D-wave superconductivity in boson+fermion dimer models

G. Goldstein[1], C. Chamon[2], C. Castelnovo[3]

[1]University of Cambridge

[2]Boston University

[3]University of Cambridge

The Rokhsar-Kivelson quantum dimer model (QDM) originally was introduced to describe a possible magnetically disordered phase - the resonating valence-bond phase in high-temperature superconducting materials. The arena where the QDM has been deployed has greatly expanded since its inception, and the model has taken on a key role in the study of a variety of magnetic quantum systems. The study of QDMs led to an abundance of new phenomena including deconfined quantum criticality and new routes to deconfinement. It also provided one of the earliest known examples of topologically ordered states in a lattice model.

Recently QDMs have been revisited as models of high-temperature superconductivity. This was motivated by the need to reconcile transport experiments and photoemission data in the underdoped region of cuprate superconductors: Whereas photoemission data show Fermi arcs enclosing an area 1+p (with p being the doping), transport measurements indicate plain Fermi-liquid properties consistent with an area p. In order to resolve this issue and produce a Fermi liquid which encloses an area p, Punk et al. [PNAS 112, 9552 (2015)] introduced a model for the pseudogap region of the cuprate superconductors which consists of two types of dimers: one spinless bosonic dimer representing a valence bond between two neighboring spins and one spin-1/2 fermionic dimer representing a hole delocalized between two sites. The boson+fermion QDM (bfQDM) was introduced and studied numerically using exact diagonalization, supporting the existence of a fractionalized Fermi liquid enclosing an area p.

We present a slave boson and fermion formulation of the bfQDM. We find that four symmetric fermion pockets, located in the vicinity of $(\pm\pi/2, \pm\pi/2)$ in the Brillouin zone, naturally appear at mean-field level. The total area of the four pockets is given by the hole (fermionic) doping, for a range of parameters consistent with the t-J model for high temperature superconductivity. We find that the system is unstable to d-wave superconductivity at low temperatures. The region of the phase diagram with d-wave rather than s-wave superconductivity matches well the region with four fermion pockets. In the superconducting phase, the fermionic dimers (holes) acquire a Dirac dispersion at eight points along the diagonals of the Brillouin zone.

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