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Van Hove scenario for high T_c superconductors

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Abstract

We give a general description of our approach which explains many physical properties in the superconducting and normal states of almost 2D high T_c superconductors (HTSC). This 2D character leads to the existence of Van Hove singularities or saddle points in the band structure of these compounds.

Keywords: High T_c superconductors; Van Hove singularities; Physical properties; Theory

Nineteen years after the discovery of the high temperature superconductivity in cuprates compounds [1], the exact mechanism of superconductivity is still not yet understood. All these compounds are strongly anisotropic and almost two dimensional, due to their CuO_2 planes, where superconductivity mainly occurs. It is well known that in two dimensions, electrons in a periodic potential show a logarithmic density of states (DOS), named Van Hove singularity (VHs) [2]. The Van Hove scenario is based on the assumption that, in high critical temperature superconductors cuprates (HTSC), the Fermi level (FL) lies close to such a singularity [3]. This hypothesis has been confirmed by many experiments, in particular by angular resolved photoemission spectroscopy in different compounds. We want to stress that the model of 2D itinerant electrons in presence of VHs in the band structure has already explained a certain number of experimental facts. In a review paper, we present our main results [4]: we compute the critical temperature T_c and the anisotropic superconducting gap [3,5,6]. We show the importance of screening and Coulomb repulsion [5]. We explain the anomalous isotope effect [3] the very small values of the coherence length [7,8]. We compute the DOS in these compounds and apply this result to the calculations of various physical parameters: the conductance of tunnelling junctions, the specific heat [6], the magnetic susceptibility [9].

The variation of all these properties with hole doping (from underdoped UD to overdoped OD samples) and temperature are obtained and compared with the experiments. The agreement is very satisfactory. The variation with the doping is linked to the distance of the FL from the singularity level ($E_F - E_S$), so does the variation with the temperature due to the Fermi–Dirac distribution. Transport properties in the normal state are described. We show that $E_F - E_S$ is critical for these properties, leading to Fermi liquid or marginal Fermi liquid [10]. We compute the Hall coefficient and its variation with doping and temperature [11]. We show that the experimental results may be explained by the topology of the Fermi surface (FS) which goes from hole-like to electron-like as the hole doping is increased. The critical doping, for which a topological transition is observed and calculated is $p = 0.21$ hole per CuO_2 plane (Figs. 1–7).

A so-called "pseudo-gap" is observed in the normal state of cuprates. These compounds are disordered metals if we refer to their coefficient of diffusion, which is very low. The Coulomb interaction between electrons must be taken into account as shown by Altshuler and Aronov [12]. The main effect is to open a dip in the DOS at the

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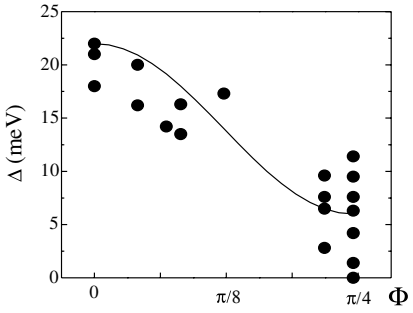

Fig. 1. Anisotropic superconducting gap.

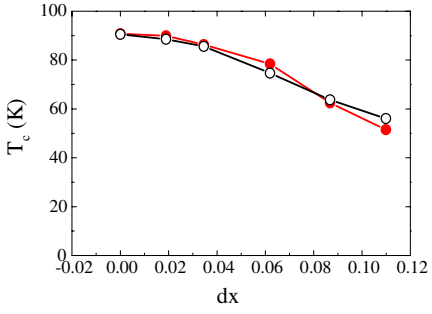

Fig. 2. Comparison of the variation of T_c versus the variation of doping dx calculated in our model (red filled circles) and the experimental results of Kŏike et al., Physica C 159 (1989) 105 (black open circles). (For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.)

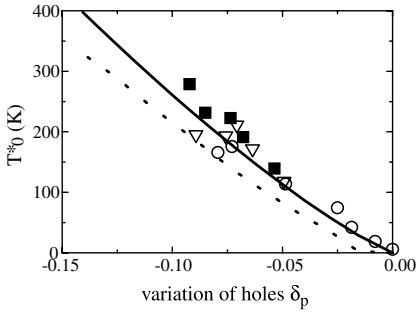

Fig. 3. The temperature, T° (directly linked to vHs), where the calculated ξ_p (dashed line) and the specific heat (solid line) go through a maximum, versus δp. For comparison we show results presented in Fig. 27 of R. Cooper, J. W. Loram, J. Phys. I France 6 (1996) 2237, the symbols are the same (solid squares: from thermoelectric power, circles: from specific heat, triangles: from NMR Knight shift data).

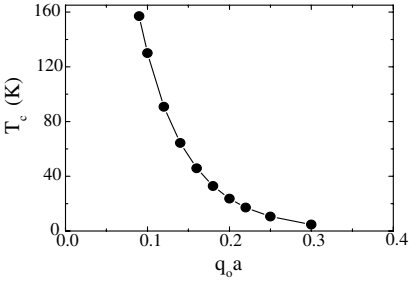

Fig. 4. T_c versus the screening parameter $q_0 a$.

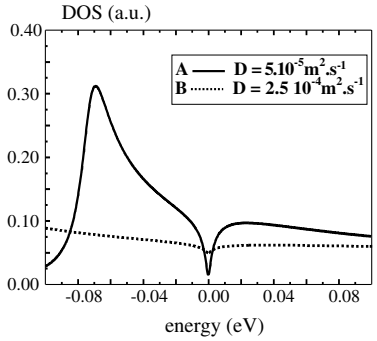

Fig. 5. Calculated DOS with Coulomb interaction with different sets of values of D: in the $(1,0)$ direction, and equivalent directions – B: in the $(1,1)$ direction.

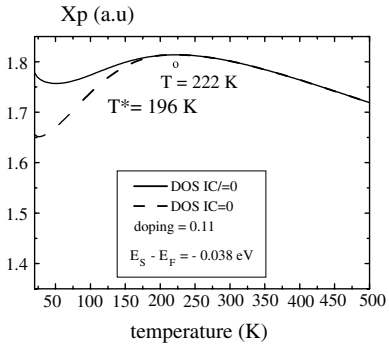

Fig. 6. Calculated Pauli susceptibilities. Full line, without disorder effect – Dashed line, with disorder effect, for 0.11 hole doping.

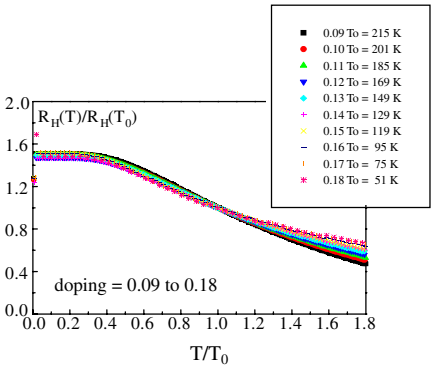

Fig. 7. Universal law $R_H(T)/R_H(T_0)$ versus T/T_0 for various hole doping levels, from 0.09 to 0.18.

FL. We show that this explains the observed features of the "pseudo-gap", value, anisotropy and variation with doping [13].

In conclusion we show that VHs play an important role in HTSC, and that by taking them into account, we may explain most of their normal and superconducting properties. We argue that the observed topological transition, occurring for $p = 0.21$ hole, is a crucial feature to explain the marginal properties of the cuprates, and especially the Hall effect.

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