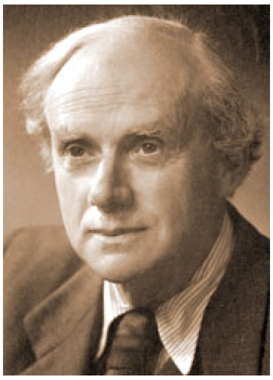
Paul Adrian Maurice Dirac



Bristol, UK, 8 Aug. 1902 - Tallahassee, USA, 20 Oct. 1984

Title Professor of Mathematics, State University of Florida at Tallahassee, USA. Nobel laureate in Physics, 1933

Nomination 11 Aug. 1961

Commemoration – Paul Adrien Maurice Dirac has been one of the most illustrious scientific personalities of our times. His formulations of the fundamental law of quantum mechanics and his discovery of the relativistic equation of the electron, place him at the same rank as Einstein and Bohr in the history of modern Science for the novelty and originality of new ideas.

He was born in Bristol on the 8th of August 1902. His father Charles had left Monthey, a French-speaking town of the Canton du Valais in Switzerland, to come to Bristol as a French tutor. His early upbringing appears to have been rather severe, for his father was known to be a strict disciplinarian at school and more so at home. Children were required to speak only grammatically exact French at the dinner table and Paul has always attributed his taciturnity to this circumstance.

Dirac's first paper on quantum mechanics parallels much of what was being done at the same time by Born, Heisenberg, Jordan and others, but expressed in his own characteristic style. This was followed by a series of papers developing, generalizing and applying the new theory. He was at first puzzled by the appearance of non-commuting quantities, i.e., that by the multiplication rules Heisenberg had been led to, the product of two quantities depended on their order, i.e., A times B did not equal B times A. This result had also worried Heisenberg. But then Dirac realized that this was the essence of the new approach. It was for him a big step to see that the commutators were the analogue in quantum theory of the Poisson brackets of classical mechanics. This thought occurred to him during a walk in the country. He had developed the habit of relaxing during weekends by going on long walks, and not thinking about his problems, but on this particular occasion he kept thinking about the problem of non-commuting variables, until the similarity with Poisson brackets occurred to him in a flash. He did not remember the theory of Poisson brackets in detail, and he waited impatiently until Monday morning when he could check the details in the library.

He commented later that it was easier for him than Heisenberg to find it since scientists who propose a new idea tend to have an emotional attitude to it, and fear it may yet prove wrong. "Lorentz did not have the courage to express relativity, and Heisenberg had the fear of non-commutativity ... the originator of an idea is not the best person to develop it".

He went to Copenhagen in September 1926. Here he completed his paper on transformation theory which shows the Schroedinger wave equation, Heisenberg's matrix equations to be special cases of more general formulation. He comments that this work gave him more pleasure in carrying it out than any other paper he wrote on quantum mechanics before or after. In this paper he also introduces a notation which has become standard for most work in quantum mechanics.

He enjoyed the formal friendly atmosphere in Copenhagen and many long conversations with Niels Bohr whom he appreciated greatly for his depth. He said later that he did not know whether Bohr had any influence on his work because Bohr tended to argue qualitatively while he himself liked to think in terms of equations.

He moved to Göttingen in February 1927. At that time he had become very well-known and appreciated by the scientific community. Recognition did not change his habits greatly. He continued to work intensely, mostly in his college room and largely following his own thoughts. He interacted particularly with fellow student Robert

Oppenheimer and he had many discussions with Max Born, James Franck, Igor Tamm, with whom a lasting friendship developed.

He kept looking for a relativistic theory of the electron and in the winter of 1927-28 he found the right equation now known as Dirac equation, probably his greatest contribution to modern physics. This equation not only gave a relativistic description of the electron, but showed that it had a spin of half a unit, as was known empirically, and associated with this spin a magnetic moment of the correct magnitude.

A comment by Mott is typical of the impact of this paper on physicists: "This seemed, and still seems to me the most beautiful and exciting piece of pure theoretical physics that I have seen in my lifetime – comparable with Maxwell's deduction that the displacement current, and therefore electromagnetism, must exist".

