In situ modification of the Quantum Hall effect with cavity vacuum fields

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Even in the absence of external illumination, a resonator exhibits modes populated with virtual photons, known as cavity vacuum fields. Placing a complementary split ring resonator (CSRR) around a GaAs-based heterostructure Hall bar, effectively immersing it in cavity vacuum fields, introduces a long-range perturbation that manifests itself effectively in opening a scattering channel for electrons in both bulk and edge states. Using this platform, previous investigations have demonstrated a breakdown of the topological protection of edge states within the integer quantum Hall regime [1]. Instead of the expected quantized Hall resistance and associated zero longitudinal resistance, quantization in Hall plateaus is lost paired with a finite longitudinal resistance. The theoretical interpretation of this effect, termed "cavity-mediated electron hopping" by C. Ciuti [2], describes the anti-resonant interaction between cavity vacuum fields and electrons in neighboring Landau levels, enabling electrons to scatter in and out of topologically protected edge states. This anti-resonant effect decays exponentially in magnetic field, with a decay rate associated to the system's Rabi frequency.

In a recent experiment, we improved the experimental platform by introducing an in situ technique to vary the coupling between the cavity and the electrons inside the Hall bar. Utilizing three Atto cube micro-positioners, we can dynamically align and adjust the position of the 2D cavity plane relative to the Hall bar, enabling selective coupling with the extruding fringing fields of the cavity. This configuration allows for real-time tuning of the coupling as a function of the distance between the cavity plane and the Hall bar sample.
As the resonator is brought closer to the Hall bar, thus increasing the coupling, we observe intriguing phenomena such as the reduction of the g factor and the hardening of the gap for fractional Laughlin states 7/5, 5/3, and 4/3 [Fig. 1].

These experimental findings offer exciting perspectives and hint at the potential emergence of a novel phenomenon within the field of cavity-engineered quantum materials.

References

[1] F. Appugliese, et.al. Science, 375(6584):1030–1034, 2022.
[2] C. Ciuti. Physical Review B, 104(15):155307, 2021.

Figures

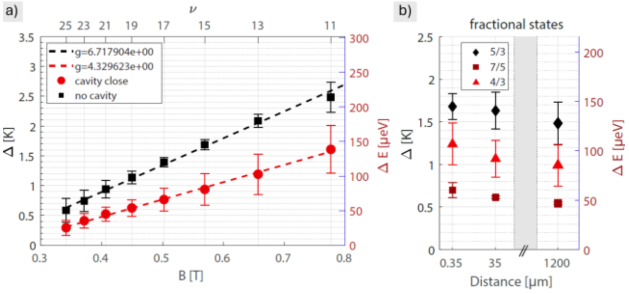

Figure 1: Figure 1a) shows the energy gap of the Zeeman-split states as a function of the magnetic field. From the corresponding linear fit, we infer the g-factor of the system indicated in the legend; in 1b) we show the activation energy for the fractional states.