Solid State Physics
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Lecture - 34
Electrical Properties of Metal (Contd.)

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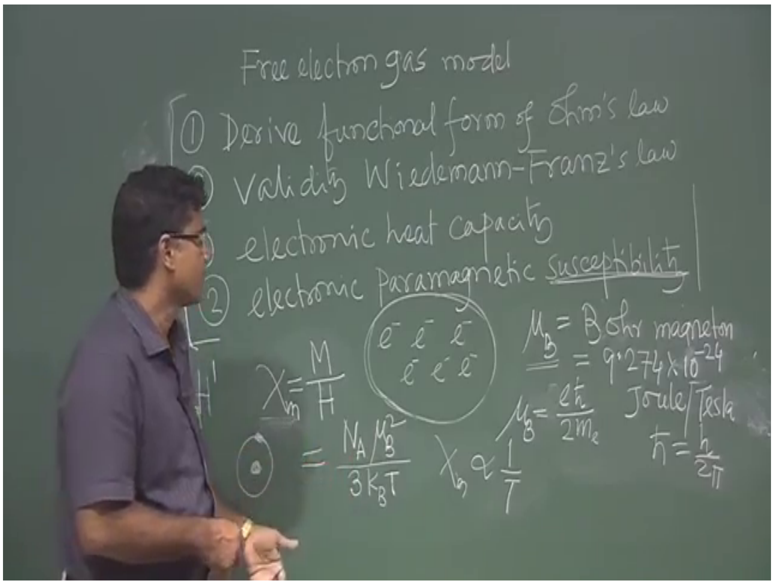

We will continue the free electron gas model for metals, as we have discussed that metals whose many properties as a function of temperature as a function of electric field as a function of magnetic field right, for to explain those properties. These free electron model is used and we have seen that that using this free electron model one can derive the Ohms one can derive functional form of Ohms law, also we have seen the validity of Wiedemann Franz law validity of right that conductivity thermal conductivity ratio of thermal conductivity and electrical conductivity that is proportional to T temperature.

These 2 are very famous law and frequently used and these 2 are completely defined on this free electron gas model or other way using the free electron gas model these 2 can be understood. This is the great success of free electron gas model, but the remarkable failure of this free electron gas model, this I can write success. This basically success and remarkable failure is one is heat capacity, electronic heat capacity or specific heat.

This is from free electron gas model, whatever heat capacity we get the degree with the experimental result and there is a big deviation. So, from free electron gas model we cannot explain this electronic heat capacity of metals. Second paramagnetic susceptibility, that also electronic contribution electronic paramagnetic susceptibility, whatever this result we get from this free electron gas model that also is thus the degree with the experimental result and not only (Refer time:05:45) huge deviation are observed.

These 2 also very important properties of metal and that cannot be explained using this free electron gas model. These are basically remarkable failure we tell although it had several success. Now, (Refer Time: 06:24) with the problem, that let us see first this, what was the result or heat capacity and susceptibility we get from the free electron gas model, this heat capacity do this that if you increase the temperature, to increase one degree temperature what amount of heat required for that material, there is the heat capacity.

This and for specific amount of heat material there will be it is specific heat it may be one gram mole or one gram, if you quantify the quantity then the specific heat otherwise as a whole this for whole mass, whole system, we tell the heat capacity right. So, free electron model is basically it is a we have free electron assembly of free electron in a box metal box means metal surface are there and inside electrons are there they cannot come out, but they can move freely inside the box, inside the metal.

If we apply heat on this metal, what will happen, it is it will absorb it and each electron will absorb heat right. If we increase at temperature T, this each electron will have energy absorb energy 3 by 2 KBT. So, basically that is equipartition energy law, how many is if I take one gram mole atom, it will have Avogadro number of atom, if each atom give one (Refer Time :09:25) electron have one (Refer Time :09:27) electron.

We will have this avagadro number of free electron right, each electron will have this energy 3 by 2 KBT it will absorb this amount of energy heat energy, then for one gram mole avagadro number of electrons are there, total energy of that system for that one gram mole it will be total energy E right. So, heat capacity is at C it is it will be basically dE by dT right for how much energy is required to change one degree temperature right, that is dE by dT.

So, that will be 3 by 2 NaKB right, this is the molar specific heat it is since it is quantity is defined one mole, it is called molar heat capacity or it is molar specific heat. So, from free electron theory we are getting that this, these will be the along of to this one can write 3 by 2 R, R is generally 2 calorie, it is around 3 calorie this specific heat will be 3 calorie or molar heat capacity will be 2 will be 3 calorie.

This value is very high compared to the experimental value whatever experimentally it is observed the value is observed. This value is quite high, because this heat capacity basically it has for metal it has 2 contributions, one is from lattice vibration and another is for from this electronic contribution. So, for insulating material it is seen that this or one gram mole one mole material insulating material the heat capacity is 6 calorie.

