Hole pairing symmetry in attractive Hubbard model.

C. Wang, O. Navarro, R. Oviedo-Roa, and L.A. Pérez.
Instituto de Investigaciones en Materiales, UNAM, A. P. 70-360, 04510, México D.F., MEXICO.

Geometrical effects on the pairing process between electrons and between holes are comparatively studied by using an attractive Hubbard Hamiltonian. For triangular lattices, it is found that the hole pairing is always stronger than the electron case due to the frustration of anti-bonding states; contrary to that occurred in bipartite lattices, where there is a complete symmetry between the electron and hole pairings. The ground state of two holes, when the attractive nearest-neighbor interaction is dominant, is surprisingly triplet and its wave function has directional nodes. On the other hand, the hole pairing in disordered lattices is analyzed and the results show an enhancement of the pair-binding energy as the self-energy difference increases in a random binary alloy $A_x B_{1-x}$. This fact suggests that the pairing process is highly sensitive to the one-particle localization condition. The ground-state phase diagram for the case of on-site interaction disorder shows regions where pairing is avoid for ordered diatomic systems but not for disordered cases.

For high-T_c superconductors, hole pairing, low dimensionality and random doping seem to be important elements to consider [1]. The real-space electronic correlation has been extensively studied by using the Hubbard model [2]. It has the advantage of being simple and general, because it does not depend explicitly on the nature of interactions between particles. Recently, we have introduced a new mapping method [3], which consists on mapping the original many-body problem onto a tight-binding one with some ordered impurities in an nd-dimensional space, being n the number of electrons and d the dimensionality of original system. In this hyper-space lattice, the on-site (U) and the nearest neighbor (V) interactions of the original Hamiltonian become the self-energies of the impurities.
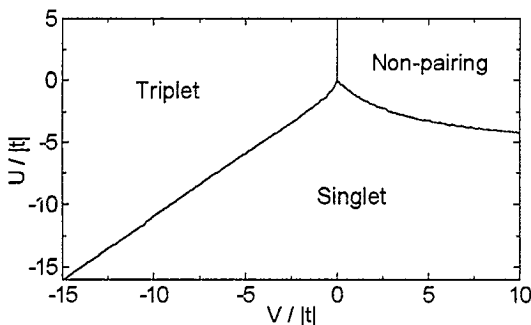

Figure 1. Ground-state phase diagram for two holes in a triangular lattice.

When a particle-hole transformation [4] is made in the extended Hubbard Hamiltonian, the holes also interact via the same Hamiltonian, except that the sign of the hopping matrix (t) is opposite and the density of holes is $1 - n$ in terms of the electron density (n). Therefore, this transformation becomes symmetric when the number of holes is equal to the number of particles and when the sign of t is irrelevant as in the cases of ordered and disordered bipartite lattices.

For the two-particle case on a triangular lattice, we have found an asymmetry between the electron pairing and the hole pairing, where the latter is always stronger due to the frustration of the anti-bonding states [5]. In Fig. 1 a ground-state phase diagram for hole pairing is shown. We can see that the pairs are singlets when U is dominant, while they are triplets in the V-dominant region. The transition between singlet and triplet bound states in the strong interaction regime can be obtained analytically and it is given by $U = V - t$ [5]. Finally, the transition between triplet and non-pairing states occurs exactly at $V = 0$, because there is no influence of U on the triplet formation. Although there is no triplet superconductivity observed up today, triplet fermion-pairing is well known, for instance, the superfluid state of ^{3}He [6], where the fermionic ^{3}He atoms form p-wave spin-triplet pairs. Another interesting result is that the triplet ground state has

directional nodes, *i.e.*, the corresponding wave function of pairs has null amplitude along several directions, similar to the recently observed d-wave pairing symmetry [7], where directional nodes or a phase shift of π predicted by the $d_{x^2-y^2}$ pairing state is found.
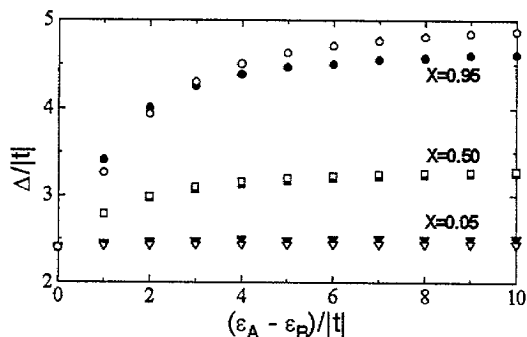

