More Variations on Aharonov-Bohm, Peter A. Sturock, Timothy R. Groves, Alexander Ershkovich, C. Alden Mead, Herman Batelaan and Akira Tonomura: Batelaan and Tonomura Reply

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Batelaan and Tonomura reply: Werner Ehrenberg and Raymond Siday did propose the magnetic version of what is now called the Aharonov–Bohm (AB) effect,[1] as Peter Sturrock and Timothy Groves point out. We had included this reference in the early versions of our manuscript. However, limited space directed the focus of the paper to the "effect without a force" discussion, rather than a historic perspective.

Alexander Ershkovich notes that in the Hamilton–Jacobi formulation of classical mechanics, both the action and the Hamiltonian depend on the vector potential; he ponders whether the AB effect might have a classical manifestation. Newton's formulation of classical mechanics is equivalent to the Hamilton–Jacobi formulation. Because the absence of a field means the absence of a force in Newton's formulation, classical trajectories are unaffected. That result is not expected to change in the equivalent Hamilton–Jacobi formulation. Thus the AB effect is usually considered to be a pure quantum effect. On the other hand, we may interpret "classical mechanics" in a broader sense, such as in general relativistic classical mechanics. In electrodynamics classical trajectories are not affected by a localized magnetic field through which they do not pass. However, considering that the energy content of a current-carrying solenoid is larger than that of one without current, the trajectory is clearly affected gravitationally, at least in principle. Though not due to the AB effect, that result elucidates that a generalized description may lead to other insights. The Hamilton–Jacobi equation may be an example of a theoretical vehicle by which to explore generalizations such as relativistic effects, separation of variables, multiple particle effects, or the classical limit of the de Broglie–Bohm theory.

C. Alden Mead recollects interesting statements made by Bohm. We agree fully with Bohm's statement that "it would be much more revolutionary for this effect to be wrong than for it to be right." Attempts to disprove the AB effect should be seen for what they are, outright attempts at finding limits to the validity of quantum mechanics itself. And although quantum mechanics is unfinished with respect to, say, decoherence theory and quantum gravity, the AB effect appears to be well within its validity range.

We do not share Bohm's astonishment that, as Mead relates, "certain physicists refused to accept the AB effect and even went to great lengths to try to disprove it." Rather, to risk overusing a platitude, extraordinary phenomena should be exposed to extraordinary scrutiny. Failed attempts to disprove an idea often provide insight into its fundamental character. In that context, we reiterate the main message of our article. Many facets of the AB effect—for example, the electric version, the dispersionless nature, relativistic momentum conservation, the relation to the Mott–Schwinger effect, and the AB effects for other than electromagnetic gauge-invariant theories—need exploration. We predict a bright future for the AB effect, with many surprises to come.

Reference

1. A. Tonomura, *Electron Holography*, 2nd ed., Springer, New York (1999), p. 63.

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