Theory of an Unusual Metal-Insulator Transition in Layered High-T_c Cuprates

Significance

The appearance of antiferromagnetism in layered high-T_c cuprates happens simul-taneously with the metal-insulator transition. More than that, in the metallic phase the Fermi surface is large and changes very little down to doping concentrations, where the transition takes place[1].The simplest tight-binding approximation for the planar electron spectrum leads to the conclusion, that at half-filling of the metallic Brillouin zone the Fermi surface has the shape of a square exactly fitting the Brillouin zone in the antiferromagnetic phase[2]. Therefore, the same, as in semimetals[3], the start can be done from an artificial and energetically unfavorable state, where at half-filling the electrons are "packed" in this square[4]. Then, due to nesting and exchange interaction, a spin-density wave (SDW) develops, which makes this state insulating and energetically favorable compared to the metallic state in a certain range of dopings.

The phase diagram in the plane of temperature and doping was calculated. Doping was described by the chemical potential. The phase transition from the insulating anti-ferromagnetic phase to a metallic paramagnetic phase proved to be a second order transition at small dopings and a first order transition at larger ones (figs. 1–3). The connection between the chemical potential and measurable physical properties was analyzed. In the metallic phase it defines, as usual, the volume enclosed within the Fermi surface, which is always large. In the insulating phase it defines the energy gap for thermal excitations. Next, the role of disorder was studied. It was shown that disorder reduces the antiferromagnetic region at the phase diagram but qualitatively does not change the nature of the transitions, namely, second order at smaller dopings and first order at larger ones.

Due to the large density of states above the gap in the insulating phase the quantity of excited quasiparticles at finite temperatures will be large. Therefore an interesting phenomenon is predicted[5]. At low frequencies the insulating phase reflects electromagnetic radiation, like a metal, whereas at somewhat higher frequencies it becomes transparent. The threshold frequency was calculated, as function of doping and temperature (figs. 4, a-c). It must be in the low infrared. A similar phenomenon was predicted by the present author in semimetals[6], and it was observed experimentally.

This theory explained two other unusual phenomena[7], [8]. One was found in NMR experiments[9]: appearance of antiferromagnetic "bubbles" around Zn, Ni and LI impurities in the metallic phase. The other, found in neutron diffraction experiments[10], was the existence in the metallic phase of the same spin ordering, as in the antiferromagneticphase, but with a 100 times smaller staggered magnetization. The first of these phenomena is due to the excess positive charge of the impurity ions causing the repulsion of holes. The second is due to the inhomogenity of doping concentration and appearance of underdoped "patches".

[1] H. Ding et al., Phys Rev. Lett. **78**, 2628 (1997)

[2] W. Pickett, Rev. Mod. Phys. **61**, 433 (1989)

[3] A. A. Abrikosov and L. A. Falkovsky, JETP **16**, 769 (1962)

[4] A. A. Abrikosov, Physica C **391**, 147 (2003)

[5] A. A. Abrikosov, Physica C, in press

[6] A. A. Abrikosov, JETP 17, 1372 (1963)

[7] A. A. Abrikosov, Physica C, in press

[8] A. A. Abrikosov, Physica C, in press

[9] A.V.Mahajan et al.,,arXiv: cond-mat/9909049v1

[10] J.A.Hodges et al..arXiv:cond-mat/0107218v2

Performers

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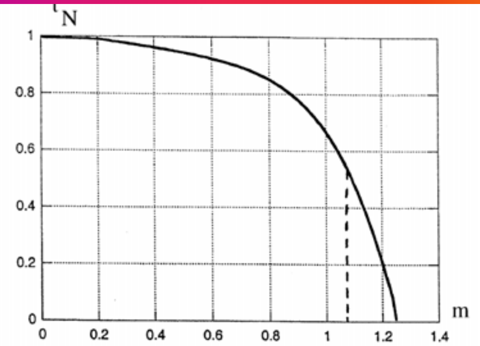
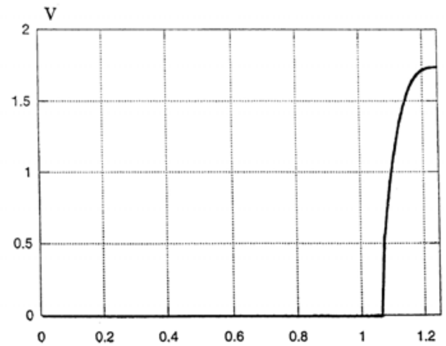
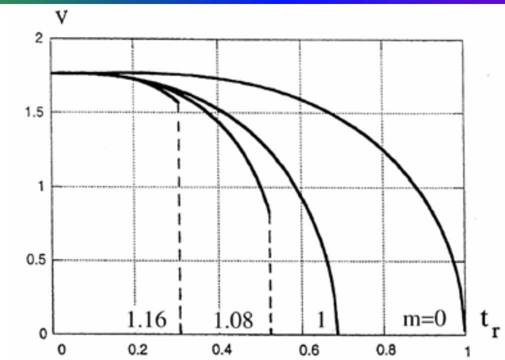


The Neel temperature $t_N = T_N/T_{N0}$ as function of doping (T_{N0} - the Neel temperature for zero doping). Doping is characterized by the reduced chemical potential $m = \mu/T_{N0}$. The dashed line is the boundary (tricritical point) between the second order (small m) and first order (large m) transitions.



Value of the staggered magnetization (reduced order parameter $\nu = V/T_{N0}$) at the transition point



Staggered magnetization v, as function of reduced temperature $t_r = T/T_{N0}$ for different values of m

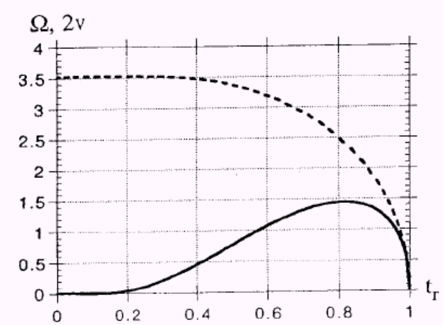
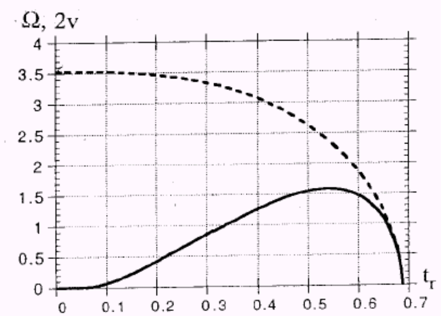
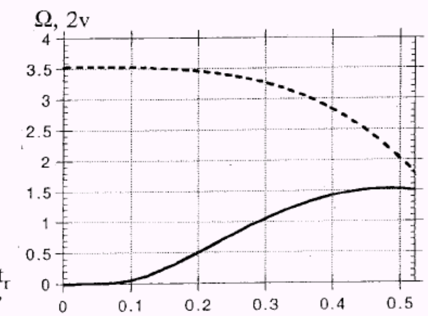


Fig. 4. a) The reduced transparency threshold frequency $\Omega = \omega_0/T_{N0}$ (solid line) and the reduced gap $2v = 2V/T_{N0}$ (dashed line) as function of reduced temperature $t_r = T/T_{N0}$ for $m = \mu/T_{N0} = 0$.



b) The same, as in a), for m = 1.



c) The same, as in a), for m = 1.08 (first orde: transition).

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