ANDREEV – SAINT JAMES REFLECTIONS AS A TOOL FOR THE STUDY OF UNCONVENTIONAL SUPERCONDUCTORS

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Abstract: Andreev – Saint James reflections have been observed at normal metal contacts and tunnel junctions with YBCO, LSCO, BSCCO and other High Temperature Superconductors. The characteristic feature of these reflections is an enhanced conductance at low bias. Its observation implies the existence of extended quasi-particle arcs around the nodal directions. The enhancement persists up to Tc and so far has not been observed above it. Return to the normal state conductance occurs at an energy that scales with Tc, including in the pseudogap regime. In YBCO, the detailed shape of the conductance at low bias is consistent with a pure d-wave symmetry of the order parameter in the optimally doped and underdoped regimes, and with a mixed symmetry in the overdoped one.

Key words: superconductivity; quasi-particles; pseudo-gap; bound states

1. INTRODUCTION

One of the clearest manifestations of the existence of electron pairs in the superconducting state is the enhancement by a factor of 2 of the conductance of a normal metal to superconductor contact at small bias. Although specifically described only in 1982 by Blonder, Tinkham and Klapwijk (1) (BTK), this enhancement follows directly from the reflection mechanism at the interface, described originally in chronological order by de Gennes and Saint James (2), Andreev (3) and Saint James (4). An incoming electron from the normal side N is reflected as a hole along the trajectory of the incoming electron, while a Cooper pair flows in the superconducting side S:

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a charge of 2e flows on both sides of the contact, compared with a charge of e in the normal state (above Tc, or at a bias larger than the gap). The conversion from quasi-particles to pairs takes place over a coherence length. Two fundamental conditions are essential for this mechanism to take place. First of all, there must exist quasi-particle excitations on the S side that can match those on the N side. Second of all, the velocity of these quasi-particles must be nearly equal to each other, otherwise normal reflections at the interface will dominate. The mere observation of an enhanced low bias conductance at normal metal – HTS contacts introduces therefore important constraints on HTS theories.

When the N side of the contact has a finite thickness d_N, an interesting cycle, first described explicitly by Saint James (4), takes place. After being reflected at the interface as a hole, the particle undergoes a normal reflection at the free surface of N, comes back to the interface, is reflected as a hole, which itself is normal reflected at the free surface, thus completing the cycle. During this Saint James cycle, composed of four legs instead of two for a usual particle in a potential well, the particle is an electron half of the time, and a hole the other half, a hall mark of an excitation in a superconductor at the gap edge. Solutions are bound states of finite energy in N, decaying over a coherence length in S. As first shown by Hu (5), the situation is different when S is a d-wave superconductor, and the normal to the interface corresponds to a node direction. Then, the Saint James cycle has for solution zero energy states. This is because of the difference of phase of π of the order parameter, between the two successive reflections at the interface. Note that these zero energy states persist down to $d_N = 0$. Thus, in addition to being sensitive to the nature and the velocity of the electronic excitations in S, the experiment is also a powerful tool for the study of the symmetry of the order parameter. Because of the chronological order of the publications, and the importance of the Saint James cycle, we propose to use the name "Andreev – Saint James reflections", or in short ASJ reflections.

2. ASJ REFLECTIONS ALONG ANTI NODAL DIRECTIONS

Experiments performed along the anti-nodal direction using point contacts on a variety of cuprates at or near optimum doping such as YBCO (6,7) have shown an enhanced zero bias conductance up to a rather well defined gap edge. These early results established the existence of quasi particles in the cuprates for that range of doping. They may not be compatible with theories of the normal state such as RVB in which the charge and spin degrees of freedom are separated. However, RVB has not