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Quantum-Mechanical Analysis of Electron Transport in a Cylindrical Crossed-Field Configuration with a Periodic Boundary Potential

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This work presents a fully quantum-mechanical theoretical framework for describing electron dynamics and collective phenomena in a cylindrical crossed-field configuration subject to a spatially periodic boundary potential. The electron cloud is considered in orthogonal radial electric and axial magnetic fields. By solving the Schrödinger equation with the corresponding gauge potentials and an effective radial potential in cylindrical coordinates, we obtain the quantized energy spectrum and spatial structure of the electron states.
In the unperturbed state, the quantum-mechanical analysis shows that the radial current vanishes. Electron transport toward the boundary is therefore described as a quantum process associated with transitions between discrete angular-momentum states induced by a spatially inhomogeneous high-frequency field. The periodic boundary potential couples states with different angular momenta and provides a mechanism for phase locking and coherent energy transfer between the electron cloud and the electromagnetic field.
A key result of the work is the identification of a mathematical correspondence between the formation of azimuthal space-charge structures, commonly referred to as spokes, and the collective phenomena described by the Landau theory of second-order phase transitions and the Ginzburg–Landau theory. The emergence of rotating electron bunches is interpreted as a spontaneous symmetry-breaking process, while the spokes are described as stable, spatially coherent structures of a complex order parameter.
The proposed framework establishes a connection between microscopic quantum electron dynamics and macroscopic order-parameter theory, providing a unified description of electron transport, collective self-organization, phase coherence, and nonlinear evolution of azimuthal space-charge structures in cylindrical crossed-field configurations.

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