

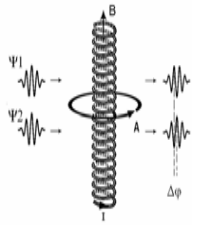
The Aharonov-Bohm Effect: microscopic coils / macroscopic analogies

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What is the Aharonov-Bohm Effect?

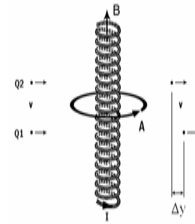
In the magnetic version of the effect, coherent electrons passing on either side of a very long solenoid experience a relative phase shift. Quantum mechanically this is attributed to the vector potential but classically it wouldn't happen as there is no **B**.

Quantum Interpretation:



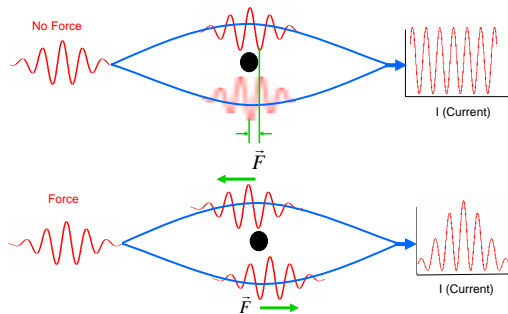
$$\Delta\phi = \frac{q\Phi}{\hbar} = \frac{qB\ell}{\hbar}$$

Quasi-Classical Explanation:



This interpretation has opponents, namely Boyer, who argue that the effect can be attributed to forces. In particular, he argues that a magnetic force due to the moving electron acts on the solenoid. The solenoid then back-acts on the electrons via a force, upholding Newton's 3rd Law. Since the electrons on opposite sides feel opposite forces a lag is introduced.

Phase or Force? The Test:

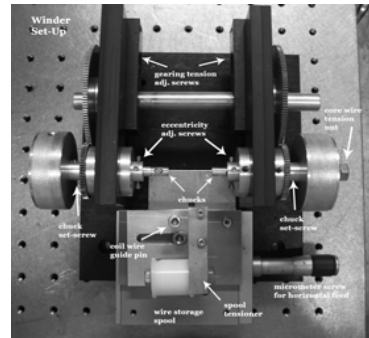


Technically, this controversy could be settled by performing an electron interferometry experiment with a magnetic flux large enough that the electrons would be shifted beyond their coherence length; that is what the tiny coils are needed for. Also if it *is* a force, we should be able to observe it macroscopically. That's the motivation for evaluating macroscopic experiment ideas.

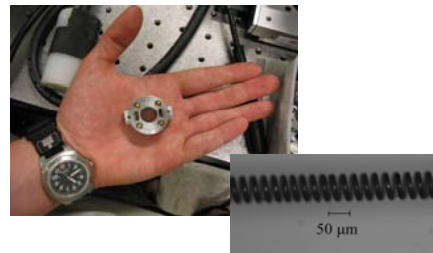
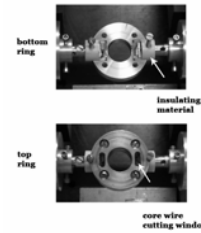
2 Tasks:

- 1) Develop a way to make and mount 50µm diameter solenoids
- 2) Explore options for macroscopic analogy experiments to look for a classically observable effect

Winding 50 µm diameter coils:



Ring (detail)



In order to wind 50 µm diameter solenoids, I had to build a miniature lathe-like winding device. Since the coils are so small, the form around which you wrap them becomes a wire. Since this core wire isn't rigid, you have to stretch it between the two ends of the device and turn them synchronously. This was accomplished by mechanically linking the ends of the device. The wire also has to be rotated very close to on-center, so an eccentricity adjustment was required.

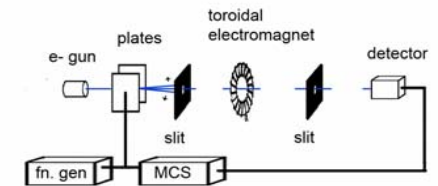
A mount compatible with the winding device was also devised to allow for the solenoid to eventually be mounted in an electron interferometer.

Macroscopic Analogy experiments:

- Free fall → Different system (accelerating) → Not measurable
- Modified Millikan Oil Drop Experiment
- Ultrashort Pulse → Tenuous analogy → Measurable
- Electron Pulse → Measurable
- Precision Turntable → No effect

A variety of macroscopic experiment ideas were considered. Most were found to be unrealizable or not appropriate analogies. One idea did look promising: an electron pulse time delay experiment. The predicted time delay in such an experiment would be within the reach of detection in the lab. The experiment remains to be done and that is where the research stands.

Proposed Experiment:



Thanks:

Herman Batelaan, Glen Groninger, Les Marquart, Brett Barwick, Shawn Hilbert, Steve Friedman, Adam Caprez, UNL, NSF

Sources:

- Y. Aharonov and D. Bohm, *Phys. Rev.* 115,485-491(1959).
 - Möllenstedt, G. and Krimmel, E.: *Zeitschrift für angewandte Physik* XVI. Band Heft 2 – 1963.
 - T. H. Boyer, "Semiclassical Explanation of the Matteucci-Pozzi and Aharonov-Bohm Phase Shifts" *Foundations of Physics* 32, 41-50(2002).
- More sources available upon request.