Local Pairs That Refuse to Localize: Strong-Coupling Superconductivity with Coherent Charge Motion

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Superconducting length scales, including the coherence length and penetration depth, are fundamental to the characterization of superconductors, as they govern critical fields, currents, and electromagnetic responses. Despite their central role, these quantities are rarely calculated in theoretical studies, particularly in strongly correlated materials. Here, we introduce a general framework to compute superconducting length scales, alongside the depairing current, from microscopic theories by probing the response of the superconducting state to a finite center-of-mass pairing momentum [1].

We apply this method within dynamical mean-field theory to investigate strongly correlated superconductivity in a three-orbital model of alkali-doped fullerides (A_3C_{60}), where an inverted Hund's coupling drives local *s*-wave pairing [2,3]. Increasing the pairing strength drives the system into an extended strong-coupling regime with highly localized pairs and a short coherence length, while the superconducting stiffness remains robust. The critical temperature is enhanced by more than an order of magnitude relative to the interaction parameters relevant to conventional A_3C_{60} and reaches a maximum upon tuning the system into an inverted local-valence configuration. This behavior originates from distinct energy scales for local pair binding and coherent charge motion, accompanied by a strongly truncated low-energy local Hilbert space.

A complementary, analytically tractable Gutzwiller description of this restricted low-energy manifold provides further insight into the enhanced T_c and resilient coherence. Stronger pairing increases the weight of local pair configurations, while coherent charge motion requires intermediate configurations that provide delocalization pathways at a minimal charge-excitation cost. The resulting balance optimizes the condensation energy and makes it predominantly kinetic-energy driven throughout the strong-coupling regime and purely kinetic at the condensation-energy optimum and along the charge-degeneracy line. These results reveal a distinct route to strongly correlated superconductivity in which strong local pairing and coherent electronic motion coexist without the kinetic-energy suppression usually associated with conventional strong-coupling limits.

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