Comment on "Anomalous Proximity Effect in Underdoped $YBa_2Cu_3O_{6+x}$ Josephson Junctions"

Recently Decca *et al.* [1] have reported an unusually long-ranged proximity effect (PE) between the superconducting and insulating phases of YBCO. These experiments have received lots of attention because they may help to discriminate between alternative scenarios for cuprate superconductivity [1,2]. However, later work [2] took for granted the claim [1] that such long range is anomalous. Here we point out that this is not warranted.

At the heart of our argument is the formula used in [1] to estimate the expected range of the PE, $\zeta \approx \zeta_0 \equiv \sqrt{\hbar D/2\pi k_B T}$, where D is the diffusion constant. Using this expression [1] obtains $\zeta = 15$ nm, which is indeed much smaller than the experimental value $\zeta^{\rm exp} = 90$ nm. However, the same formula agrees with earlier experiments on YBCO [3], which poses the question why it fails to account for the data of [1]. To answer we first note that $\zeta \approx \zeta_0$ is only the $V_N \rightarrow 0$ limit of the more general expression [4]

$$\frac{\zeta}{\zeta_0} = \int_0^\infty \frac{d\eta}{\pi\eta}\left[-\frac{\Sigma'}{\Sigma} + \frac{NV_N\Sigma'}{1 - V_N/V_S + NV_N\Sigma} + \frac{2}{\eta}\right] \quad (1)$$

for an interface of a superconductor and a normal conductor with coupling constants V_S and V_N, respectively. Σ is a function defined in [4] and N is the density of states at the Fermi level. A numerical evaluation of Eq. (1) is presented in Fig. 1. The key point is that in the experiments of [1] superconductivity is induced in part of an underdoped sample by photodoping. The PE thus takes place not between two different materials (as in standard experiments), or in an inhomogeneous material a region of which has been severely damaged in the creation of the normal region (as in [3]), but between two differently doped parts *of one and the same material.* The limit $V_N \rightarrow V_S$ is then more appropriate than $V_N \rightarrow 0$. In this limit Eq. (1) does predict $\zeta \gg \zeta_0$, suggesting that the long range is not an unconventional feature of YBCO.

At $V_N = V_S$ Eq. (1) predicts $\zeta \rightarrow \infty$. This infinity reflects the fact that in Eq. (1) the density of states is assumed to be the same on both sides of the interface ($N_N = N_S = N$), so that for $V_N = V_S$ both materials are identical. The restriction to $N_N = N_S$ can be overcome in the one-frequency approximation [5]. Numerical evaluation of Eq. (4.15b) of [5] yields the dashed curves in Fig. 1. Clearly, a large but finite value of ζ/ζ_0 is obtained, e.g., if $V_N \approx V_S$ and $N_S \gtrsim N_N$ [6].

In summary, although there are unconventional features in the experiments, the claim that the long range of the PE is one of them [1] seems presently unfounded. Conventional theory [4,5] predicts comparably long ranges, once the novel nature of the experiments is accounted for. We thus recommend performing similar experiments on conventional superconductors. The lines of thought on cuprate superconductivity stemming from the assumption that $\zeta^{\rm exp}$ is anomalously large [1,2] must also be critically reexamined.

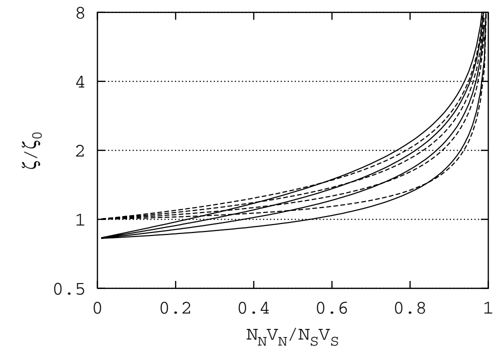

FIG. 1. Dependence of the range of the proximity effect on the parameters of the interface. Solid lines: results obtained from Eq. (1), valid for $N_S = N_N \equiv N$. Dashed lines: results obtained from Eq. (4.15b) of [5], valid also for $N_S \neq N_N$. Each line corresponds to a different value of $N_S V_S = 0.1, 0.2, 0.3, 0.4$ (from bottom to top).

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