P10: Experimental Considerations for Verifying Electron-Photon Entanglement in a Transmission Electron Microscope

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Entanglement [1, 2] is a vital component of quantum mechanics and provides crucial advantages in quantum computing, imaging, and communications. The presence and application of entanglement in the transmission electron microscope (TEM) is currently of growing interest [3-8], motivated by the possibility of extrapolating the success of quantum imaging technologies to electron microscopy.

Coherent cathodoluminescence (CL) photons [9], produced by the interaction of a fast electron with a specimen, provide a promising avenue towards demonstrating and utilizing quantum entanglement phenomena in the TEM. Here we present a protocol for verifying entanglement between a coherent CL photon and the originating electron [8]. We address the illustrative system of Cherenkov photons emitted by electrons travelling faster than the speed of light within a material. Using this example, we illuminate the practical considerations necessary to set up and perform an experiment to verify entanglement between a swift electron and the coherent CL photon it emits.

Our proposal relies on coincidence-counting (*e.g.*, as demonstrated in our lab [10]) to make joint measurements of the electron-photon pair in position space and in momentum space. These carefully designed measurements allow us to certify the presence of entanglement without making assumptions about the two-particle quantum state. We will further discuss the constraints that utilizing real-world equipment imposes on the theoretical possibilities and how these constraints affect the entanglement witness. Verifying entanglement between electrons and photons reveals new paths for adapting established photonic quantum optical schemes to the realm of electron microscopy.

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