Angular Momentum Quantization in Two-Dimensional Charge-Flux Composites: A Quantum Electrodynamic Approach

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The fractional angular momentum, commonly referred to as "fractional spin," of a two-dimensional charge-flux composite is a foundational concept in the study of anyons and fractional statistics [1]. When derived from a standard semiclassical Hamiltonian, the kinetic angular momentum of such a system takes the fractional value $L_k = n\hbar - q\Phi/2\pi$. However, if the charge and magnetic flux are treated together as an isolated quantum system in free two-dimensional space, the fundamental rotational and reflection symmetries of the $O(2)$ group demand that the total net angular momentum be quantized in integer or half-integer units of $\hbar$.

In this work, we address this apparent theoretical discrepancy by adopting a full quantum electrodynamic (QED) framework, building upon recent studies on treating the locality problem in the Aharonov-Bohm effect [2]. We demonstrate that when the charge and flux interact via the vacuum electromagnetic field, the composite system possesses an intrinsic interaction angular momentum derived directly from Noether's theorem. This interaction component naturally incorporates both the localized field momentum and the hidden relativistic mechanical momentum.

Our formalism shows that this gauge-invariant interaction angular momentum exactly compensates for the fractional portion of the kinetic angular momentum. Consequently, the integer quantization rule for the net angular momentum of the isolated system is fully restored. Our approach clarifies that the conventionally accepted fractional spin corresponds to the expectation value of the kinetic contribution within the perturbed QED ground state. Ultimately, we demonstrate that the exotic fractional spin of two-dimensional charge-flux composites can be rigorously understood without abandoning fundamental spatial symmetries when the vacuum electromagnetic field is properly accounted for.

[1] F. Wilczek, Magnetic Flux, Fractional Statistics, and the Topological Mass Term, Phys. Rev. Lett. 49, 957 (1982).

[2] K. Kang, Gauge invariance of the local phase in the Aharonov-Bohm interference: Quantum electrodynamic approach, EPL 140, 46001 (2022).