Neutron Interferometry: Lessons in Experimental Quantum Mechanics

Helmut Rauch and Samuel A. Werner
Oxford University, New York, $120.00 (393 pp.)
ISBN 0 19 850027 0
Reviewed by Jeffrey W. Lynn for Physics Today, **55**, 52 (2002).

The copious availability of thermalized neutrons makes them an ideal probe of condensed matter physics and materials research, and it is this same abundance that makes them the particle of choice for many fundamental physics investigations. A prime example is the field of neutron interferometry, which is a technique developed to investigate a wide variety of fundamental aspects of quantum theory. Helmut Rauch and Samuel Werner have been pioneers in the field of neutron interferometry since the first demonstration of a neutron interferometer in 1974, and the book they have written, *Neutron Interferometry: Lessons in Experimental Quantum Mechanics*, is both a very readable introduction to the subject, and a comprehensive and up-to-date review of this elegant experimental technique. It is written at the advanced graduate-student/researcher level, and serves as a reference text for the field of neutron interferometry.

Interferometry is a technique familiar to all physicists and can be carried out with any wave phenomenon. An incident beam of particles with wavelength λ is split and then recombined, forming an interference pattern. This interference pattern is sensitive to any change in the effective path length of one (or both) leg(s) of the interferometer, and changing this "optical" path length in a controlled manner allows the experimenter to probe the perturbing interaction with extraordinary precision. In contrast to the familiar optical interferometers that employ wavelengths $\approx 10^{-6}$ m, for neutrons the de Broglie wavelength is $\approx 10^{-10}$ m (Å) and the interferometer uses Bragg reflection from perfect silicon single crystals instead of mirrors both to split the beam and recombine it. Neutrons have the additional advantage that they are sensitive to the four "basic" interactions—strong, weak, electromagnetic, and gravitational—and this makes the neutron interferometer a particularly versatile tool for testing fundamental physics concepts. Indeed just the existence of the neutron interferometer is a striking example of the wave-particle duality of quantum mechanics.

The first half of the book introduces the basic aspects of neutron interferometers and the interactions of neutrons with matter. It is a very readable exposition, which by necessity includes the detailed quantum mechanical mathematics to fully elucidate the fundamental operation of neutron interferometers and the capabilities of the technique. This material can be compared with the book edited by Ulrich Bonse and Helmut Rauch, *Neutron Interferometry* (Oxford, New York, 1979), which articles were written by a variety of authors. The present text brings together in a coherent description most of the material in this earlier compendium, and of course includes the developments in the field in the intervening twenty years. The only shortcoming in Rauch and Werner's text is the index, which is a very short two pages. Interferometry is a complex and advanced subject, and the utility of the book would have benefited from a more inclusive effort, particularly when employing it as a reference text for people who are not fulltime practitioners in the field.

The second part of the book describes some of the benchmark experiments of neutron interferometry. For example, rotating a classical vector by 2π restores the original state, while quantum mechanically the rotation of the spin of an S=½ fermion particle is expected to change the sign of wave function, and the spin must be rotated by 4π to return to its initial value ($\psi(0)=-\psi(2\pi)=\psi(4\pi)$). This 4π spinor symmetry of fermions was for many years thought to be an unobservable nuance of quantum mechanics, but was then experimentally demonstrated with a neutron interferometer, by varying a magnetic field in one leg and observing the change in the interference pattern. The neutron interferometer has been used in an analogous manner to examine a wide variety of topological or geometrical effects on the phase of the neutron. Examples include the Aharonov-Casher effect (vector Aharonov-Bohm effect), and gravitationally induced quantum interference.

One of the interesting aspects of Rauch and Werner's text is their willingness to gaze into the future. They discuss possible applications of interferometry in materials science, which is just in its infancy, and have an intriguing chapter on "forthcoming and more speculative experiments". This includes tests for non-linear terms in the Schrödinger equation, quaternions in quantum mechanics, delayed choice experiments, non-Newtonian gravity effects, and a host of other fascinating possibilities. It is clear that the field of neutron interferometry will continue to be vital and exciting for many years to come, and the Rauch and Werner's *Neutron Interferometry* will become the standard text for the field.

Jeffrey W. Lynn is Team Leader of Condensed Matter Physics at the NIST Center for Neutron Research, and Professor of Physics at the University of Maryland. He has used thermal, cold, and ultracold neutrons in his research for some 30 years, with well over 300 articles in books and journals.

Ulrich Bonse and Helmut Rauch, editors
Neutron Interferometry (Oxford, New York, 1979), ISBN 0-19-851947-B