Solid State Physics
Lecture 31
Thermal Conductivity

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Ok. Now, let us find the Thermal Conductivity. So, thermal conductivity was expressed as κ and this can be estimated to be $\frac{1}{3}v^2\tau C_v$. And the correct specific heat is smaller than the classical guess by Drude. It is a factor $\frac{\epsilon_F}{k_BT}$ lower than the Drude's estimate, where we can write ${v_F}^2 = \frac{2\epsilon_F}{m}$, that this comes from the expression of kinetic energy where Fermi energy is the electronic kinetic energy, only we are considering free electrons. And this is the Fermi velocity, so this is just the expression for kinetic energy, nothing else. So, Fermi energy here is given using the Fermi velocity this way. And now let us consider the thermopower. Drude again overestimate the estimated the thermopower and Fermi-Dirac distribution, considering Fermi-Dirac distribution applicable on electrons improves this one as well. From the expression of specific heat, we can write the thermopower expression for the thermopower as $Q = -\frac{\pi^2}{6}\frac{k_B}{e}(\frac{k_BT}{\epsilon_F})$. This becomes the expression for thermopower which is of the order of $-1.42(\frac{k_BT}{\epsilon_F}) \times 10^{-4} Volt/K$, which is smaller than the Drude's estimate. How about the other properties? Other properties like DC and AC conductivity, these quantities remain almost unchanged because the Maxwell-Boltzmann statistics and Fermi-Dirac statistics does not really make a real difference in these two, except if we consider that the relaxation time depends on energy. If the relaxation time depends on energy, then the energy distribution function is different in Fermi-Dirac and Maxwell-Boltzmann distributions then that will change. And if we consider relaxation time depends on energy, then even the Drude expression that we obtained that will change significantly. At different temperature it will have different conductivity, AC and DC conductivity. And those conductivities will differ in Drude and Sommerfeld model. But if we do not consider temperature that is energy dependence of the relaxation time then those kind of differences do not come in. And we have found out the magnetoresistance, the Hall coefficient, these are the quantities that remain unaltered in Drude and Sommerfeld model as long as we are not considering any temperature dependence or energy dependence of the relaxation time. Well, we have learnt the free electron model the transport elementary, transport properties for free electrons considering the collision between electrons and the nuclei. And otherwise, the electron they move under the influence of the external electric field. So, what are the things that we could estimate correctly? Actually, nothing. None of the things that we estimated are to be accurate, are correct. But we still value these theories because from these we obtain some physical insight into the process, exactly what is happening. We made certain drastic approximations, we know where the approximations fail, what are the reasons for the approximations to fail, and we treat it in a semi classical way where we consider the quantum part of the indistinguishable particle statistics, but everything else is almost classical. In this kind of a scenario, we obtain, we generate certain insight into the problem. Otherwise, if we consider quantum state, if we try to write down or calculate the quantum state of the electrons its certainly very difficult. Imagine that you can do that accurately, even in that kind of a situation the physical insight that you obtain from that kind of a quantum approach is very little. It is very difficult to understand exactly what the wave function or the quantum state means. You can find out the properties, but the physical understanding would be missing. So, the main contribution of these models is providing us with the physical understanding of the process and of course, there are shortcomings of these models. The shortcomings are that we do not really estimate the Hall conductivity, Hall coefficient properly. Hall coefficient can be described better, magneto resistance can be described better. The temperature dependence of conductivity which we know that with increasing temperature conductivity decreases that is not captured in a linear way, that is not captured within this theory. And we also cannot explain why some of the materials are conductor's metals, while some are insulators, some are semiconductors, why situation is, why the situation is like that we cannot really understand from these theories. So, these are the major shortcomings of these three theories. And in future we will try to develop different theories to improve upon these. But these theories are still quite valuable because of the physical insight that it provides.