Effect of Localization, Correlations, and Scattering from Magnetic Impurities on the Superconducting Critical Temperature

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The decrease of the critical temperature of high temperature superconductors due to disorder effects and correlations is considered. The disorder induced by impurities gives rise to localization which is strongly affected by the correlations and spin-dependent scattering. Such a mechanism gives rise to a strong depression of the critical temperature, which seems to be specific for the high temperature superconductors.

1. INTRODUCTION

One of the most important features of superconductors is that relatively small changes in composition may give rise to important effects on the critical temperature $T_c$. The influence of magnetic impurities has been described by the Abrikosov–Gor’kov pairbreaking theory which gives the dependence of $T_c$ on the concentration of impurities. The effect of the randomness due to non-magnetic impurities has been treated according to the Anderson theorem which states that there is no influence on $T_c$ due to non-magnetic impurities. However, in this theorem the interference effects between Bloch waves and the change of the matrix elements of the mutual interactions due to the absence of the translational symmetry in random system have been neglected. On the other hand the occurrence of magnetic correlations in the electronic system gives rise to a weakening of the attractive interaction near to the magnetic transition.

In this paper we will consider the effect of the disorder, magnetic correlations, and the scattering on the magnetic impurities on the critical temperature $T_c$. This is a very difficult problem and in order to calculate $T_c$ we will

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consider that the superconducting state will appear in a Fermi system with strong magnetic correlations and disorder due to impurities. The disorder effects will give rise to localization but the magnetic correlations and localization are competitive phenomena. This picture, valid for non-magnetic impurities, becomes more complicated for magnetic impurities. In this case we also have scattering from magnetic moments which acts against the magnetic correlations from the electronic system, but the magnetic correlations are working against localization due to the disorder.

In the standard BCS superconductors the Abrikosov–Gor’kov theory and the Anderson theorem work well but the discovery of the high temperature superconductivity (HTS) showed that these descriptions cannot explain the decrease of $T_c$. In the following we will mention some experimental results which indicate that the competition between magnetic correlations and the disordered effects may be important for HTS. The first remarkable effect given by the impurities is the strong depression of $T_c$ given by non-magnetic impurities. Indeed, it is well known, at the present time, that Zn, Li, and Ga give rise to a stronger depression in $T_c$ than Ni, Fe or Gd. The measurements of the electrical resistivity of the HTS containing impurities$^{1-6}$ showed the same temperature dependence as the HTS irradiated with neutrons$^{12}$ and this behaviour has been explained in terms of localization effects. The neutron scattering experiments,$^6$ the explanation of the results of the nuclear magnetic resonance (NMR)$^{7,8}$ and the tunneling data are consistent with the picture of the occurrence of superconductivity in a disordered Fermi liquid with magnetic correlations. The electronic spin resonance (ESR)$^{10-11}$ in HTS (YBa-CuO-containing Fe) showed the occurrence of local magnetic moments which are strongly disordered and may be located in the Cu(1) or Cu(2) positions.

These facts suggested that the magnetic correlations, localization and scattering from magnetic moments are important to the particular behavior of the HTS-containing impurities, but the results are valid for all superconductors in which magnetic correlations and disorder are present.

In order to have a (partial) realistic description of the mentioned effects on $T_c$ we have to consider: (i) the effect of localization given by impurities, (ii) the effect of magnetic correlations on the localization, and (iii) the effect of the scattering from the magnetic impurities on localization.

This is not a simple problem because each of these effects considered separately decreases $T_c$ but there is also a destructive effect of the magnetic correlations on the localization, as well as a destructive effect of the scattering from the local magnetic moments on the localization.

In the next section (Sec. 2) we will discuss the model which will be used to describe these effects.