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# Role of electromagnetic energy and momentum in the AharonovBohm effect

February 2024 · Proceedings of the Royal Society A · 480(2283)

DOI: 10.1098/rspa.2023.0286

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## Abstract

We analyse the physical meaning of the Aharonov–Bohm (AB) phase based on its representation through electromagnetic (EM) potentials as a sum of four components, which, in addition to the known electric and magnetic phase components, contains two more terms recently disclosed by our team in the analysis of quantum phase effects for dipoles and charges, and which we named the complementary electric AB phase and the complementary magnetic AB phase. Using the complete expression for the AB phase, we reveal that the phase component, explicitly depending on time, is determined by the interactional electric energy, while the phase component, explicitly depending on the velocity of charge, is determined by the interactional EM momentum for an isolated system 'source of EM field and charge'. These findings shed new light on the origin of the AB phase and, in particular, allow us to generalize the de Broglie relationship and the Heisenberg uncertainty relations for a charged particle in an EM field.



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Cite this article: Kholmetskii AL, Missevitch OV, Yarman T. 2024 Role of electromagnetic energy and momentum in the Aharonov–Bohm effect. *Proc. R. Soc. A* **480**: 20230286.
https://doi.org/10.1098/rspa.2023.0286

Received: 28 April 2023
Accepted: 5 January 2024

**Subject Areas:**
quantum physics

**Keywords:**
Aharonov–Bohm effect, electromagnetic energy–momentum, de Broglie relationship, Heisenberg uncertainty relations

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# Role of electromagnetic energy and momentum in the Aharonov–Bohm effect

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We analyse the physical meaning of the Aharonov–Bohm (AB) phase based on its representation through electromagnetic (EM) potentials as a sum of four components, which, in addition to the known electric and magnetic phase components, contains two more terms recently disclosed by our team in the analysis of quantum phase effects for dipoles and charges, and which we named the complementary electric AB phase and the complementary magnetic AB phase. Using the complete expression for the AB phase, we reveal that the phase component, explicitly depending on time, is determined by the interactional electric energy, while the phase component, explicitly depending on the velocity of charge, is determined by the interactional EM momentum for an isolated system 'source of EM field and charge'. These findings shed new light on the origin of the AB phase and, in particular, allow us to generalize the de Broglie relationship and the Heisenberg uncertainty relations for a charged particle in an EM field.

## 1. Introduction

Since the discovery of the Aharonov–Bohm (AB) effect [1,2] and until recently, it was commonly interpreted as a local effect, where the quantum phase $\phi_{AB}$ is determined by the scalar $\varphi$ and vector $A$ potentials at the location of the charged particle [1,2]:

$$\phi_{AB} = -\frac{1}{\hbar}\int_t e\varphi \mathrm{d}t + \frac{1}{\hbar c}\int_s eA \cdot \mathrm{d}s. \qquad (1.1)$$