Quantum Interference

Neutrons feel the effect of an electric field that apparently exerts no force

By IVARS PETERSON

Theoretical physicists often invent "thought" experiments to test their ideas, illustrate principles or make points in arguments, usually without expecting that anyone could actually carry out the experiments. But experimental techniques are catching up with the predictions of theorists, and researchers can now tweak matter far more precisely than many theorists would once have dreamed possible.

A team of physicists from the University of Missouri at Columbia and the University of Melbourne in Australia recently achieved just such an experimental *tour de force*. They detected an unusual quantum-mechanical effect in which neutrons seem to respond to a static electric charge without "feeling" the charge's electrical force.

"This demonstration of a subtle effect is an elegant example of the experimentalist's art," I.J.R. Aitchison of the University of Oxford in England comments in the Sept. 14 NATURE.

In quantum theory, light and matter have both wave and particle characteristics. In some observations, objects such as electrons, neutrons and atoms behave more like waves than like particles, and the equations of quantum mechanics provide ways of describing these wave properties. The square of the amplitude of such a "matter wave" corresponds to the probability of finding the particle at a particular location at a certain time, and the phase describes the relative positions of the wave's crests and troughs.

The phase is important when a number of waves overlap, or interfere. Like overlapping ripples, waves cancel out whenever crest meets trough and reinforce each other when crest meets crest or trough meets trough. Thus, light of a single wavelength passing through a pair of narrow, closely spaced slits in an otherwise opaque plate creates a pattern of alternating dark and bright bands. The location of each band depends on how much farther light from one aperture travels than light coming from the other aperture.

Particles, such as electrons of a particular energy passing through a pair of slits in an electron-absorbing plate, create similar interference patterns for the same reasons. A detector recording the arrival of each particle finds areas where many particles arrive and other areas where few particles arrive, clearly demonstrating that a particle has a well-defined phase.

In 1959, Yakir Aharonov of Tel Aviv University in Israel and David Bohm of the University of London in England predicted that if two beams of electrons pass on either side of a magnet shielded so that it can't exert a force on another magnet, the phases of the quantum-mechanical waves describing the electrons change – even if the electron paths never cross the magnet's field. In other words, a magnetic field can alter the dynamics of charged particles in a subtle but measurable way without actually touching the particles.

One of the best places to look for this quantum-mechanical effect is in an interference experiment. Putting a shielded solenoid between the two beams of electrons emerging from a plate with two slits should retard the phase of particles in one beam with respect to the other, shifting the interference pattern. Experimentalists demonstrated this effect in 1986 (SN: 3/1/86, p.135).

What happens when the roles of charge and magnetic field are exchanged? In 1984, Aharonov and A. Casher predicted that particles having a magnetic moment but no net charge passing on either side of a charged electrode would also experience a phase shift, so long as the particles' magnetic moments were aligned at right angles to the electrode's electric field.

As in the case of the Aharonov-Bohm effect, an interference experiment is a good place to look for evidence, this time with neutrons substituted for electrons and a charged electrode for the solenoid. The trouble is that a neutron has a very small magnetic moment, so the predicted phase shift is tiny. Moreover, neutron beams with the right characteristics are weak, so it takes a long time to conduct the experiment.

Nevertheless, Samuel A. Werner of the University of Missouri and his collaborators from Australia took up the challenge and carried out an ingenious neutron-interference experiment at the university's research reactor to look for the Aharonov-Casher effect. Using two detectors, the researchers counted the number of neutrons observed after the neutrons passed by a specially designed electrode.

It took several months to accumulate enough data. After observing roughly 50 million neutrons, the researchers found a change of about 1 count per 1,000 in the number of neutrons detected at a given position. This corresponds to a phase shift 1.46 times that predicted by Aharonov and Casher. They reported their results in the July 24 PHYSICAL REVIEW LETTERS.

The experiment was a remarkable achievement, says Alfred S. Goldhaber of the State University of New York at Stony Brook. "The main trouble is that the effect is so small. There may still be something there which they didn't think of that could make the result inconsistent with the prediction."

One way to improve the result is to do the experiment with neutral atoms instead of neutrons. This should yield an effect about 1,000 times larger, but experimentalists have not yet devised a way to produce atomic beams with the right characteristics for such an experiment.

The question of whether neutrons feel a force as they pass a line of electrical charge at right angles is still somewhat controversial. Most physicists who have studied the issue agree that the Aharonov-Casher effect is strictly quantum mechanical. They argue that classical electrodynamics shows that no net force acts on the neutron.

However, Timothy H. Boyer of the City College of the City University of New York contends a classical force does act to slow particles in one of the two neutron beams. That slowing, rather than the phase shift predicted by quantum mechanics, accounts for the shift in the interference pattern, he says.

"I'm guessing that it's a velocity difference along the two different paths that leads to the effect, and if you make that velocity difference big enough, you'll wash out the interference pattern," Boyer says. "I'm still doing calculations hoping to clarify the situation."

"Boyer is in the minority, although that's not the same as saying he's wrong," Goldhaber says. "Nevertheless, I believe that when the dust settles, the consensus will come down on the side that the Aharonov-Casher effect is a purely quantum-mechanical effect."

Aitchison adds, "All the same, we can expect to see further discussion of this point and further exploration of the possibilities opened up by the new effect." □