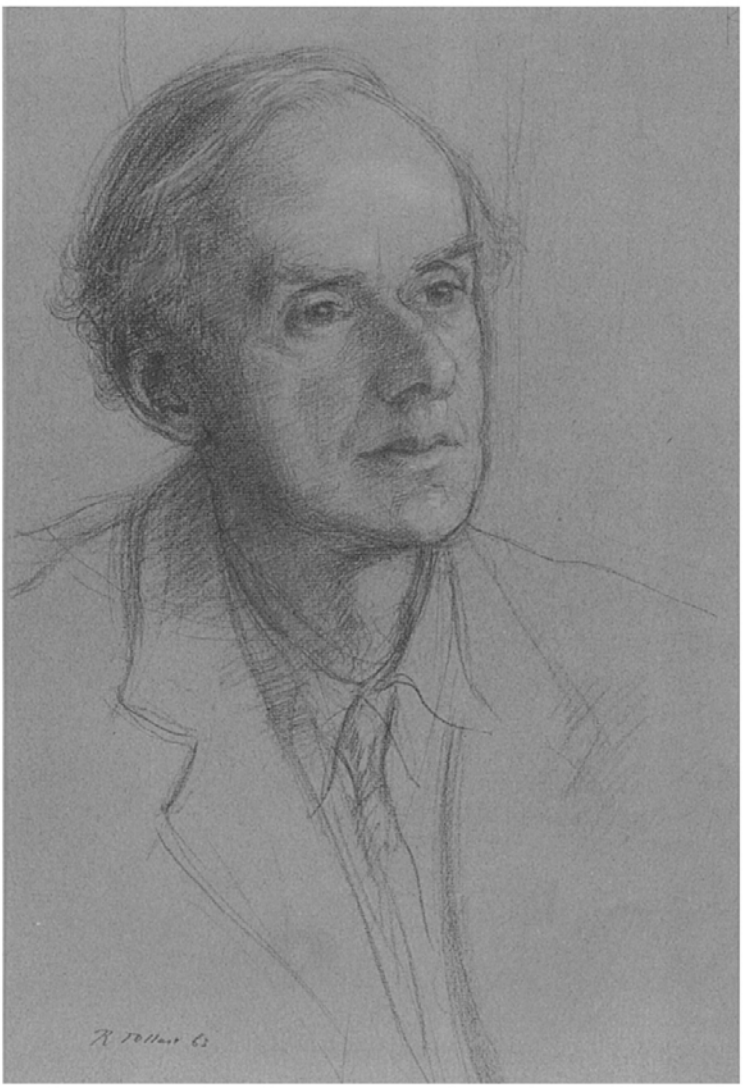
Paul Adrien Maurice Dirac was one of the founders of quantum theory and the author of many of its most important subsequent developments. He is numbered alongside Newton, Maxwell, Einstein and Rutherford as one of the greatest physicists of all time.

This volume contains four lectures celebrating Dirac's life and work, and the text of an address by Stephen Hawking, which were given on 13 November 1995 on the occasion of the dedication of a plaque to him in Westminster Abbey. In the first lecture, Abraham Pais describes from personal knowledge Dirac's character and his approach to his work. In the second lecture, Maurice Jacob explains not only how and why Dirac was led to introduce the concept of antimatter, but also its central role in modern particle physics and cosmology. In the third lecture, David Olive gives an account of Dirac's work on magnetic monopoles and shows how it has had a profound influence in the development of fundamental physics down to the present day. In the fourth lecture, Sir Michael Atiyah explains the widespread significance of the Dirac equation in mathematics, its roots in algebra and its implications for geometry and topology. Together the four lectures in this volume give a unique insight into the relationship between Dirac's character and his scientific achievements.

PAUL DIRAC

THE MAN AND HIS WORK



PAUL DIRAC

THE MAN AND HIS WORK

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Preface

Paul Adrien Maurice Dirac was one of the founders of quantum theory and the author of many of its most important subsequent developments. He is numbered alongside Newton, Maxwell, Einstein and Rutherford as one of the greatest physicists of all time. He was born in Bristol on 8 August 1902 and died on 20 October 1984 in Tallahassee, Florida. On Monday 13 November 1995, after evensong, a plaque was dedicated in Westminster Abbey commemorating Paul Dirac. The simplicity and almost austere beauty of the plaque's design reflected in some ways the qualities of Dirac's unique intellect.