Figure 2. Comparison between the CPA (open symbols) and ensemble-average (solid symbols) results of the pairing energy (Δ) as a function of the difference of self-energies for alloys A_xB_{1-x}.

On the other hand, in order to analyze the effects of disorder on the hole pairing in low-dimensional systems, we have applied [8] the coherent potential approximation (CPA) to the hyper-space lattice of a disordered binary chain A_xB_{1-x}, since in this space we have just a single-particle tight-binding problem. To verify the CPA results we have performed the average of the Green's function over all possible configurations for lattices of few atoms.

In Fig. 2 the CPA results are compared with those obtained from the ensemble-average calculation. Notice that there is an asymmetry with respect to $x = 0.5$. It is unexpected because lattices entirely formed by atoms A or B should have the same pairing behavior. This asymmetry is caused by the confinement effect, since it is enhanced when self-energies $\epsilon_A > \epsilon_B$ and A-atom concentration increases. For the case of disorder in hole-hole interactions (U_A and U_B), Fig. 3 shows the two-hole ground-state phase diagram for $U_A > 0$, $U_B < 0$, and $x = 0.5$, in which the lower curve indicates the transition between pairing and non-pairing within the CPA and the upper one represents the same transition obtained from an ordered diatomic chain. The latter curve

coincide with those calculated by Alexandrov, *et al.*[9]. Notice that there is an intermediate region where the electron pairing is avoided for the diatomic ordered case, but not for disordered systems. This fact is due to that the pairing states, or impurity states in hyper-space, are proper only for attractive-interaction atoms (B) and then the extension of B-atom clusters in the system could be essential for the binding energy.

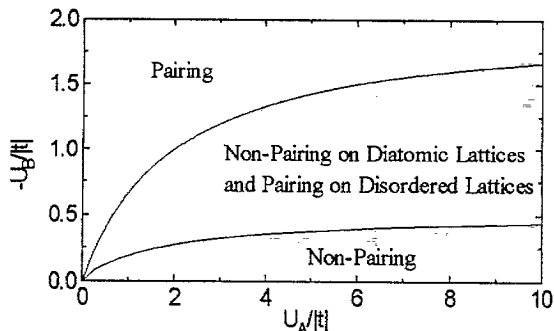Figure 3. Two-hole ground-state phase diagram for ordered and disordered diatomic chains.

REFERENCES

1. E. Dagotto, *Rev. Mod. Phys.* **66** (1994) 763.
2. R. Micnas, *et al.*, *Rev. Mod. Phys.* **62** (1990) 113.
3. O. Navarro and C. Wang, *Solid State Commun.* **83** (1992) 473.
4. M.W. Long, in *The Hubbard Model (Recent Results)*, edited by M. Rasetti (World Scientific, 1991), p. 1.
5. L.A. Pérez, *et al.*, *Phys. Rev. B* **53** (1996) 15389.
6. P. Schiffer and D.D. Osheroff, *Rev. Mod. Phys.* **67**, 491 (1995).
7. D.A. Wollman, *et al.*, *Phys. Rev. Lett.* **71**, 2134 (1993); C.C. Tsuei, *et al.*, *ibid.* **73**, 593 (1994).
8. R. Oviedo-Roa, *et al.*, *J. Low Temp. Phys.* **105** (1996) 651.
9. A.S. Alexandrov, *et al.*, *J. Phys.: Condens. Matter.* **4** (1992) L89.