Order parameters in the cuprate superconductors and the new fermion index

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We perform a systematic microscopic study of order parameters such as charge density wave (CDW) and pair density wave (PDW) for the copper oxide high T_c superconductors (cuprates). There are ample relevant experimental data on these order parameters, calling for elucidation of their origin, and pointing to concrete directions for the understanding of the true ground states in these important materials.

In our previous work G. Kastrinakis, Ann. Phys. **349**, 100 (2014), hereafter (I), the new fermion index was introduced. This is, roughly, an additional degree of freedom for all fermions, and for the electrons in particular. It allows for complex correlations between electrons to be systematically accounted for, something which is otherwise impossible in the thermodynamic limit. This index has no classical analogue, does not correspond to an observable, and is consistent with known fermionic physics.

In this work, we treat a single band model for the cuprates. We use realistic band structures and realistic (non-separable) fully momentum dependent electron-electron potentials.

Using the new index, we assume simultaneous correlations between singlet electron pairs with momenta $(k, -k)$, (k, k_*), and $(k, -k_*)$, where $k_* = (k_x, -k_y)$. These correlations are incorporated in an appropriate variational wavefunction, as in (I). There is no a priori restriction on the momenta k which may (or not) participate in these correlations, which are responsible for charge density wave and pair density wave orders. This procedure allows for the (highly complex) self-consistent numerical calculation of the ground state and, subsequently, of various observables.

We compare our results for charge density wave and pair density wave orders with relevant (uni-directional etc.) experimental data (X-ray diffraction, nuclear magnetic resonance etc.) for a range of system parameters. These include the electron filling factor, the band structure parameters, and the type and strength of the potential used. The ground states have characteristic unusual fermionic occupation factors equal to *one half* (instead of unity - c.f. (I)) deep below the Fermi surface.

[l] G. Kastrinakis, Ann. Phys. **349**, 100 (2014).