DIRAC'S PHYSICS AND HIS INTERACTION WITH THE SCIENTIFIC COMMUNITY

Dirac: A Scientific Biography

Helge S. Kragh
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Reviewed by Sylvan S. Schweber

Paul Adrien Maurice Dirac (1902–1984) was not only one of the creators of quantum mechanics, he was also one of the principal architects of quantum electrodynamics and quantum field theory. Some work of Dirac is at the starting point of all the major developments in the synthesis of quantum mechanics and the special theory of relativity. Abdus Salam and Eugene Wigner, in the preface to the *festschrift* that honored Dirac on his 70th birthday in 1972, succinctly gave the measure of the man: "Posterity will rate Dirac as one of the greatest physicists of all time. The present generation values him as one of its greatest teachers." They also noted that Dirac had achieved the status of being "a legend in his own lifetime and rightly so."

One of the valuable features of Kragh's fine if impersonal biography is that he dispels the myths surrounding Dirac and paints a portrait that clearly indicates Dirac's limitations without diminishing his greatness.

In a very instructive appendix, entitled "Dirac Bibliometrics," Kragh observes that Dirac's publications can be divided into three groups: those written between 1924 and 1934, those between 1934 and 1945 and those published after World War II. During the first period almost all his publications were research papers. Among these are his most original and seminal contributions: laying the foundations of nonrelativistic quantum mechanics and of quantum electrodynamics, inventing the Dirac equation; introducing the Dirac sea and the notion of an antiparticle; exploring the consequences of the existence of magnetic monopoles; and indicating the effects of external electromagnetic fields on the Dirac sea (vacuum polarization). The first edition of *The Principles of Quantum Mechanics* (1930), his classic exposition, was also written during that period.

After 1934 Dirac's productivity fell. Most of his scientific papers during the second period were written during the war and concerned war-related research. It is during this period that Dirac began speculating about cosmology and making allusions to the role of beauty in the construction of physical theories. Most of his publications dating from the third period were not research papers; in fact, only 18 out of 128 were.

Kragh gives a competent presentation of Dirac's accomplishments during the first period. However this book lacks the critical insights that Abraham Pais gave to Einstein's work, or Max Dresden to Kramers's writings after 1934. His account of Dirac's "adventures in cosmology" and of Dirac's philosophical musings are important, original contributions to our knowledge and understanding of Dirac's thought. Kragh's presentation delineates the character of Dirac's later works, and his thoughtful, critical assessment puts them in their proper perspective. Impressive historical erudition marks the writing of the biography. Kragh draws skillful sketches of the institutions (for example, the Merchant Venture's College, Bristol University and Cambridge University) and of the people (such as Henry Baker, Ebenezer Cunningham, Arthur Eddington and Ralph Fowler) that helped shape Dirac's approach to physics and mathematics. The book also contains a fairly detailed account of Dirac's travels and of his interactions with other physicists. It is accurate and trustworthy; the few mistakes I found are either minor or obvious typographical errors. A valuable feature of the book is its bibliography, which not only gives a complete enumeration of Dirac's publications but also provides the reader with a fairly complete list of references to the rich literature on Dirac.

Kragh has called his book a scientific biography. He never met Dirac and so he depended for his insights into the character of Dirac on the interviews and writings of others. As is well known, Dirac experienced a most difficult childhood. Dirac's domineering father made it a rule to be spoken to only in French. Unable to express himself satisfactorily in French, the young Dirac often had to remain silent. He stayed "a very silent man for life." When his father died in 1935, Dirac wrote his wife: "I feel much freer now." Throughout his life, his interactions with others—or rather the lack thereof—reflected the trauma of his childhood.

Even though it was not Kragh's intention to plumb and connect the psychological and scientific dimensions of Dirac's life, a sensitive portrait is drawn. What also emerges from Kragh's presentation is a correlation between the relevance—and importance—of Dirac's research and the strength of his coupling to his scientific community. During his most productive years—from 1924 to 1934—he was a member of the scientific circles in the Cavendish laboratory and an active participant in the activities of the Kapitza and the $\nabla^2 V$ clubs; he travelled to Copenhagen, Göttingen, Leipzig and various places in the United States and Russia to deliver lectures, and he carried on an extensive scientific correspondence with Werner Heisenberg, Wolfgang Pauli, Niels Bohr, Igor Tamm and many others. Thereafter the strength of the coupling decreased and he became much more isolated.

