Superconductors

Beyond the Standard Model of Ginzburg-Landau Theory: Multiband Mookerjee, S.N. Bose National Centre for Basic Sciences, Kolkata, and Astronomy, Uppsala University, Uppsala, Sweden and A. superconductors [2].

We shall present a novel real space approach to study the effect of disorder on superconductivity in a multiband system modeled by a two-band attractive Hubbard model [1]. Our calculations reveal that in the presence of only intraband pairing with disorder in either or both bands, the gap survives in the quasiparticle spectrum ceases to exist beyond a critical value of disorder strength. In the presence of both interband and intraband pairing interaction, depending on the relative magnitude of the pairing strength, only a particular kind of pairing is possible for a half-filled two band system. Finally we shall discuss the relevance of these results for the impurity effects in the superconductivity of Fe based superconductors [2].

Work done in collaboration with S. Ganguly, Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden and A. Mookerjee, S.N. Bose National Centre for Basic Sciences, Kolkata, India


B7-01 Invited
Superconductivity in Multiband Disordered Systems
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B7-02 Invited
Beyond the Standard Model of Ginzburg-Landau Theory: Multiband Superconductors
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In the recent past a series of novel superconductors have been discovered, which have multi-band electronic structures. Such materials include Boro-carbides, MgB2, Pnicotides and others.

There have been attempts to use multi-band BCS mechanism to study these novel superconductors, where the inter-band coupling plays a dramatic role. This coupling produces a special type of collective modes, known as Leggett modes. In three-band superconductors with repulsive inter-band couplings, frustration between the bands can lead to an inherently complex gap function. We have investigated a new phase of time-reversal-broken symmetry state that appears as a phase transition from the conventional BCS state [1].

Since the traditional Ginzburg-Landau (GL) theory is a popular theory of conventional and multi-band superconductors, we have undertaken an extended GL version [2] of it systematically for the one and multi-band superconductors including many higher terms of expansion in \( \tau \) \( (\tau = 1/T_\tau) \). Several new features in gaps vs. temperatures are studied as the inter-band couplings vary. The theory is applied to a range of multiband materials.


B7-03 Keynote
Nanoscale superconductors

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When the dimensions of a superconductor are comparable to the Fermi wavelength, the superconducting properties are strongly affected by quantum confinement. For example, shape resonances appear and manifest as oscillations of the critical temperature and critical magnetic field with the lateral dimension. By numerically solving the Bogoliubov-de Gennes equations, we uncover several peculiar effects induced by quantum confinement. First we show that the vortex structure of a nanoscale superconducting square deviates from the conventional structure observed at mesoscopic scales, and depends on the ratio between the superconducting coherence length and the Fermi wavelength [1]. We found a plethora of unconventional vortex ground states and the tendency of forming multi-vortex rather than giant-vortex configurations [2]. A new Tomasch effect [3] is predicted which results from the confinement induced nonuniform distribution of the superconducting order parameter. This leads to oscillations in the density of states and a modulated wave pattern in the local density of states [4]. For a single vortex we predict that quantum confinement breaks the chirality of in-core fermions which prevents the collapse of the core of the vortex for \( T \to 0 \) (i.e. the Kramer-Pesch effect [5]) and as a result the core of a single quantum vortex extends at low temperatures [6]. The profile of the condensate mimics the one of a multi-quantum vortex.

If time permits, we will also present the effect of non-magnetic impurities and show that: 1) impurities strongly affect the superconducting properties, 2) the effect is impurity position-dependent, and 3) it exhibits opposite behavior for resonant and off-resonant wire widths [7].


B7-04 Invited
Exotic Superconductivity in Multi-Condensate Superconductors
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Multi-band superconductors exhibit many interesting properties. In N-gap superconductors, the \( \Omega(N) \) phase invariance is spontaneously broken. Important phenomena in multi-band superconductors are (1) the time-reversal symmetry breaking (TRSB), (2) the emergence of massless modes and (3) the existence of fractionalized-flux vortices. We consider a multi-band superconductor with interband frustrated Josephson couplings for general \( N > 2 \). (1) The gap functions are written as \( \Delta_j = \mid \Delta_j \mid \exp(i \theta_j) \) for \( j = 1, \cdots, N \). The Coulomb repulsive interaction turns the mode \( \Phi_0 \theta_1 + \cdots + \theta_N \) into a gapped plasma mode. Thus there are N-1 phase modes in superconductors. These modes are in general massive due to Josephson interactions. They will, however, become massless Nambu-Goldstone modes in the case with frustrated Josephson couplings. We show some typical models. We also discuss on massless modes which appear as a result of fluctuation effects. (2) When the gap functions are complex, the time-reversal symmetry is broken. In the simplest case of \( N = 3 \), the condition for TRSB has been obtained. When all the bands are equivalent, the chiral superconducting state is realized. We generalize this for general N by simplifying the Josephson couplings to some extent. The condition

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for TRSB is closely related to that for the existence of massless modes. We present some models which show TRSB.

(3) Fractional-flux vortices have been anticipated for multi-band superconductors. A fractional-flux vortex corresponds to a defect in the phase space and can be regarded as a monopole in superconductors.

**B7-05**

Vortex Dynamics in Multi-band Superconductors

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Over the years, dynamics and pinning of vortices in multiband iron superconductors has proved to be a subject of considerable interest. Large flux creep rate has been observed in iron selenium superconductors (Fe\(_{1+\delta}\) (Te\(_x\)Se\(_{1-x}\))) and also in other iron superconductors. Moreover, the vortex creep undergoes a transition from a single vortex to a three dimensional bundle creep regime. Theoretically such a study is still lacking.

To understand the dynamics of superconducting vortices we solve the time dependent Ginzburg Landau (TDGL) equations numerically using semi implicit Crank-Nicholson algorithm in which the vector potential is taken into account through real Link variables. The temporal evolution of the current density and magnetization and vortex dynamics are calculated. The computation of the relevant parameter space to explain the mechanism of flux creep and phase diagram demarcating the regions of single vortex and vortex bundle creep in the iron superconductors will be discussed.

We will also discuss about the effect of two length scales on the properties of another multi-band superconductor MgB2 for arbitrary applied magnetic field.