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Evolution of Fermion Pairing from Three to Two Dimensions¹

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The behavior of interacting fermions in two dimensions has long been of great interest. Unconventional superconductivity in high-transition-temperature superconductors arises in the two-dimensional cooper-oxide planes, with only weak intralayer coupling. Layered organic conductors and certain heavy-fermion superconductors also feature a quasi-2D structure, with strongly anisotropic conductivity. In two dimensions, the role of thermal and quantum fluctuations is enhanced, destroying long-range order and leading to algebraic decay of the order parameter. On the other hand, in quantum mechanics, two particles in vacuum with arbitrarily weak interactions may still bind in two dimensions, while binding of weakly interacting fermions in three dimensions requires a many-body effect, Cooper pairing. It is thus interesting to ask whether superconductivity or superfluidity is enhanced somewhere in between two and three dimensions. In recent years, experiments on ultracold gases of fermionic atoms in three dimensions have allowed access to the crossover from Bose-Einstein condensation (BEC) of tightly-bound fermion pairs to Bardeen-Cooper-Schrieffer (BCS) superfluidity of long-range Cooper pairs. Such a fermion pair superfluid loaded into a periodic potential should form stacks of two-dimensional superfluids with tunable interlayer coupling, an ideal model for Josephson-coupled quasi-2D superconductors. For deep potentials in the regime of uncoupled 2D layers, increasing the temperature of the gas is expected to destroy superfluidity through the Berezinskii-Kosterlitz-Thouless mechanism, while more exotic multi-plane vortex loop excitations are predicted for a 3D-anisotropic BCS superfluid near the critical point. In this talk I will present our recent experiments, where we follow the evolution of fermion pairing in the dimensional crossover from 3D to 2D as a strongly interacting Fermi gas of ^6Li atoms becomes confined to a stack of two-dimensional layers formed by a one-dimensional optical lattice. Decreasing the dimensionality leads to the opening of a gap in radio-frequency spectra, even on the Bardeen-Cooper-Schrieffer side of a Feshbach resonance. The measured binding energy of fermion pairs closely follows the theoretical prediction for the binding of two particles in isolation. In the two-dimensional limit, it is in surprising agreement with zero-temperature mean-field BEC-BCS crossover theory that predicts the energy threshold for radio-frequency dissociation to lie at the two-body binding energy.

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