Aharonov-Bohm with neutrons

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IN Aharonov-Bohm experiments a solenoid carrying magnetic flux penetrates the area between the two beams in an electron interferometer with the magnetic field shielded such that it vanishes along the electron beams. Even so, a phase difference arises between the two electron beams which is topological because it is dependent *only* on the total flux enclosed by the beams. Recently another topological phase shift, this time with neutral particles, has been observed by a University of Melbourne-University of Missouri collaboration (1989 A Cimmino *et al. Phys. Rev. Lett.* 63 380), an effect predicted five years ago by Aharonov and Casher.

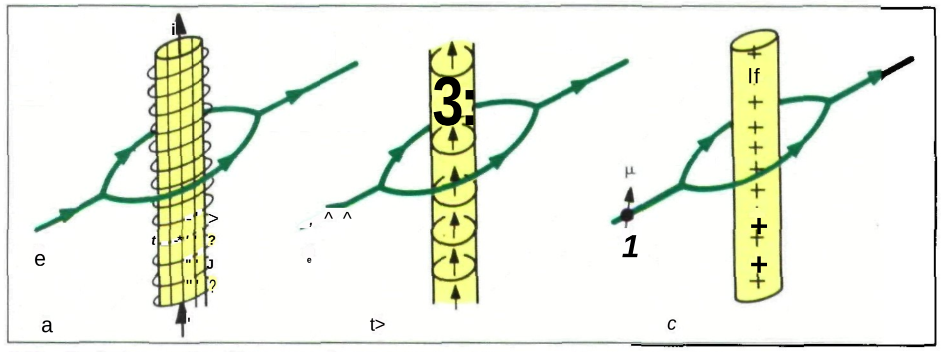
In the new experiment the topological phase shift occurs in a neutron interferometer when electric charge is enclosed between the two beams. This effect is complementary to the Aharonov-Bohm effect (figure 1): the effect is unchanged if we replace the solenoid of the original set-up (figure la) by a line of magnetic momenta (figure 16). We get the Aharonov-Casher situation then by interchanging the roles of the magnetic momenta and the electric charges. In the Aharonov-Casher experiment we thus have a line of electric charge penetrating the area between the beams of a neutral-particle interferometer (figure lc)..

The Aharonov-Casher effect arises from the coupling of the neutron magnetic moment to the electric field of the line of charge. Since the neutron magnetic moment is so small the phase shift is not easily observed. In practice this meant that Cimmino and colleagues had to pack as much charge as they could between the beams of their neutron interferometer. However, such an interferometer is made from a perfect silicon crystal and is only a few centimetres in size. In the experiment the electric field of 300 kV cm^{-1} resulted in an observed phase shift of only 2 milliradians. To detect such a tiny phase shift they had to accumulate more than 10^7 neutrons which, at the intensity level available at the Missouri University Research Reactor, took them several months! It is evident that this poses special requirements on the long-term stability of the whole apparatus.

Interesting experiments remain to be done. The topological property of the Aharonov-Casher effect means that the phase shift is independent of the specific location of the line of charge between the interferometer beams. The effect should always be of the same magnitude as long as the line of charge penetrates the area enclosed by the beams. On the other hand, the phase shift should always vanish if the line of charge is located outside the interferometer area, no matter how close to either beam. Clearly, experimental confirmation of these topological features will have to wait for larger neutron, or maybe even atomic beam, interferometers. Such devices are currently under development at various places.

Another prediction is that if the neutron spin is oriented parallel to the line of charge there should not be any observable effect on either beam separately. Specifically, there should be no lag of the wave packet or no distortion of its internal structure. This is related to another topological feature of the effect which is that the magnitude of the phase shift should also be independent of the wavelength of the neutrons used, i.e. it should be independent of the time the neutrons spend in the electric field of the line of charge. This prediction may be easier to confirm by just repeating the experiment with neutrons of different energy.

The experimental verification of topological effects of the Aharonov-Bohm and of the Aharonov-Casher type is significant because of their intimate connection to modern gauge theories and to strings. Such topological effects reveal something about interconnectedness of things on a very general level independent of the specific geometrical features of an experiment. Many physicists think that universal theories should be based on such topological considerations. •



1 Duality between the Aharonov-Bohm and the Aharonov-Casher topologies

Magnetic froth

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THE magnetic bubble memory is one of the most entertaining tricks of modern materials science. Even if it loses out in the hard commercial world of the computer industry, it will continue to offer exciting possibilities for new kinds of experiments using the uniaxial garnets and amorphous films which have been developed. Thus does solid state physics feed on its own offspring. The originators of the bubble memory might not readily recognise the latest variation of this game, offered by K L Babcock and R M Westervelt in the form of magnetic froth (1989 *Phys. Rev. Lett.* 63 175).

Fifteen years ago G R Woolhouse and P Chaudhuri showed how magnetic bubbles, instead of being individually shuttled around in the alleyways of a bubble memory, could be given the right of free assembly, to form a two-dimensional disordered or close-packed array. This is reminiscent of Lawrence Bragg's celebrated soap bubble raft model, still invoked in the elementary description of grain boundaries and other aspects of crystal structure. Babcock and Westervelt take the close-packed array as their starting point. They increase the magnetic field until the magnetic domains which constitute the bubbles expand and contact each other to form the hexagonal cellular structure seen in the lower right of figure 1. The upper

1 Hexagonal cellular domain structure in a garnet film, together with a disordered 'magnetic froth' phase. The cell boundaries (dark areas) have magnetisation opposite to the imposed magnetic field