The Times (London) Higher Education Supplement (Sept. 1998)

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Measured successes

Conceptual Foundations of Quantum Mechanics: An Overview from Modern Perspectives

By Dipankar Home

Plenum, 386pp, £83.64
ISBN 0 306 45660 5

Quantum mechanics is the jewel in the crown of 20th-century physics. The beginnings of quantum physics more or less coincided with the turn of the century with Max Planck's explanation of the properties of thermal radiation and Einstein's elucidation of the photo-electric effect. Its basic principles were fully established soon after the first quarter of the century was over, and these have been refined and extended since. At the end of the 20th century, quantum theory not only explains the properties of the quarks and other fundamental constituents of matter, it also describes the collective properties of electrons and atoms in solids — accounting for their relatively mundane properties as well as exotic behaviour such as superconductivity. No quantum prediction has ever been falsified.

However, the triumphs of quantum physics are not what this book is about. Despite its outstanding success, there have always been problems understanding what quantum mechanics actually means. Einstein and others challenged the early orthodoxy, associated mainly with Neils Bohr, and the modern version of this orthodoxy is still challenged by many. Much of this is explained in Dipanker Home's book. The first chapter sets out the standard formalism of quantum mechanics with its standard interpretation and introduces the alternative model associated with David Bohm.

The standard approach is based on the idea that it is meaningless to attribute any property to a quantum system unless the experimental situation is such that it is in principle capable of being observed, but the Bohm model asserts that electrons always possess properties such as position and momentum. This means that the ontology of Bohm's model is in essence the same as that used in the physics of everyday objects. Home quotes Bohm as admitting that there are no differences in the predicted outcomes of the rival theories. Nevertheless, he is clearly attracted by Bohm's realism and comes close to implying (I believe wrongly) that conventional quantum theory cannot explain the results of a particular example concerning the decay of K mesons, which is particularly amenable to Bohm's approach.

The second chapter, "Quantum measurement paradox", is the crux of the book. Many of us believe that the only real problem in quantum physics is the measurement problem. Home clearly describes how this problem arises by reference to a commonly quoted example. Experiments can be conducted to measure the components of the angular momentum (spin) of an atom, which classically would point in some direction in space. If we first ask whether this direction is up rather than down, then a measurement will tell us which it is quite unambiguously. However, if it is up, say, and we then ask whether its horizontal component points to the right or to the left, problems arise. A definite outcome of such a measurement is always obtained, but only at the cost of losing our knowledge about the spin's "upness" or "downness". Conventionally this is explained on the basis that the second measurement has disturbed the system and destroyed the information extracted from the previous measurement: in Bohrian terms, the up-down property is meaningless in the context of the right-left measurement.

However, as Home explains, a direct application of the rules of quantum mechanics yields quite a different result: the state of the particle should be unaffected by the measurement, but the measuring apparatus should be put into a state where it is simultaneously indicating left and right. The conventional Bohrian view denies the possibility of macroscopic objects, such as measuring apparatus, being in such quantum states — because we never observe them as such. A measurement then implies a quantum "jump" or "collapse" into one of the states allowed in the new experimental context (right or left in the earlier example).

Home criticises this approach for its arbitrariness and outlines some alternatives that have been proposed to resolve this problem. These include "many worlds" theory, in which no collapse actually occurs though we think it has, various attempts to modify the laws of quantum physics to include collapse, and the Bohm model again.

After the peak of chapter two, the rest of this book is a slight anti-climax. The third chapter discusses how the laws of quantum mechanics approach those of classical physics in the limit of systems being large and complex. However, no significant problems emerge that are not further manifestations of the measurement problem discussed in the previous chapter. The fourth chapter, "Quantum nonlocality", contains a thorough account of the work started by John Bell, in which it has been showed that experiments carried out on particle pairs explicitly refute at least the naive version of local realism underlying the Bohm ontology. If it were not for this, Bohm's approach would probably be the orthodoxy by now, but most believe that Bell's theorem and its subsequent experimental confirmation have fatally flawed it.

A chapter on "Wave particle duality" has an account of some fascinating experimental work by Alan Aspect that reveals the inadequacy of many of the arguments used to explain to students why light has a particle nature. The last three chapters contain a description of the quantum zeno effect, a discussion of causality and a reappraisal of Einstein's contributions in this field.

Home has written a wide-ranging scholarly text. General readers should be aware that it is aimed at students taking graduate courses in quantum mechanics and active researchers. The amount of physics knowledge assumed is not great, but the level of mathematical sophistication is quite high. I would have preferred a fuller discussion of some of the more unorthodox ideas touched on, and I would like to know where Home stands on many of the issues discussed. However, overall this is a very good book that should be highly recommended to its target audience.

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