Multiphoton Ionization Quantum Eraser

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In bipartite quantum systems, the visibility of interference fringes in double-slit-type experiments fundamentally depends on the availability of "which-way" information. In this work, we demonstrate the formation of a Bell-like entangled state between a photoelectron and its residual molecular ion, generated via the multiphoton dissociative ionization of the D_2 molecule. We employ a Cold Target Recoil Ion Momentum Spectroscopy (COLTRIMS) reaction microscope to measure the momentum vectors of both the photoelectron and the ion in coincidence. Our observations yield direct evidence for quantum entanglement through the correlated emission directions of the two particles. In the presence of this correlation, the holographic interference fringes, typically present in the photoelectron momentum distributions, are suppressed, indicating the presence of which-way information. We go on to demonstrate a "quantum eraser" effect: by post-selecting a single ionic state, the which-way information is effectively erased, leading to the restoration of the holographic interference pattern. These experimental findings are rigorously corroborated by numerical solutions of the electronic-nuclear time-dependent Schrödinger equation (TDSE). Our results highlight that coincidence spectroscopy of ions and electrons serves as a powerful and adaptable methodology for exploring fundamental concepts of quantum information science, opening new pathways for studying entanglement and coherence within the domain of ultrafast light-matter interactions.