The role of virtual photons in the quantum locality of the Aharonov-Bohm effect

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In the Aharonov-Bohm (AB) effect, quantum interference is observed for a charged particle even when there is no local overlap with the external magnetic field. Here we argue that the quantum electrodynamic approach provides a microscopic picture that can solve this "locality problem". In particular, the interaction between a charge and a distant magnetic flux is mediated by virtual photons. We show the gauge invariance of the local phase shift induced by an external magnetic flux [1], which is in sharp contrast to the standard semiclassical result.

In addition, the effect of virtual photons in the interference is manifested by a change in their spectrum. When a vacuum is confined between two ideal conducting plates, the photons acquire effective mass and satisfy the 2D Proca equation. This results in a short-range interaction between the charge and the magnetic flux, and the AB effect is exponentially reduced at a large distance between the two bodies [2]. On the other hand, a semiclassical description of this short-range AB effect is also possible. This raises an interesting question about the reality of virtual photons.

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

[2] K. Kang, "Aharonov-Bohm effect mediated by massive photons", arXiv:2403.03495.