[Typesetter: uses Greek capital phi: Φ. Subscripts were set in 14 rather than 12, for legibility]

**The Aharonov-Bohm Effect**

The arrows in the center of this diagram represent lines of magnetic flux, completely shielded from the outside world by a metal tube. The tube is surrounded by two bands, each representing a group of charged particles passing on one side (*c*1) or the other (*c*2).

According to classical physics, since in this experiment the electromagnetic field is totally contained inside the tube, it should not matter which path the particles take.

But in fact, if a beam of electrons is split, with one half following path *c*1 and the other half following *c*2 , when the two halves are brought together again they produce an interference pattern. This is the Aharonov-Bohm effect, first confirmed experimentally in 1959. It can only be explained using quantum mechanics.

In quantum mechanics, besides the electric and magnetic fields, one must take into account the magnetic vector potential. What happens in this experiment is that the magnetic vector potential, which is non-zero even outside the tube, interacts with the phases of charged particles that traverse it. In the language of gauge fields, the magnetic vector potential acts as a connection in the bundle of phases. This means that when a particle moves along a path, the magnetic vector potential can cause its phase to advance or retard. In this experiment the potential retards phases along path *c*1 and advances them along *c*2. At any point where the two beams are brought together, electrons in one beam and electrons in the other may be in or out of phase, according to the exact lengths of the paths they have followed: this forms the interference pattern that allows the effect to be detected. This phenomenon is part of the physics that would make a quantum computer more powerful than a classical computer.

The formula below the diagram represents the difference in the phases associated with the two paths: it is proportional to the total flux in the tube, here denoted by Φ.

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Related items: The Yang-Mills Equations, p. 36; Maxwell’s Equations, p. 26.