Quantum mechanics

Bulletins delivered from the quantum world

from Abner Shimony

MORE physicists at present than in the past seem to be discontented with using quantum mechanics merely as a tool for ordering phenomena. There is a widespread desire among those who apply quantum mechanics to understand it fully to their own satisfaction and many investigations have been stimulated by the conceptual difficulties of the theory. There have been attempts to devise new interpretations or alternative theories, such as theories of hidden variables, which would eliminate these difficulties, as well as attempts to formulate a philosophical world-view that would accommodate them in a natural manner. Many experiments have been performed for the purpose of testing quantum mechanics against alternative proposals, or just to see whether quantum effects can be detected in new domains. Investigations of all of these types were represented at a recent meeting* in New York, which was the first major international conference on the foundations of quantum mechanics to take place in the United States.

Superposition

Most of the conceptual difficulties of quantum mechanics result from the superposition principle, which permits a physical system to have states in which a quantity (such as position or energy) does not have a definite value. When a measurement of that quantity is performed a definite value is found, but it is obscure how the mathematical laws of quantum mechanics permit a definite experimental result. Quantum mechanics also predicts that experiments performed on a properly prepared pair of spatially seperated particles can yield results which are correlated in a way that is inexplicable by classical physics — a characteristic known as non-locality. At the conclusion of the meeting there was a widespread sentiment (although not a consensus) that these difficulties are not fully understood. Nevertheless, the theory which generates these difficulties remains well entrenched, for the most beautiful experiments reported fully agree with quantum mechanics.

There were many reports of experimental results in optics, neutron interferometry, electron interferometry and magnetic phenomena. One such experiment was the coherent splitting of a beam of neutrons polarized in the z-direction into two beams polarized respectively in the x and $-x$ directions and then recombined to exhibit the initial z-polarization (H. Rauch, Atominstitut, Vienna). Also described were an interference phase shift in a neutron interferometer, which agrees with quantum-mechanical calculations of the Sagnac effect — the effect of the Earth's rotation (S. Werner, University of Missouri); and the realization of a 'delayed choice' experiment in an optical interferometer (C. Alley, University of Maryland; A. Zajonc, Amherst College). In this experiment, a Pockels cell switch, activated after a single photon has been split in an interferometer, decides whether there will be an observation of which path the photon is in or of a coherent combination from both paths. These and other experiments described at the meeting agree with quantum mechanics in a good, sometimes spectacular, manner.

But several experiments in progress are motivated by doubts about the decisiveness of previous experiments which have been widely accepted as excluding local hidden-variables theories. A notable example is the experiment of A. Aspect and collaborators, which tests Bell's inequality in an apparatus with polarizer setting chosen while the two photons are in flight. J.-P. Vigier (Institut H. Poincaré) predicted that a revised version of Aspect's experiment, to be performed at Catania, would show non-quantum-mechanical correlations when the time interval between the detections of the photons is sufficiently small.

J.D. Franson (Johns Hopkins University) has constructed a 45-metre optical interferometer, for which he calculates that a hidden-variables theory would permit interference results in agreement with quantum mechanics only at the price of a violation of relativity theory. A completed experiment, using a shorter interferometer, does agree with quantum mechanics (P. Grangier, Institut d'Optique, Orsay), but Franson claimed that this experiment fails to exclude a local hidden-variables alternative to quantum mechanics, both because of the shortness of the interferometer and because of the failure to use a single-photon light source, as he is planning to do.

There was much discussion about the possibility of reconciling quantum-mechanical non-locality with relativity theory if the earlier non-local results are sustained by future experimentation. It was generally agreed that quantum-mechanical non-locality has the pecularity that a signal cannot be transmitted faster than light, and in this sense there is 'peaceful coexistence' with relativistic space-time structure; but there is no consensus that a full understanding of this coexistence has been achieved. Furthermore, there are great difficulties in achieving a special relativistic quantum-mechanical treatment of the measuring process, because an actual measurement occupies a space-time region, which can have arbitrarily great spatial or temporal extent, according to the frame of reference (E.P. Wigner, Princeton University). Wigner also noted the profound difficulties that quantum mechanics poses for general relativity, which postulates that space-time structure is physically variable. These considerations are part of his general contention that the domain of validity of quantum mechanics must be limited.

Limitations

If quantum mechanics does indeed have limited validity, one reasonable place to look for its breakdown is at the level of macroscopic bodies, which are normally amenable to description by classical physics. A. Leggett (University of Illinois) and several speakers associated with him have explored the feasibility of observing macroscopic quantum-mechanical effects (see Eckern, U. *Nature News and Views* **319**, 726; 1986 for a discussion of this point).

The magnetic flux trapped in a superconducting ring is macroscopic in the sense that it can be measured directly by a magnetometer without amplification devices, and yet it may exhibit quantum-mechanical behaviour in two ways: tunnelling of trapped flux through a potential barrier; and coherent superposition of two distinct flux states (by analogy to the superposition of chiral states in ammonia). Experimental evidence for the occurrence of genuine quantum-mechanical tunnelling, distinguishable by temperature dependence from classical thermal barrier penetration, has been obtained (S. Washburn, IBM Watson Research Center).

If quantum mechanics is confirmed at the macroscopic level, which most of the participants seemed to think probable, then the great problems of interpreting the theory will in one way become more intractable and in another less pressing for working physicists — according to the old Viennese maxim, "the situation is hopeless but not serious". But there is little doubt, in view of the intensity of interest exhibited at the conference, that imaginative and responsible speculation on these problems will continue. □

*Techniques and Ideas in Quantum Measurement Theory, 21 – 24 January 1986 at the World Trade Center, New York. Sponsored by the New York Academy of Sciences and dedicated to Professor E.P. Wigner.

Abner Shimony is in the Department of Physics and Philosophy at Boston University, 590 Commonwealth Avenue, Boston, Massachusetts 02215, USA.