

Local Pairs That Refuse to Localize: Strong-Coupling Superconductivity with Resilient Coherence

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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 fullerenes (A_3C_{60}), where an inverted Hund's coupling, J , drives local s-wave pairing [2,3]. Increasing the inverted Hund's coupling drives the system into a strong-coupling regime with highly localized pairs and 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} in an extended region in the U - J plane of the phase diagram. Highest critical temperatures are realized closely to the line, $U = 2|J|$, where three valencies become degenerate. In contrast to the lattice BEC limit, where the superconducting critical temperature is suppressed inversely proportional to the coupling constant, we find persistent high- T_c superconductivity in the strong coupling limit of $U = 2|J| \rightarrow \infty$. An analytic understanding of this limit is given.

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

[2] M. Capone, M. Fabrizio, C. Castellani, and E. Tosatti, Rev. Mod. Phys. 81, 943 (2009)

[3] Y. Nomura, S. Sakai, M. Capone, and R. Arita, Sci. Adv. 1, e1500568 (2015)