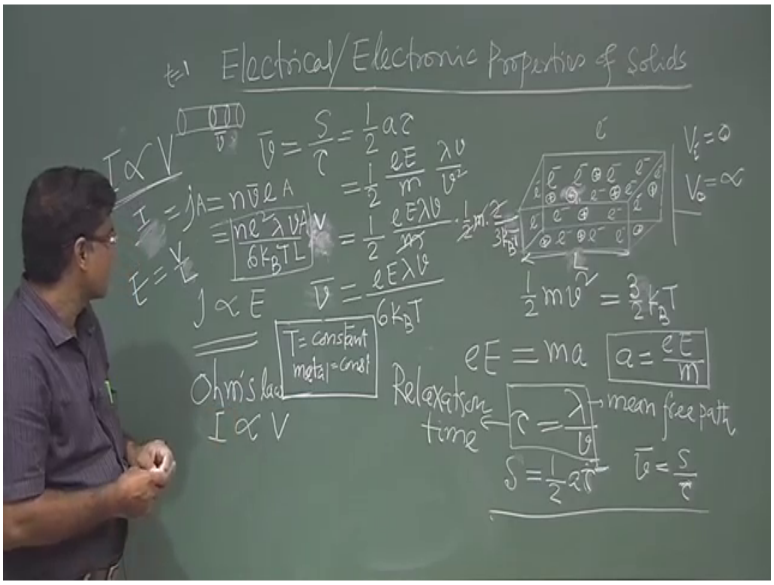

So, that will be the acceleration of the electron and relaxation time in terms of, mean free path; that is on another relation. Now this velocity, basically this velocity and after applying electric, before applying electrical these the velocity right.

So, from kinetic theory, one can get the velocity that depends on the temperature and then velocity after applying electric field. So, that is called drift velocity. So, it is along the direction of the electric field. So, that is v dash v bar. So, drift velocity bar equal to S by tau is equal to half a tau square tau square and this by tau, so its tau right.

Now, if I put value of a. So, I will get half a is E by m, and tau is lamda by v right . So, these are the drift velocity. Here charge mass electric field and lambda is mean free path. Now V one can find, one can find from here. So, what is the v? see if I replace V half eE by m this lambda let me write here. So, 1 by v, so its V square is there.

See if I write one v here, then v square. So, 1 by v square I will replace with one v will be there, and this v square is basically we will get 1 by v square, 1 by v square, I will get half m 2 by 3 KB T right. Sorry it has to be 3 KB T right. So, what we are getting? We are getting this m, then this 2 will go. So, 6 we are getting 6 KB T e Elambda v. So, that is the drift velocity of electrons under electric field.

So, now we can define the current in terms of known parameter. So, current density j. What is current density? What is current? Current we define that per unit time, number of electron passing through a cross sectional area a, so that will be the current. So, current density is just per unit area, per unit cross sectional area.

So, this current density what can write I have to see, if this is the conductor right, if I take this cross section right. Now per unit time at t equal to per unit time t equal to 1, how many charge will move. So, if charge density n, any charge density, number of electrons per volume right.

Now, in once if velocity is v bar. So, velocity is nothing, but the distance traverse by a unit time right, per second. So; that means, this length, it will traverse this length unit time, this length is v bar right, because this length it is traversed by 1 second. So, in 1 second, this is the traversed by the electron. And now this cross section if it is 1 per unit cross section, if I take unit cross section this one.

So, this will be the volume,. So, volume will be this into cross section, this is the velocity, but it is now length for per unit time and cross section a. So, length into this cross section that will be the volume. So, that basically this is the volume. So, V bar will be the volume right, and in that volume, if volume density is n; number density of electron is n. So, how many electron will be in this volume n v bar and so, these many number of electrons will be in this volume. So, into charge, charge e for one electron. So, total charge is this. So, this much charge is passing through a cross section, unit cross section per unit time. So, that is defined as a, it is defined as a charge density right, it is defined as charge density.

So, to get this charge densitythis n, this e and that v bar we have got this v bar is this. So, one can write e is here. So, I will write e square lambda v by 6 KB T into this E . So, it is a, its current density, I was telling charge density. So, charge density is n. This is the current density.

So, this is now expression from higher I can see, thatn for a particular material n is constant. These all are constant, and this lambda, this v. So, this, it is a lambda is, it will it will depend on that material, which material metal, we have taken right. So, temperature for a particular temperature T is constant. So, here I can write that j is proportional to E when, when T is constant, when T is T constant and metal is constant, means for a particular metal. For a particular temperature for a particular metal, other parameter depends on that metal, except T other parameter depends on that metal right.