The energy levels predicted by Dirac's equation were the same as those given by Sommerfeld's formula, which agreed well with observation. The equation had, however, a serious flaw in that it allowed unphysical solutions in which the electron moved with negative energy. Dirac gave much thought to attempts at avoiding this trouble, and in 1930 hit on the idea that all negative-energy states might in nature be filled, thus preventing, by Pauli's exclusion principle, any further electron going into any of these states. A vacant place, or "hole", would then appear as a particle of positive charge, and of the same mass as the electron. Such a particle had never been seen, and Dirac decided that if it existed it could not have escaped detection. The only known positively charged particle was the proton, and for a time Dirac believed that the "holes" were protons. In that case their very much larger mass would have to be attributed to the Coulomb interaction between charged particles, which is difficult.

However, he had to abandon this hypothesis, and by 1931 he came to seriously consider the possibility that there was a new, as yet undiscovered particle, which he called "anti-electron". This idea was indeed confirmed when the positron was discovered in 1932. In an autobiographical interview he candidly said that he had forgotten that he had made this remark, and it is not generally realized that he was the first to speak of such a particle.

Meanwhile, besides a substantial output of research, he completed his book *The principles of quantum mechanics*, of which the first edition was published in 1930. This, and the three later editions, which were substantially revised, have helped generations of physicists to learn the spirit of the new physics. It reflects Dirac's very characteristic approach: abstract but simple, always selecting the important points and arguing with unbeatable logic.

Although in the 1930's the quantum mechanics of atoms and systems of atoms was complete and well understood, in no small part due to the work of Dirac, the quantum theory of the electromagnetic field was still giving trouble. To many questions the theory gave infinite answers. Dirac was unhappy about these difficulties and made numerous attempts to eliminate them, but without success. At the same time he continued working on new applications and new methods. In addition he produced two quite revolutionary ideas not directly connected wIth the search for an improved quantum electrodynamics.

One of these was the magnetic monopole. He showed that the equations of physics could consistently accommodate a magnetic pole, not previously regarded as possible, provided the product of its strength and the charge of the electron was in integral multiple of hc/2. An interesting implication of this result is not only that the pole strength of any magnetic pole would have to be a multiple of hc/2e, where e is the electron charge, but that if there exists a pole of strength nhc/2e, the charge of any particle would have to be multiples of e/n. This would account for the quantization of charge.

The other idea was what he later called the "large numbers hypothesis". This hypothesis, first put forward in 1937, starts from the belief that the laws of nature should not contain fundamental dimensionless constants of enormous magnitude, and that, where such numbers appear, they are not constant but related to the present age of the universe, which, measured in atomic units, is also a very large number.

Both these ideas attracted much attention and were discussed in many papers besides Dirac's own further work. On their reality there is as yet no final verdict; no certain experimental evidence for magnetic poles or for the variation in the planetary orbits predicted by Dirac has been found, though there are some positive indications.

However, since 1947, a large number of new particles have been discovered experimentally and their properties confirm the idea and the consequences of the Dirac equation. Fundamental particles which are now believed to be ultImate constituents of matter, namely the ordinary electrons, muons and tau and their neutrino partners, as well as six quarks, have their properties connected to the principles contained in the Dirac equation. In particular the properties of spin and the existence of the antiparticle were all observed experimentally.

The genious of Dirac has permitted a better understanding of the symmetry principle which dominates nature. Amongst those who had the fortune of knowing him personally, he will be however long remembered for his proverbial modesty and taciturnity. As a very general style of life he did not seek honours and replied "regretfully no" when any University sought to award him with honorary degrees. When in 1933, he shared the Nobel Prize

for Physics with Schroedinger, at first he was inclined to refuse the prize because he did not like publicity, but then he accepted when Sir Ernest Rutherford told him: "a refusal will get you much more publicity".

He retired in the United States, where so many of his friends lived. From 1969, he spoke regularly at the Coral Gables conferences.

Right to the end Dirac was opposed to the doctrine of renormalization of field theory and this was the topic of his last talk in January 1984. Although visibly failing, he spoke clearly and firmly, albeit softly. His lecture is to be published in a book, originally intended as commemoration of his 80th birthday, now entitled "The Dirac Memorial Volume".

Paul Adrien Maurice passed away peacefully on October 20, 1984.

Carlo Rubbia