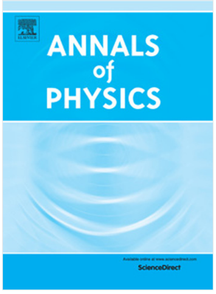

Finite temperature phase diagrams of a two-band model of superconductivity

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Finite Temperature Phase Diagrams of a Two-band Model of Superconductivity

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We explore the temperature effects in the superconducting phases of a hybridized two-band system. We show that for zero hybridization between the bands, there are two different critical temperatures. However, for any finite hybridization there is only one critical temperature at which the two gaps vanish simultaneously. We construct the phase diagrams of the critical temperature versus hybridization parameter α and critical temperature versus critical chemical potential asymmetry $\delta\mu$ between the bands, identifying the superconductor and normal phases in the system. We find an interesting reentrant behavior in the superconducting phase as the parameters α or $\delta\mu$, which drive the phase transitions, increase. We also find that for optimal values of both α and $\delta\mu$ there is a significant enhancement of the critical temperature of the model.

I. INTRODUCTION

Magnesium diboride (MgB_2) is a simple and, at the same time, unusual superconductor. Experimental measurements have indicated that MgB_2 has two distinct superconducting gaps [1–8], but only one critical temperature (T_c). With a $T_c \sim 40$ K [1] this metallic compound has the highest known critical temperature at *ambient* pressure amongst conventional superconductors.

Hybridization i.e., the mixing of atomic orbitals, plays an important role in the physics of multiband superconductors (see, for instance [9–16]). This seems to be also the case for MgB_2. Indeed, as shown in Ref. [17], the MgB_2 Fermi surface (FS) is determined by three orbitals, but only two different energy gaps are experimentally detected. This happens because two of the three orbitals hybridize among themselves and determine one single band, responsible for a large superconducting gap on the σ FS, while the non-hybridized orbital determines a smaller superconducting gap at the FS of the π band.

As pointed out in Ref. [18], besides MgB_2 the importance of multiband superconductivity has also been suggested to other materials as, for instance, simple metals [19, 20], and heavy fermion compounds [21–25].

The hybridization among orbitals can be symmetric or antisymmetric under inversion symmetry. It has been shown that symmetric (k-independent) hybridization acts in detriment of intra-band superconductivity [26, 27]. On the other hand, antisymmetric (k-dependent) hybridization enhances superconductivity [28]. It has been considered recently the cases at which two bands are formed by electronic orbitals with angular momentum, such that, the k-dependent hybridization $V(k)$ between them can be symmetric or antisymmetric [29]. Only intra-band attractive interactions have been taken into account in these two bands and the appearance of induced inter-band pairing gaps were investigated. It was shown that these inter-band superconducting orderings are induced even in the total absence of attractive interaction between the two bands, which turns out to be completely dependent on the hybridization between them. For the case of antisymmetric hybridization, which causes an odd-parity mixing between the a and b bands, the induced inter-band pairing gap that emerges in the hybridized bands has p-wave symmetry [29].

In this work we study the temperature effects on intra-band pairing gaps under the influence of the hybridization of two single bands, say a and b. We consider superconducting interactions only inside each band, resulting in intra-band pairing gaps Δ_a and Δ_b, respectively, in these bands. We take into account symmetric and antisymmetric $V(k)$. We find how the critical temperature of the hybridized system depend on the strength of the hybridization and on the particles chemical potential asymmetry. Based on these results, we construct the respective phase diagrams of the model and find an intriguing reentrant behavior. For optimal values of both α and $\delta\mu$ we find a significant enhancement of the critical temperature of the model.

The paper is organized as follows: In Sec. II we introduce the generic model Hamiltonian describing the two-band system. In Sec. III we obtain the diagonalized Hamiltonian and the grand thermodynamic potential of the model from which the gap equations for symmetric hybridization are derived. From the self-consistent solutions of the gap equations the critical temperatures and chemical potential asymmetries are obtained and from these results the corresponding phase diagrams are constructed. Sec. IV contains the same investigations of the previous section, but for antisymmetric hybridization. We conclude in Sec. V.