That electron density mean free path its kinetic velocity basically, maximum velocity and yeah. So, it depends on temperature. So, when temperature is constant, so this is fine. So, this these are constant. Under these condition this is very important I emphasized on this point that, under these condition j is proportional to E, current density is proportional to electric field right. So, this is nothing, but Ohms law. So, all metals obey ohms law and that generally without knowing in details we use for our electrical circuit right, to study the electrical property just we use, but why it behaves like these, why current density is proportional to electric field or current is proportional to V right, this potential. So, we are familiar with this form, clearly we are familiar with this form. So, why it is like this. So, that origin of this relation, now we can see it is, because of the free electron available in the metal

So, we could derive this on, and you know the relation of current density and current. So, to get current density. To get current from current density, one has to multiply with the cross sectional area. So, current, this through a rod, through a metal, so charge will pass through that rod, means through the whole cross section or unit time, so that is the current. And current density just current, current density is basically, the current density is nothing, but current by cross sectional area right.

So, its basically for a particular material, or a particular material see it is not enough when we express in terms of current, when we express in terms of current. So, we have to tell that for a. It is not only for a particular material, but for a particular geometry of that material also that is important. So, then it will, if I talk in terms of currents, so it will it will depend on the geometry of the metal, but if I talk in terms of current density. So, it will be independent of the geometry of the metals.

That is why its more general parameter than the current, and voltage also. What is the relation voltage V. V is basically, it is, V is, it is related to electric field V by d right. what is d. d is the if we have applied voltage, if we have applied voltage across this two surfaces, then electric field in these, between this length, it will be this voltage and that separation d. So, then you will get electric field.

So, now electric field is the voltage per unit, voltage per unit length . So, then again electric field is, more general term than the voltage potential difference. So, these basically potential gradient electric field, is basically potential gradient. So, this V by d. So, let then find. So, of if I multiply with a in both side, if I multiply with a. So, then this will be current, this will be current, this will be current right. Here a term will come, this will be current, here electric field if I multiply with d of l, if I take say l , if I take l.

So, e can be replaced by V by l right. So, then I can write l here. Now these will be the constant, because here this will be constant right for a particular temperature for a particular metal, and for a particular geometry of the, for a particular geometry of that metal. So, then here I can write that I is proportional to V, I is proportional to V right. So, we are familiar with this form, so this ohms law.

And what is the proportionality constant. So, these will be the proportionality constant, and this proportionality constant will be 1 by r right, if I write this some constant.

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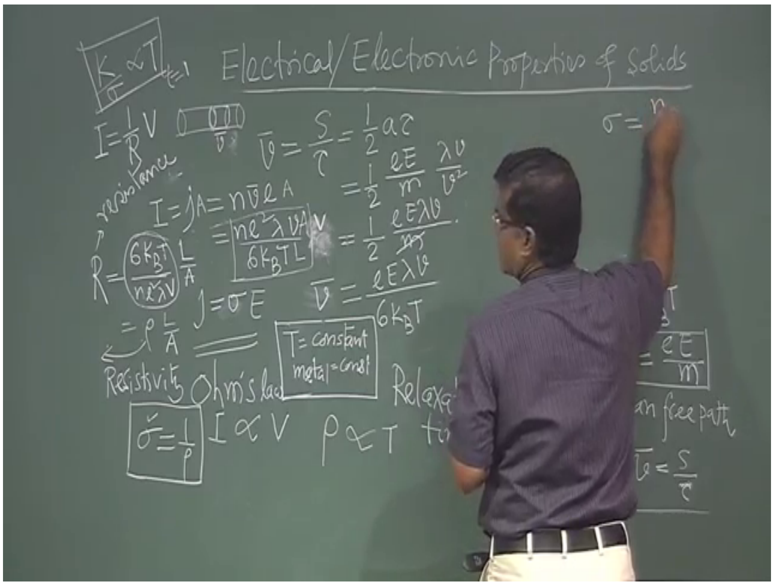

So, I can write I equal to V, some constant I have to write. So, I can r, R is a constant. So, 1 by R I can write for my convenience . So, this R is called the resistance 1 by R, it will be conductance right. So, 1 by R will be conductance

So, R equal to from here you can. So, just I have to inverse it. So, 6 KB T l by n e square lambda V right. So, this you can write, and if I take this as a rho l by a, this rho is called the resistivity, this rho is call the resistivity. So, R is resistance and rho is resistivity right

So, rho is basically resistance per unit length, and per unit cross section right. So, this, and if you see this, if I have included A and L right, when I consider the j. So, if you just leave this A and L. So, what about this term will be here, this here I have taken inverse 1 by R, but if I do not take inverse. So, this. So, j equal to sigma E, the sigma that sigma will be sigma, is called conductivity, and it will be just 1 by rho.