After graduating from Bristol University with a first class degree in engineering, Dirac stayed on to study mathematics there before obtaining a studentship in 1923 to enable him to undertake research at St John's College, Cambridge. In 1925, he became a Fellow of St John's College. In 1932, he was elected Lucasian Professor of Mathematics in the University. The Lucasian Professorship was once held by Sir Isaac Newton, and the present holder, Stephen Hawking, was present in the Abbey to give an address at the service of commemoration and the text of this address is included in this volume.

Dirac shared the 1933 Nobel Prize for Physics with Erwin Schrödinger. After retirement from the Lucasian chair in 1969, he accepted a research professorship at the Florida State University in Tallahassee. There he continued to work on fundamental physics, frequently returning to St John's College for summer visits, until shortly before his death.

This volume contains four lectures celebrating Dirac's life and work which were given at the Royal Society as a preface to the ceremonies in the Abbey, as well as the text of the address given by Stephen Hawking. The main force behind this commemoration was Richard Dalitz of Oxford University.

In the first lecture, Abraham Pais, of Rockefeller University, New York, and distinguished both for his contributions to fundamental physics and his works on its history, surveys the life and work of Paul Dirac. Although he was famous for his taciturnity and rather retiring nature, Dirac travelled frequently in order to maintain contact with leading physicists in many parts of the world. He visited the Institute for Advanced Study in Princeton several times over the years and there Pais came to know him quite well. His lecture conveys Dirac's singular personal qualities and their relationship to his approach to physics with its emphasis on beauty and simplicity.

The work of Dirac which has most caught the popular imagination is his prediction of the existence of antimatter, which was described by Dirac's lifelong friend, Werner Heisenberg, as 'the most decisive discovery in connection with the properties or nature of elementary particles ... [It] changed our whole outlook on atomic physics completely'. Seeking to find a theory which reconciled quantum theory with relativity, Dirac found himself led inexorably to the equation which bears his name and which is now engraved on a plaque in the Abbey. As so often when two fundamental ideas are brought together, a third was born, and the existence of antimatter came to be seen as an inevitable consequence of the Dirac equation. Maurice Jacob, of CERN, Geneva, in the second lecture in this volume, explains not only how and why Dirac was led to introduce the concept of antimatter, but also its central role in modern particle physics and cosmology and its importance in practical applications.

Dirac cited mathematical beauty as the ultimate criterion for selecting the way forward in theoretical physics, and he would follow the paths he discerned with great consistency, clarity and

courage, often far away from the more well-trodden routes. In the third lecture, David Olive, of the University of Wales Swansea, gives an account of Dirac's work on magnetic monopoles, initiated in 1931, showing that although they have remained undetected experimentally, the ideas Dirac initiated have had a profound influence on the development of fundamental physical theories down to the present day.

The influence of Dirac's ideas has been felt almost as much in mathematics as in physics. In the fourth lecture, Sir Michael Atiyah, speaking as President of the Royal Society and Master of Trinity, explains the significance of the Dirac equation in mathematics, its roots in algebra and its implications for geometry and topology, again taking us forward to very recent developments.

Together the four lectures in this volume make clear how the purity of Dirac's nature and intellect guided his whole work and gave him a penetrating vision, revealing concepts of great depth and prevailing influence in mathematics and physics. They give a unique insight into the relationship between his character and his scientific achievements. Dirac wrote 'it is more important to have beauty in one's equations than to have them fit experiment ... It seems that, if one is working from the point of view of getting beauty in one's equations, and if one has really sound insight, one is on a sure line of progress. If there is not complete agreement between the results of one's work and experiment, one should not allow oneself to be too discouraged, because the discrepancy may be due to minor features ... that will get cleared up with further developments of the theory.' Dirac was writing about Schrödinger but it was his own work that showed just how powerful such an approach could be when adopted by someone with the deepest insight.

