

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

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Superconducting length scales govern critical fields, currents, and electromagnetic responses, yet they are rarely calculated for strongly correlated materials. We introduce a general framework to obtain the coherence length, penetration depth, and depairing current from microscopic theories via the response to a finite pairing momentum [1].

Applying it within dynamical mean-field theory to a three-orbital model of alkali-doped fullerenes (A_3C_{60}), where an inverted Hund's coupling drives local s -wave pairing [2,3], we find an extended strong-coupling regime with highly localized pairs but robust superconducting stiffness upon increasing the pairing strength. T_c is enhanced by more than an order of magnitude and reaches its maximum when the system is tuned 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 Gutzwiller analysis of this restricted manifold shows that stronger pairing increases the weight of local pair configurations, while coherent charge motion requires intermediate configurations that provide delocalization pathways at minimal charge-excitation cost. This balance optimizes the condensation energy, which remains predominantly kinetic-energy driven throughout the strong-coupling regime. These results identify a route to strong-coupling superconductivity in which charge motion is no longer limited by the pairing scale.

[1] N. Witt et al., npj Quantum Mater. **9**, 100 (2024).

[2] M. Capone et al., Rev. Mod. Phys. **81**, 943 (2009).

[3] Y. Nomura et al., Sci. Adv. **1**, e1500568 (2015).