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World War II once again made him interact strongly with his scientific colleagues. In the early 1930s, Dirac had been interested in the separation of isotopes by the centrifugal effect. His research at that time included the design and construction of apparatus. With the encouragement of Peter Kapitza, Dirac carried out the experimental work himself. He returned to these problems during the war and made important contributions to the separation of uranium isotopes and to gas centrifuge technology in general.

After the war, he became a loner once again, marching to the tune of his own drum. The "inadequacies" of quantum field theory became a constant refrain, and on many occasions he explained why he was not satisfied with the renormalization program, even though it was "a big success": He felt that physicists should concentrate on trying to find "*the* correct Hamiltonian."

Science is a social process and the consequences of isolation are strikingly apparent in the cases of men of genius like Dirac and Einstein.

A Journey into Gravity and Spacetime

John Archibald Wheeler
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G. D. Birkhoff is reputed to have said that any intelligent 12 year old can understand general relativity—provided he or she is familiar with tensor analysis. In this remarkable book John Archibald Wheeler sets out to explain the central ideas of general relativity to readers whose previous acquaintance with mathematics stops at elementary algebra. His strategy is not to skirt the difficulties of tensor analysis but to dig beneath them. In his 1973 graduate text *Gravitation*, written with Charles W. Misner and Kip S. Thorne, Wheeler introduced a generation of physics students to Elie Cartan's coordinate-free approach to differential geometry and general relativity. Cartan's language of differential forms, wedge products and exterior derivatives is more abstract than tensor analysis, but in certain respects it is also simpler. In *A Journey into Gravity and Spacetime*, Wheeler undertakes the monumental task of translating key aspects of Cartan's version of Einstein's theory into words and pictures.

Some aspects of Einstein's theory lend themselves readily to a pictorial–verbal approach—for example, the notions of curved space and curved space–time, and of geodesics and geodesic deviation. But Wheeler isn't content to stop here. His far more ambitious aim is to make intelligible to nonmathematical readers what he regards as the heart of Einstein's theory, the contracted Bianchi identity. Cartan showed that this identity follows from a principle that Wheeler sums up as "the boundary of a boundary is zero," and that it expresses the conservation of a geometric object, the moment of rotation. Einstein's field equation makes this geometric object proportional to momentum–energy, which has the same symmetry characteristics, thereby ensuring that momentum and energy are conserved. "Thus simply," Wheeler and his coauthors wrote in *Gravitation*, "is all of general relativity tied to the principle that the boundary of a boundary is zero." In his new book Wheeler seeks to elucidate "the double grip of mass on spacetime and of spacetime on mass" by guiding the mathematically naive reader along the path that leads to this conclusion.

Having secured this primary objective, Wheeler next builds up a detailed picture of the curvature of space and space–time in the vicinity of a center of mass. In this context he introduces the reader, gently but firmly, to some basic notions of differential calculus. A partial derivation of the Schwarzschild metric paves the way for a clear account of particle orbits near a black hole, based on the angular-momentum and energy integrals of the exact equations of motion. There follow insightful but less detailed accounts of black-hole thermodynamics and gravitational radiation.

In a short final section on cosmology, Wheeler attacks several pillars of contemporary conventional wisdom. He concludes that the nonluminous component of galaxies and galaxy clusters is ordinary matter rather than some hypothetical kind of nonnucleonic matter (for example, "cold dark matter") and that gravitation alone is responsible for both the large-scale structure of the universe (filaments and voids) and hierarchical gravitational clustering. He also states that the fact that the present cosmic mass density is not greatly different from the value corresponding to zero spatial curvature requires no "fine-tuning of the initial expansion rate" and no "new principle that will automatically guarantee the desired delicacy of adjustment of the energy." I agree with these heterodox conclusions but not with some of the arguments used to support them. For example, given Wheeler's assumptions, the cosmological model he de-