Carrier-Carrier Scattering in High-T_c Superconductors

Lee and Read[1] first proposed that the linear-in-T resistivity ρ of the high-T_c superconductors is due to carrier-carrier scattering. This scattering should also lead to a frequency dependence of the conductivity,[2] and the recent observations of Thomas *et al.*[3] are very suggestive in this respect.

The frequency dependence of the electron-electron scattering rate Γ is closely related to its temperature dependence. The carriers are spread over a range k_BT about the Fermi energy E_F, leading to $\Gamma \sim T^2$, and likewise $\Gamma \sim \omega^2$. Gurzhi and Kaganov[2] find $\Gamma \sim \omega_2^2$, where $\omega_n^2 = \omega^2 + (n\pi k_B T/h)^2$, and that $\Gamma \rightarrow 0$ if $\omega \gg E_F B$ (with B the bandwidth). This cannot, however, be the whole story. Since the system is causal, a frequency-dependent Γ must lead to a frequency-dependent mass renormalization m^*, which is given by a Kramers-Kronig relation. This m^* *cannot* simply be a function of ω_n.

Figure 1 shows that Γ found by Thomas *et al.*[3] scales as ω_1 (not as ω_2), except near the high-temperature saturation, for T between 70–270 K. The frequency-dependent m^* is also observed.[3] Away from saturation, Γ appears to be quadratic in ω_1. However, the data could also be fitted by a linear dependence, with a small quadratic correction. This latter form is consistent with the dc resistivity measured on these samples.[3]

This scaling has important consequences. First, this is very different from the frequency-dependent conductivity observed in heavy-fermion superconductors.[4] Moreover, in extracting the gap function from the low-T optical properties, it is essential to compare the superconducting reflectivity to the normal-state reflectivity at the same temperature.

The frequency dependence of m^* is readily understood in a Fermi-liquid picture. The strong linear-in-T electron-electron scattering is evidence that the hole Fermi surface is near the Van Hove singularity (VHS) in these materials.[1] To explain the low carrier density observed in Hall measurements, these carriers must be separated into two groups: a high density of heavy holes near the Van Hove singularity, with a few light holes associated with the rest of the Fermi surface.[5] The strong scattering of the heavy holes ensures that they become localized at low temperatures, contributing negligibly to the Hall effect. The T and ω dependence of m^* can be directly related to this localization since the effective carrier density is proportional to $\omega_p^2 m/m^*$. The role of additional free carriers associated with intact Cu-O chains[6] will probably complicate interpretation of $\sigma(\omega,T)$ in stoichiometric $Ba_2YCu_3O_7$.

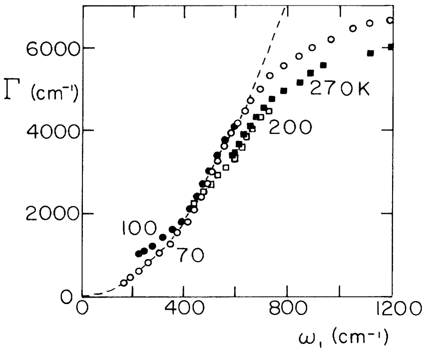

FIG. 1. Replot of data of Ref. 3, upper part of Fig. 4: Γ vs ω_1. Dashed line: $\Gamma \propto \omega_1^2$.

It should be stressed that the VHS can coincide with the Fermi level only at a fixed carrier density. Hence, if the VHS is important for high-T_c superconductivity, there must be an electronic or structural instability which pins the Fermi level at the Brillouin zone boundary, similar to the Hume-Rothery phases in alloys. This appears to be the case.[5]

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[1] P. A. Lee and N. Read, Phys. Rev. Lett. **58**, 2691 (1987); see also G. J. Morgan, M. A. Howson, and W. M. Temmerman, Solid State Commun. **65**, 231 (1988).

[2] R. N. Gurzhi and M. I. Kaganov, Zh. Eksp. Teor. Fiz. **49**, 941 (1965) [Sov. Phys. JETP **22**, 654 (1965)].

[3] G. A. Thomas, J. Orenstein, D. H. Rapkine, M. Capizzi, A. J. Millis, R. N. Bhatt, L. F. Schneemeyer, and J. V. Waszczak, Phys. Rev. Lett. **61**, 1313 (1988).

[4] B. C. Webb, A. J. Sievers, and T. Mihalisin, Phys. Rev. Lett. **57**, 1951 (1987).

[5] R. S. Markiewicz, Physica (Amsterdam) **153-5C**, 1181 (1988), and unpublished.

[6] R. S. Markiewicz, Phys. Rev. B **38**, 5010 (1988); J. C. Phillips, Phys. Rev. B **38**, 5019 (1988).