Free-Electron Quantum Optics

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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.

Recent theoretical and experimental breakthroughs involving quantum interactions of free electrons spawned an exciting new field: *free-electron quantum optics*. We developed a platform for exploring free-electron quantum optics at the nanoscale, and used it to demonstrate 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. Free electrons emerge as quantum optical sources for desired photonics states used in fault-tolerant quantum computation and communication such as Schrodinger cat states and GKP states.

Concepts of quantum optics with free electrons also promote new modalities in electron microscopy. We demonstrated the first instance of *coherent amplification* in electron microscopy. Our vision is to develop a microscope that can *image coherence*, going beyond conventional imaging of matter to also image the coherent quantum state of matter and probe quantum correlations between individual quantum systems.

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