Pairing mechanism of high-T_c cuprates

Takao Morinari
Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

A pairing mechanism of high-T_c superconductivity is proposed. We take a model Hamiltonian in which the spin of hole at O sites interacts with the localized spin at Cu sites via Kondo coupling. In addition, we include a spin-orbit coupling term arising from the buckling of CuO_2 plane. Since the spin of hole is twisted by this term in the hopping process, frustration is introduced in localized spin system.

In the presence of the spin-orbit coupling term, a Chern-Simons term for the gauge field describing the phase fluctuation of the spin system is induced. In contrast to anyon superconductivity, this Chern-Simons term does not imply the time-reversal symmetry breaking because the Berry phase arising from the Chern-Simons gauge flux is 2π, which leads to a fermion to fermion mapping. Through this Chern-Simons term holes behave like skyrmion excitations, which introduce disorder in the spin system.

Some implications of the theory are listed below.

1. **Destruction of AFLRO and Metal-Insulator transition**
   In the presence of the antiferromagnetic long range order(AFLRO), holes are pinned because of the excitation gap of skyrmions. Since holes behave like skyrmion excitations, upon hole doping disorder in the spin system increases. At the phase transition point from Néel ordered state to a spin disordered state, a metal-insulator transition occurs because at this point the skyrmion excitation gap vanishes.

2. **$d_{x^2-y^2}$ wave superconductivity**
   After AFLRO is destroyed, superconductivity occurs. The pairing interaction is a "Lorentz" force. Such an interaction induces a chiral pairing state and there are two kind of Cooper pairs with opposite chiralities because of the antiferromagnetic correlation. We can show that the combination of them leads to the $d_{x^2-y^2}$-wave superconductivity.

3. **Suppression of superconductivity at structural phase transition point and $x = 1/8$ problem**
   Above scenario can be applied only for the orthorhombic phase. In tetragonal phases, there is no Chern-Simons term. So we can not apply above scenario to the tetragonal phase. Superconductivity is suppressed at the structural phase transition point between them, for example, at $x = 1/8$ in $La_{2-x}Ba_xCuO_4$ system.

4. **Neutron resonance peak at 41meV**
   Since there are two kind of Cooper pairs with opposite chirality and they are displaced by $\mathbf{Q} = (\pi, \pi)$ in momentum space, there is an quasi particle excitation with $\omega = 2\Delta$ and $\mathbf{q} = \mathbf{Q}$. (Δ is the gap of superconductivity.) This excitation may be identified with the experimentally observed 41meV peak at (π, π) in neutron scattering.