The Aharonov-Bohm effect

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M. Peshkin and A. Tonomura. *The Aharonov-Bohm Effect* (Lecture Notes in Physics, Vol. 340), Springer-Verlag, Berlin, Heidelberg, New York, London, Paris, Tokyo, Hong Kong, 1989, 154 pp.

Rarely has any new physical effect encountered in our time such mistrust as the effect discovered in 1959 and named the Aharonov-Bohm effect from the names of the authors of the paper "Significance of Electromagnetic Potentials in the Quantum Theory".[1] It may be surprising, but the stream of papers on this subject still continues in physics journals. True, papers in which the very existence of the effect is refuted have disappeared, but ideas about hidden parameters and a nonlocal nature continue to fascinate the writing community. Therefore, the appearance of this monograph devoted to the effect is very useful, since the physics content of the problem is revealed very clearly in it.

The first author, Peshkin, who has studied the theory of the effect for a long time, gives in 35 pages a practically exhaustive review of the literature. He adds to traditional reviews an exposition of bound states (the noninteger quantization of angular momentum), he introduces into the theory toroidal magnetic flux (which has been examined by V. L. Lyuboshits and the author of the review), and he discusses fairly critically the paradoxes associated with causality and locality. One can add two remarks to what the author has written.

1. The statement that, according to classical electrodynamics, an electron does not interact with a magnetic flux is inaccurate. Since the electric field of an electron penetrates into a solenoid, the momentum of the solenoid changes, and both the momentum and angular momentum of the electron change with it. One must remember that momentum is conserved in classical electrodynamics (examples: the scattering of light by an electron and the Thomson formula) only in the limit of an infinite mass for the scatterer, the solenoid in our case. The paradox is increased if one attempts to describe the field of a solenoid which has started to move.

The problem of the interaction of two solenoids, which does not yet have a rigorous solution, also belongs to this same type of paradoxes.

2. One may interpret noninteger quantization as integer quantization, but in a rotating coordinate system. This remark imparts new meaning to the effect of rotation in quantum mechanics.[2]

The second author, Akira Tonomura from Tokyo, presents a long (over 100 pages) experimental review. The history of the effect, its physical meaning, and a large number of experiments are recounted in detail in this paper. Probably, the most interesting thing in the review is the description of experiments by the author himself, a superb experimenter, in which a long-standing dream, electron beam holography, has been achieved. The idea of the experiment is simple. A beam of electrons with energies of about 100 keV was separated into two converging beams by means of a birefringent prism. The object, a magnetized torus for demonstrating the Aharanov-Bohm effect, was inserted into one of the beams. The interference pattern on the screen contains all the information (amplitude and phase) for the electrons.

Electron holography will undoubtedly continue to be developed, and Tonomura presented a detailed review of the initial period of this interesting field of technical physics.

One may say from the point of view of general physics that such a hologram demonstrates the wave nature of the electron very clearly. Because of the presence of the reference beam, not only the square of the amplitude of the wave function (as in Young's experiment), but also the phase, referred to the undisturbed reference beam, are recorded on a hologram.

The review includes a long list of references.

As always, the problem of how to make the book accessible to our readers arises in such cases. It appears that one can accomplish this by the publication in *Uspekhi Fizicheskikh Nauk* of at least a part of what Tonomura has written. It is somewhat long, but the usefulness of its publication would be undoubted.

[1]See Y. Aharonov and D. Bohm, Phys. Rev. **115**, 485 (1959).
[2]An analogous argument is well known for the Berry phase.

Translated by Frederick R. West