obituaries

Paul Adrien Maurice Dirac

Paul Adrien Maurice Dirac, who died on 20 October 1984, was one of the great physicists of the century. Born on 8 August 1902, he obtained an engineering degree at Bristol in 1921, but his outstanding mathematical ability was soon recognized, and after concentrating on mathematics at Bristol for two years he was offered a grant for graduate studies at Cambridge. There he worked under R. H. Fowler; five of his papers written during that time show his already firm command of relativity, quantum theory and statistical mechanics.

His first paper on quantum mechanics was written while he was still a student. He had obtained from Fowler a proof copy of Werner Heisenberg's paper and immediately saw the significance of the new ideas. In particular, he saw the fundamental role of noncommutative algebra and started extending the ideas even before Heisenberg's paper was published. From then on he developed the structure of quantum mechanics in his own way, introducing his own characteristic notation, much of which came into general use. He showed how to combine both Erwin Schrödinger's and Heisenberg's approaches into one common system by using what we now call transformation theory. In this context he introduced the bracket notation and later found it useful to split the brackets in two parts, which he called "bra" and "ket," further pieces of terminology that have come into general use. (I believe he was not aware at the time of the alternative meaning of bra.) The inclusion of continuous variables in the general transformation theory was made possible by the "delta function," another invention of Dirac, which horrified the purists until it was made respectable by Laurent Schwartz.

Dirac took many more important steps in completing the foundations of quantum mechanics, including the first discussion of the emission and absorption of radiation, and of dispersion. He introduced the density matrix, which besides being a convenient tool for quantum statistics is an important concept for the interpretation of quantum mechanics. He saw, independent of Heisenberg and Enrico Fermi, the connection between the symmetry of the wave function and the Pauli principle, leading to Fermi–Dirac statistics.

In 1928 he formulated what is now called the Dirac equation, the relativistic wave equation, which became the keystone of atomic quantum mechanics. Considered as a wave equation for one particle, it is beset by the difficulty of the negative-energy states—but by another stroke of genius he conceived the hole theory, in which all negative-energy states are normally occupied. At first he thought the holes, or empty places in the negative-energy region, were protons, but this hypothesis could not be maintained, and they turned out to be the positrons.

Paul Dirac and Werner Heisenberg in 1933.

In 1932 Dirac succeeded Sir Joseph Larmor as Lucasian Professor of Mathematics in Cambridge (where, traditionally, theoretical physics is regarded as part of mathematics) and he held this position until his retirement in 1969. In 1971 he became professor of physics at Florida State University.

By the early 1930s, quantum mechanics was essentially complete, and it owed an enormous debt to Dirac, who was recognized with an award of a Nobel prize in 1933.

His work would have secured him a position amongst the great names in physics, even if he had done nothing after 1933, but he continued without slackening his pace. Some of the later work involved applications of quantum mechanics, but most of it was trying new departures to advance into as yet uncharted areas of physics. His suggestion of a magnetic monopole ("one would be surprised if Nature had not made use of [this possibility]") and of the change with time of the gravitational and other constants of physics have attracted much attention, but there is as yet no final verdict on their validity. Many other highly original and ingenious ideas have not made any impact on physics, but it would be rash to assert that we may not learn to make good use of them one day, or that we may not see their significance, as was the case with the brief aside in his book *The Principles of Quantum Mechanics*, which turned out to contain the idea of Feynman's "integral-over-paths" method.

All of Dirac's writings are characterized by brevity and extreme clarity. Often he seems to be saying the obvious—only it was far from obvious before he said it. Where other people would hesitate in following a thought through to the end, letting their prejudices divert them, Dirac would show the direct path.

His unusual way of thinking often showed up in conversation about everyday affairs. There are many "Dirac stories" about—some apocryphal, many genuine. They have led to an image that is far too simple and stereotyped to apply to such an unusual person. He was said to be very silent, but he could be very articulate if he had something to say. He was thought to be concerned only with very abstract things, but he invented a method of isotope separation and, encouraged by Kapitza, set up an experiment to test the method. When, during the war, isotope separation became a very practical problem and a team in Oxford decided to try his method, he made many practical suggestions. He collected puzzles and took a great interest in gardening.

Dirac did not supervise many research students, perhaps because he did not like to discuss unsolved problems or speculate what the answers might be. But any students who asked questions would get clear and patient answers.

He received, of course, numerous honors and distinctions, including the Order of Merit—the highest and most selective British honor for great minds.

RUDOLF PEIERLS
Oxford University