This for this metal that 6 calorie 3 R or 3 Rs, that will be there plus additional from electronic contribution this will (Refer Time: 13:10), total heat capacity of this metal should be around this value, but it is seen that, it is the, contribution for electric contribution in specific heat it is almost 50 percent right it is 50 percent, but it is seen that this contribution of electronic electron of metal, it is very very small. So, whatever the value is observed it is 100 of it is around 100 of this value.

It is the experimental value; it is deviated from the experimental value and thus this considering this free electron gas model, this electronic heat capacity we cannot explain right. So, that is one remarkable failure of this model and second is paramagnetic susceptibility, you know this there are 4 types of mainly 4 types of magnetic property one can see this one is Diamagnetic, another is Paramagnetic, third one is Ferromagnetic, and fourth one is Anti ferromagnetic right

These are the main magnetic property, everything we express in terms of one can express in terms of susceptibility, so susceptibility is defined as the chi susceptibility chi it is defined as magnetic movement or magnetization by magnetic field, while we apply magnetic field on a material. This magnetic movement of each atom or each electron, they aligned along the magnetic field direction.

So, because of magnetic field we get net magnetic movement we get net magnetic movement of that material and now this magnetic movement per unit volume that is defined as a magnetization. Magnetization divide by magnetic field at this magnetic field what was the magnetization, then that is the susceptibility. So, this susceptibility or this for metal one can, here just I mentioned this also all of them are can be differentiate using this term this susceptibility.

So, but I will not discuss about these all things I think when I will teach this magnetic property of solids then I will discuss. So, just here I want to mention about the susceptibility and susceptibility there important parameter which can tell about different kind of magnetic property. This susceptibility, chi equal to M by H, one can find out, if you take one gram mole material say metal, again.

Then I can write this molar susceptibility I m right, it has one gram mole material and this will have this metal will have the free electron, say it has avagadro number of atoms, avagadro number of electrons in free electrons will be there, if it is one balance electron per atom. In that case, avagadro number of electrons free electrons will be there and one can find out that this molar susceptibility it will be just let me write this expression NA, I will not derive just it comes NA mu B square divided by 3 KBT.

So, considering the free electron gas model it will take one gram mole, metal, in that case this molar susceptibility calculate this expression comes based on this free electron gas model. Here this is NA is avagadro number and mu B, what is mu B, mu B is called the Bohr magneton it is called Bohr magneton, this is very important universal constant, it is as important as this electronic charge e right electronic charge e.

Charge of electron it is basically one point 9 into 10 to the power minus 9 coulomb right charge of a one electron so, but we can express in terms of this unit e right, 2 e, 3 e, 5 e; that means, 5 times of charge of one electron. We can either express in terms of coulomb or we can express in terms of e, this is a universal constant. Similarly this mu B also for magnetic magnetism is very is universal unit; it is value is 9.274 into 10 to the power minus 24 Joule or Tesla, Joule per Tesla.

This is S I unit joule per tesla I think not able, joule per tesla joule per tesla still it is not going out of this, joule per tesla, that is S I unit basically. So, this, Bohr magneton (Refer Time:23:15) Bohr Magneton you know probably I do not know whether you are familiar with this or not, may be equal to e h cross by 2 M e, it is a mass of electron this is the electronic charge.

All are constant you know the value of e you know the h cross, h cross means h by 2 pi, plank constant mass of the electron. So, this expression this basically comes from this from Bohr orbit, when hydrogen in a ground state it has one electron, electron is in a one is orbital right this is a hydrogen atom one is, one electron is moving we know one electron is moving as I have shown earlier.

You can find out the magnetic movement and that magnetic movement is basically it comes this. So, that may be you can say that it is the magnetic movement of this electron of this hydrogen atom when the electron the atom is in ground state, atom is in ground state means, electron will rotate in the lowest energy state right. All the time it will be the for ground state it will be the in this orbit and then when it is rotating in that orbit, current is flowing in a close path. So, then one can calculate magnetic movement for this close path, that I have shown you earlier.

That basically whatever magnetic movement for this that is this is the value and that is taken as a unit. So, in terms of mu B one can express the magnetic movement of other atoms or material. Here this is the according to free electron gas model this is the expression and here you can see that is chi M is inversely proportional to temperature.

That is the result from free electron gas model, but experimentally it shows that metal non ferromagnetic metal non ferromagnetic normal metal, it is not ferromagnetic material non ferromagnetic metal. It generally this chi M is independent of temperature it does not depend on temperature, but free electron gas model is saying no it is inversely. It is a big deviation and it is whatever magnitude comes from here, these also very high compared to the experimental result experimental value.

Thus it is also big deviation from the experimental result and thus these free electron gas model also is failure or this or explaining the electronic paramagnetic susceptibility. This free electron gas model it is successful in some cases and it is failure also in other case. So, there is a it is not a very correct model, it has deficiency, what is that deficiency that we will see in next class, actually this whatever (Refer Time: 28:05) we have here we have done.

So, that considering this is the classical theory basically we have used classical theory or classical approach, this is not the right one, this system demands the quantum theory, when we will consider quantum theory, then we can explain everything based on that quantum theory, we will start this quantum theory in next class.

Thank you very much for your kind attention.