Theory of High-T_c Superconducting Cuprates Based on Experimental Evidence

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A model of superconductivity in layered high-temperature superconducting cuprates is proposed, based on the extended saddle point singularities in the electron spectrum, weak screening of the Coulomb interaction and phonon-mediated interaction between electrons plus a small short -range repulsion of Hund's, or spin-fluctuation, origin. This permits to explain the large values of T_c, features of the isotope effect on oxygen and copper, the existence of two types of the order parameter, the peak in the inelastic neutron scattering, the positive curvature of the upper critical field, as function of temperature etc.

1. Phonon-mediated interaction

The origin and the symmetry of the order parameter in the HTSC is the primary topic in the physics of high-temperature layered cuprates. The crystalline symmetry, even if it is assumed tetragonal, and the order parameter to be real (this follows from time-reversal symmetry), requires only that at a $\pi/2$ rotation in the ab-plane it either does not change, or changes its sign. Symmetry by itself does not tell us how many nodes must exist in either case, or whether the formula $\cos k_x - \cos k_y$ is correct. Therefore the only way to find the order parameter is to study the interaction between electrons, which leads to pairing. The high values of T_c and absence of the isotope effect in optimally doped $YB_2Cu_3O_{7-\delta}$ (YBCO) led to the conclusion that this interaction cannot be mediated by phonons. However the experiments by the groups of J. Franck and D. Morris [1], [2] showed that a partial substitution of Y by Pr, or of Ba by La leads to the increase of the isotope effect simultaneously with the decrease of the critical temperature, so that at $T_c \approx$ 40K $\alpha \approx 0.4$ ($T_c \propto M^{-\alpha}$) (Fig.1).

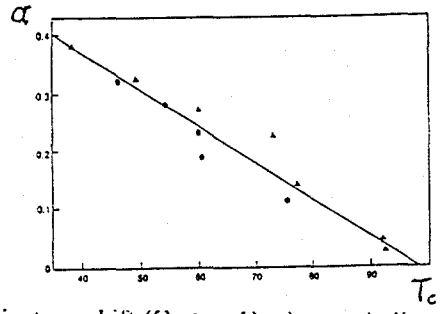

Fig.1. Experimental results for the isotope shift ($O_{16} \rightarrow O_{18}$) in partially substituted YBCO (Y$\rightarrow$ Pr, and Ba $\rightarrow$ La). The exponent α in $T_c \propto M^{-\alpha}$ is presented as function of T_c together with the linear regression.

An alternative appears: either these substituted compounds have a different mechanism of superconductivity

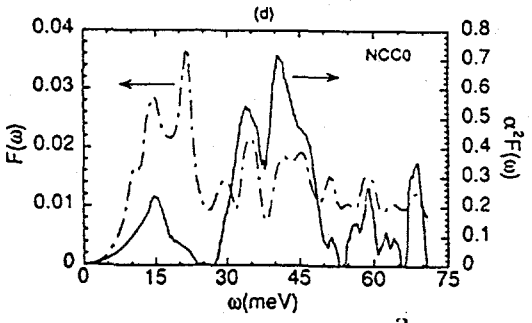

Fig. 2. Compilation of tunneling $\alpha^2F(\omega)$ for NCCO (solid line) and the phonon density of states $F(\omega)$ obtained from the inelastic neutron scattering from single-crystal NCCO

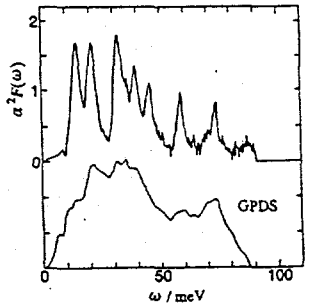

Fig. 3. The same, as in Fig. 2, for BSCCO. The lower curve is $F(\omega)$ from inelastic neutron scattering