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Phase diagram for strong-coupling Bose polarons

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Important properties of complex quantum many-body systems and their phase diagrams can often already be inferred from the impurity limit. The Bose polaron problem describing an impurity atom immersed in a BEC is a paradigmatic example. However, its description at strong coupling is challenging due to the intricate competition between the emergent impurity-mediated attraction between the bosons and their intrinsic repulsion. Using a Gaussian-state variational technique, including fully the boson-impurity and the boson-boson interactions, we find two regimes of qualitatively different behavior for a sweep of the boson-impurity interaction strength. If the impurity-mediated interactions overcome the repulsion between the bosons, the polaron becomes unstable due to the formation of large bound clusters [1,2]. If instead the interboson interactions dominate, the impurity will experience a crossover from a polaron into a small molecule. We achieve a unified understanding [3] incorporating both of these regimes and the transition between them and show that these features are accessible in realistic cold-atom experiments. Moreover, we develop a simple analytical model that allows us to interpret these phenomena in the typical Landau framework of phase transitions, revealing a deep connection of the Bose polaron model to both few- and many-body physics.

[1] A. Christianen, J.I. Cirac, R. Schmidt, Phys. Rev. Lett. 128, 183401 (2022)
[2] A. Christianen, J.I. Cirac, R. Schmidt, Phys. Rev. A 105, 053302 (2022)
[3] A. Christianen, J.I. Cirac, R. Schmidt, arXiv:2306.09075 (2023)

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