So, before putting this A and L whatever things was there. So, if you check just it will be inverse of this one. So, it can right. So, from free electron model we could explain microscopically, that why metal follows the ohms law and from there everything got.

Now, what is the parameters on which this resistivity or conductivity depends right. So, definitely depends on the, mainly depends on the electron density in that metal. So, metal to metal it varies, the conductivity mainly this electron density is responsible, if you keep other parameter for, if you study for same temperature and etcetera.

So, this is one part, we could derive from that free electron model. So, here I will, I think I can use this part, now this . So, there I showed you that, I think this temperature conductivity. So, resistivity I, as I told you this proportional to t, if you think about the temperature. So, resistivity I have written, that is the resistivity. So, resistivity basically proportional to T right. It is a room temperature at room temperature. So, it follows resistivity, resistivity follows is proportional to temperature T, and that also one can see from here right, and yes next if I want to see this K by that Bridgman French Law K by sigma is proportional to T Bridgman French Law I want to prove it. So, I need this sigma expression.

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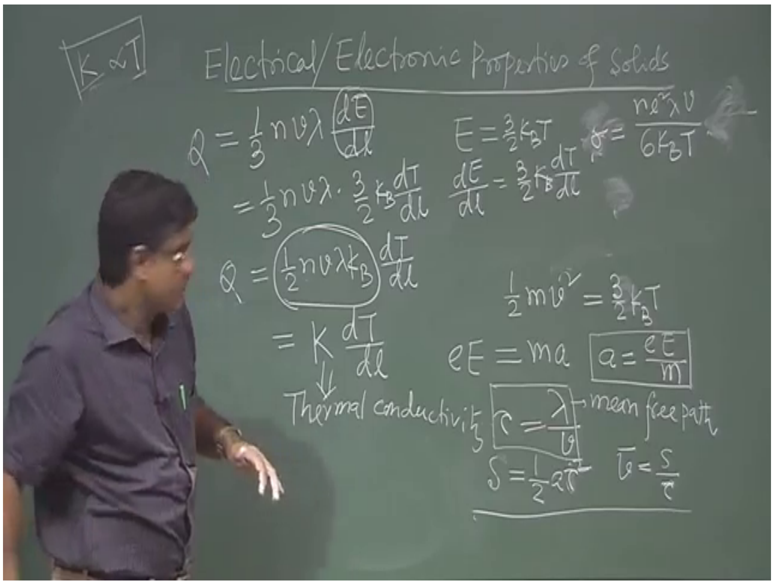

So, sigma is n e square lambda v lambda v by 6 KB T right . So, then I can. So, this expression. So, for thermal conductivity. What is thermal conductivity? It is a just similar to electrical conductivity, see in case of electrical conductivity if you apply electrical potential difference, potential difference and then charge flows, it goes from one place to another place ohm.

So, when it is going. So, what is the velocity of that of the electrons, and what is the electron density of that material. So, depending on that, this conductivity is decided. Similarly for thermal conductivity, for thermal conduction this we have to apply temperature difference. Now this, the amount of current, earlier in case of electrical amount of, we express amount of charge or amount of, this current flows through that potential difference.

So, here amount of heat, thermal heat, heat transfer from one temperature to another temperature. So, how fast it moves, or what is the resistance of this of this, passing this heat from one place to another place. So, that we express in terms of thermal conductivity right. So, from kinetic theory of, using kinetic theory of gas one can.

So, this one can found out that quantity of heat passing through a cross sectional, cross section of a rod or unit area and per unit time. So, that is similar per unit area and per unit time, amount of charge passing through the potential gradients . So, that is the charge density right, current density. So, here also definition is similar. So, amount of charge. So, from kinetic theory, applied kinetic theory, because this in case of free model of electron gas.

So, this one can apply kinetic theory. And apply kinetic theory one can get the expression, I will not derive that one. So, I will just take that one. So, that is basically one third, one third n v lambda dE by dl . So, this is the density, electron density or gas density in case of gas. So, gas density here electron density, electron gas electron density.

