Quantum Optics with Free Electrons

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Until recently, work in quantum optics focused on light interacting with *bound-electron* systems such as atoms, quantum dots, and nonlinear optical crystals. In contrast, *free-electron* systems enable fundamentally different physical phenomena, as their energy distribution is continuous and not discrete, allowing for tunable transitions and selection rules.

We have developed a platform for studying free-electron quantum optics at the nanoscale. We demonstrated the first features of this emerging field: observing the first coherent interaction of a free electron with a photonic cavity and with the quantum statistics of photons.

These capabilities open new paths toward using free electrons as carriers of quantum information. Henceforth, free electrons emerge as quantum optical sources for photonics states used in fault-tolerant quantum computation and communication.

Studies of quantum optics with free electrons suggest a new modality in electron microscopy: *imaging coherence*. This microscopy modality goes beyond conventional imaging of matter, to also image the quantum state of matter and quantum coherence of individual quantum systems.

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