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Strong coupling of an electron ensemble on the surface of liquid helium to a microwave cavity

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Recently there has been a significant interest in the strong coupling of an ensemble of quantum particles to the electromagnetic modes of a resonator. Besides traditional systems used in cavity QED experiments such as Rydberg atoms, strong coupling regime has been recently studied in various electron and nuclear spin ensembles, as well as two-dimensional electron systems (2DES) in semiconductors [1,2]. The hallmark of the strong coupling regime is the splitting in the resonator spectrum revealed in the signal reflected from or transmitted through the resonator. In case of a collection of N quantum particles this splitting scales as $\sqrt{N}$. Besides general interest in the fundamental problem of light-matter interaction, the particular interest in the strong coupling regime comes from the quantum information processing as strong coupling to a high-Q resonator enables coherent information transfer between, for example, a qubit and quantum system excitations. Therefore, most of the recent observations of strong coupling have been interpreted as pure quantum phenomena. However, it is rarely mentioned that the strong coupling between large N-particle ensemble and the coherent state of electromagnetic mode in a resonator can be described completely classically in many cases. We present experimental observation of the strong coupling between cyclotron mode of 2DES on the surface of liquid helium and a microwave cavity resonator. The splitting in the eigen spectrum of coupled motion is observed in the cavity reflection signal, as well as in the ac current of electrons detected by measuring their bolometric photoresponse [3]. A simple model based on classical mechanics and electrodynamics accounts for all experimental features including the observed splitting. The $\sqrt{N}$-scaling of the splitting follows naturally from our model. Thus, our work reproduces all main features of the strong coupling regime for a large N-particle 2DES, including those reported in Refs. [1,2], but puts them on a completely classical ground. [1] G. Scalari, Science 335, 1323 (2012). [2] Q. Zhang et al., Nature Physics 12, 1005 (2016). [3] L. V. Abdurakhimov et al., Phys. Rev. Lett. 117, 056803 (2016).