Novel droplet phase of exciton-polariton mixtures in atomically thin semiconductors

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Quantum droplets are self-bound low density configurations which may appear in ultracold gases with competing interactions. Dilute bosonic mixtures, where the attractive mean-field energy is balanced by the repulsive Lee-Huang-Yang correction stemming from quantum fluctuations, are the prototypical platform where this novel state has been first predicted [1] and shortly after experimentally observed [2, 3]. Since then, quantum droplets have gained significant interest and their study has been extended to various cold-atomic settings.

In this talk, I will show how a similar scenario arises in solid-state systems, as well. We specifically consider atomically thin semiconductor layers embedded in an optical microcavity, where exciton-polariton quasiparticles (polaritons) result from the strong coupling between semiconductor excitons and cavity photon modes. Polaritons carry a spin degree of freedom inherited from both their matter and light components, thus resulting in the possibility of interactions between these quasiparticles [4]. Within this spin mixture of polaritons, the competition between the attractive spin-singlet and repulsive spin-triplet channels of the interaction leads to the formation of a novel self-bound state analogous to a quantum droplet.

Motivated by the success of variational approaches to the polaron problem, I will present a suitable variational ansatz which includes bosonic pairing. This is motivated by the attractive interspecies interaction that allows two excitons in different species to form a bosonic pair [5], in analogy with Cooper pairs of fermions in the conventional Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity. The resulting analysis of the free energy of the polariton mixture proves to be a general criterion providing an unambiguous signature of the formation of a self-bound droplet of polaritons.

References

[1] D. S. Petrov, *Phys. Rev. Lett.* **115**, 155302 (2015).
[2] C. R. Cabrera *et al.*, *Science* **359**, 301 (2018).
[3] G. Semeghini *et al.*, *Phys. Rev. Lett.* **120**, 235301 (2018).
[4] O. Bleu, G. Li, J. Levinsen and M. M. Parish, *Phys. Rev. Res.* **2**, 043185 (2020).
[5] H. Hu and X.-J. Liu, *Phys. Rev. Lett.* **125**, 195302 (2020).

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