Scheme for Directly Observing the Noncommutativity of the Position and Momentum Operators with Interference

Jong-Chan Lee

Department of Physics, Pohang University of Science and Technology (POSTECH)

*spiritljc@gmail.com

The noncommutativity of complementary observables is the ground for many unique quantum effects, as well being the active subject of many illuminating debates on quantum physics. Yet, although the commutation relation has been well established theoretically since Heisenberg introduced the canonical commutation relation of the position and the momentum operators, experimental tests on the noncommutativity of conjugate operators have been rather limited.

The noncommutativity of photonic Pauli spin operators has been demonstrated [1]. Also, the noncommutativity of bosonic creation and annihilation operators has recently been demonstrated with photons [2]. However, the noncommutativity between the position and the momentum operators has always been associated with the uncertainty principle and, in experiment, it has been demonstrated in single-slit diffraction [3]. Note that the noncommutativity relation for the position and the momentum operators itself has not been directly observed to date unlike the Pauli spin operators or the bosonic creation and annihilation operators.

We propose and analyze an experimental scheme to directly observe the noncommutativity of the position and the momentum operators using the transverse spatial degree of freedom x of a single-photon wave function $\psi(x)$ [in the sense that $|\psi(x)|^2$ gives the probability distribution] [4]. Although the interferometric scheme proposed in this paper is focused on single-photon interferometry, the proposed concept can readily be expanded to matter-wave interferometry.

References

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