PETER GODDARD
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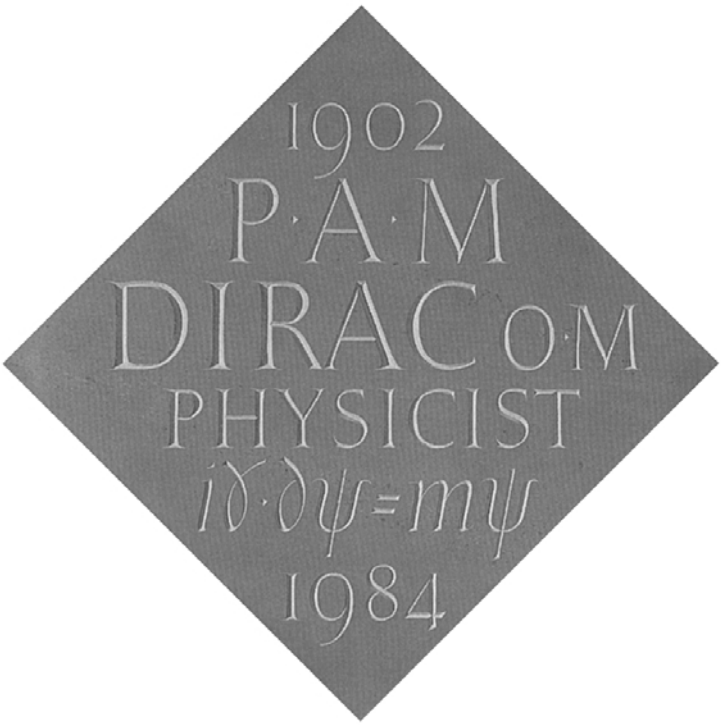

This green slate memorial at Westminster Abbey was designed and cut at the Cardozo Kindersley workshop in Cambridge, UK.
(Photo taken by Michael Manni)

Dirac Memorial Address

STEPHEN HAWKING

Paul Adrien Maurice Dirac (my speech synthesizer isn't very good with his name) was born in Bristol in 1902, to a Swiss father, and an English mother. He went on to become the Lucasian Professor at Cambridge, and to win a Nobel Prize, but was never well known to the public. His death in 1984 drew a short obituary in the *Times*, but otherwise it went almost unnoticed. It has taken 11 years for the nation to recognize that he was probably the greatest British theoretical physicist since Newton, and belatedly to erect a plaque to him in Westminster Abbey. It is my task to explain why. That is, why he was so great, not why it took so long.

In the early years of this century the way we picture the world, and our view of reality itself, were completely transformed by two discoveries: the Theory of Relativity and Quantum Mechanics. Dirac played a major role in quantum theory, and his efforts to make it compatible with relativity turned up new and unexpected phenomena.

Dirac was a research student at St John's College, Cambridge, when Werner Heisenberg visited his supervisor, R. H. Fowler, in the summer of 1925. Heisenberg told Fowler about his ideas on

what he called 'matrix mechanics' and sent him a proof copy of his paper on the subject. Fowler passed this to Dirac, who recognized a striking similarity with objects called Poisson brackets in classical mechanics. This led him to write a remarkable paper in which he formulated general rules for the quantum mechanics of any system. These rules incorporated the ideas of both Heisenberg and Schrödinger and showed they were equivalent. Of the three founders of modern quantum mechanics, Heisenberg and Schrödinger can claim to have caught the first glimpses of the theory. But it was Dirac who put them together and revealed the whole picture.

For that alone he would be worthy of a memorial in Westminster Abbey. But he went on, working on how to combine the Special Theory of Relativity with Quantum Theory. In 1928 he discovered what he called the relativistic equation for the electron, but everyone else calls the Dirac equation. As Dirac himself said, this equation governs most of physics and the whole of chemistry. If Dirac had patented his equation, like some people are now patenting human genes, he would have become one of the richest men in the world. Every television set or computer would have paid him royalties.

Dirac made a number of other important contributions to physics, but I won't go into them now. Dirac saw things in very simple and clear terms, and wasn't always able to understand why other people didn't see things similarly. This led to a whole host of Dirac stories. I won't repeat other people's stories, but would like to tell one of my own.

I was a member of the same department as Dirac from 1962 to 1969, but I never saw him. That was because Dirac belonged to the old school who didn't believe in these new-fangled departments of pure and applied mathematics, but worked in their college rooms. And I was working on classical general relativity and not quantum theory at that time, so I didn't go to his lectures. It was not until

1975 that I met him in Rome. I had just been awarded a gold medal by the Pope. Dirac told me that he had nominated someone else for the medal, but had then decided I was better and told the Pontifical Academy so. That was why they had given it to me.

After that I saw Dirac almost every year until his death, when he came back from the University of Florida where he had retired and visited Cambridge in the summer. He never said much, in contrast to his wife, who was Hungarian, and a great character. It was said that this silence was a result of his childhood, when his father would allow him only to speak perfect French at meal times. That may be true, but I suspect he would have been silent even without that. But when he did speak, it was all the more worth hearing.

Dirac has done more than anyone this century, with the exception of Einstein, to advance physics and change our picture of the universe. He is surely worthy of the memorial in Westminster Abbey. It is just a scandal that it has taken so long.