Circuit Quantum Electrodynamics with two-dimensional materials-based devices

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Abstract: Within a non-perturbative approach, we analysed the ground state properties of a hybrid superconductor-semiconductor system consisting of a superconducting loop with a ballistic graphene Josephson junction, which is inductively coupled to a quantum LC resonator.

Hybrid superconductor-semiconductor systems are platforms where superconducting cavities are coherently coupled to semiconductor devices [1]. Lately, they have become promising platforms for quantum information processing since they have opened the possibility of realizing noise-protected qubits [2]. In the above framework, devices composed of graphene combined with superconductors, such as the so-called graphene Josephson junction [3], embedded in nanocircuits have shown exciting potential applications in quantum technologies due to the possibility of tuning resonant frequencies and couplings in situ by exploiting the gate voltage tunability and the peculiar low energy characteristics of 2D materials.

In this work, we studied the inductive interaction [4] between a superconducting loop with an embedded short ballistic graphene Josephson junction and a quantum LC resonator. Specifically, within a mean-field approach, we analysed how the properties of the global system ground state are affected by the light-matter coupling strength and the graphene chemical potential. In Fig. 1 we show that the current-phase relation (CPR) of the equilibrium supercurrent exhibits signatures relatable to a spontaneous time reversal symmetry (TRS) breaking. Furthermore, we computed the hybridized light-matter excitations spectrum by calculating the retarded linear response function of the quantum LC resonator flux.

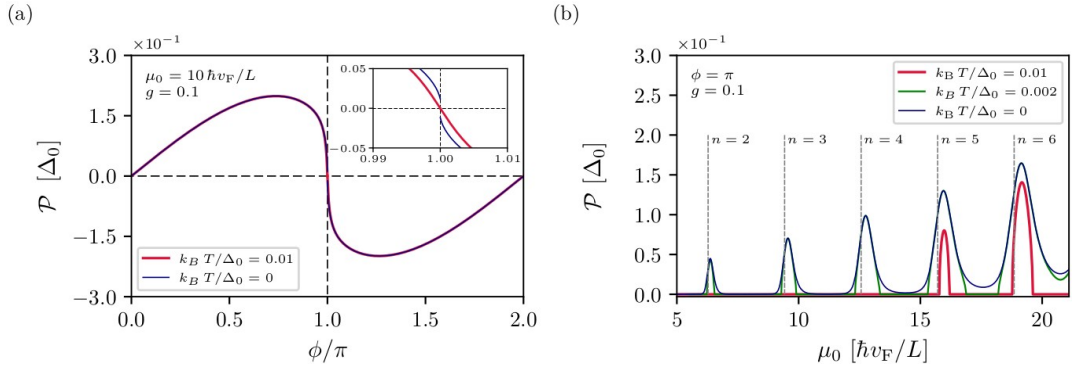

Fig. 1. (a) The mean-field P (proportional to the equilibrium supercurrent) as a function of the superconductive phase difference ϕ for two different values of the temperature T. A non-vanishing even value at ϕ = π is appreciable in the insert, we assume that is a consequence of the spontaneous TRS breaking. (b) The behaviour of the upper branch value of P at ϕ = π as a function of the graphene doping μ_0. It exhibits peaks located near multiple integers of π. Thermal effects result in a progressive quenching and partial suppression of those peaks as the temperature increases.

References

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