V is the velocity, whatever velocity you have seen earlier. So, that is the velocity and lambda mean free path, and dE by dl. So, d E,E is the kinetic energy, E is the kinetic energy of the, E is the kinetic energy of this, electrons, and this change of kinetic energy. When it is change of kinetic energy, when it is passing through this length dl length.

So, this e, what is the kinetic energy e; that is 3 by 2 KB T right. So, dE by dl, it will be 3 by 2 K dT by dl . So, how much energy transferred, heat energy transferred from one end to the other end, where temperature difference is applied. So, from kinetic theory one can find out this, this is the amount of heat will transfer.

So, then these, I can replace these, I can replace with dl right. So, this will give me half n v lambda , this is let me write kB. Earlier we used kb. So, its kB dT by dl . So, this amount of q. So, this, now this one can write, its a constant, it is a constant term for a particular material metal. So, this per unit time, we have to remember this, you have defined per unit time per unit cross section, it is similar to this j, it is similar to j, you know this similar to j current density.

So, this k is called thermal conductivity. Now if you find k by sigma k by sigma or sigma by k, let me write sigma by k, because already sigma is here. So, by k means into 2 by, I do not know whether I can go out of the, yes, so keep it here. Now, here I will use that I think this is the better place.

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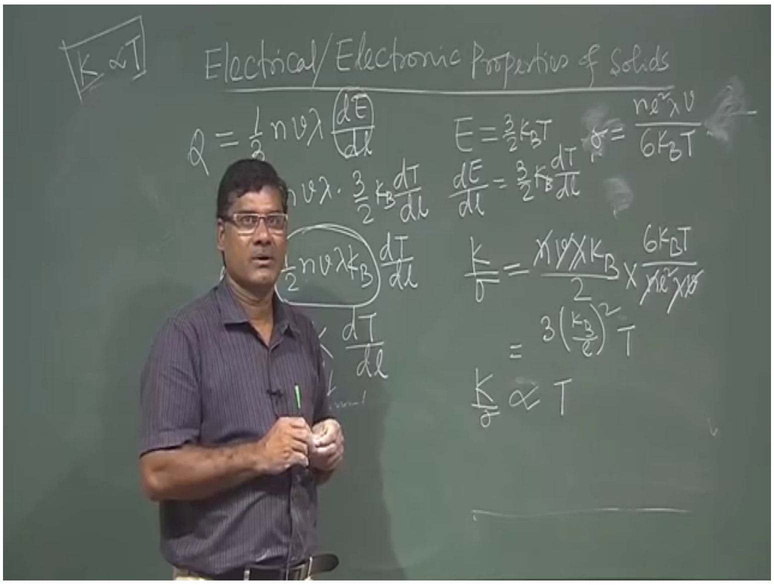

So, k by sigma, k by sigma ratio of thermal conductivity and electrical conductivity. So, this n nv lambda kB divide by 2 by sigma 6 KB T by n e square lambda v right. So, I will get 3. So, what I am getting n will go, v will go, lambda will go, and yes I am getting 3 kB by e square into T right into T.

So, obviously, this is that k Bb by sigma, it is proportional to T, and this proportionality constant is 3 k B by e whole square right. So, that is the Bridgman French Law as I mentioned. So, from the model free electron, gas model apply kinetic theory, one can get the proof of laws, which are experimentally verified. So, free electron model is very successful model to explain ohms law, to explain Bridgman French Law.

But it has drawbacks also, it cannot explain everything, it cannot explain the magnetic, this susceptibility, magnetic susceptibility of metal. This model cannot explain, it cannot explain this, why this mean free path for metal is very high. So, it can, 1 electron can move, can go the path of 10 to the power say 9 times of the lattice constant. So, why it is. So, transparent to electron metal is. So, transparent to electron. So, it can travel a very long distance, may be few centimeter without collision. So, why it. So, free electron model cannot explain them.

So, this model is quite successful for some cases, but it has drawbacks. So, reason is that there is a difference of, between the free electron gas and the gas atomic gas, because these are charge particle, and these are neutral particle for gas, and charge particle here.

Whatever distribution we have used, there we used some Maxwell Boltzmann statistics is used. So, that is good for the gas neutral gas, but that is not applicable to the, it is not applicable to the electron gas, because electron is charge particle, its called fermial ok.

So, for that this appropriate statistics is fermi dirac statistics. One has to use fermi dirac statistics instead of, can be Maxwell Boltz statistics, Boltzmann statistics. So, we have to go further to get the correct pictures of metal in term, for explaining the electrical or electronic properties of solid. So, we will continue in next class. So, let me stop here.

Thank you for your attention.