BOOKS & ARTS

Paul Dirac: a physicist of few words

A detailed biography argues that the Nobel prizewinner's notorious reticence delayed experimentalists from discovering the antimatter that would confirm his elegant theory, explains **Frank Close**.

The Strangest Man: The Hidden Life of Paul Dirac
by Graham Farmelo
Faber & Faber: 2009. 560 pp. £22.50

Among scientists, Paul Dirac is widely regarded as being in the same league as Albert Einstein. In London's Westminster Abbey, Dirac's eponymous equation describing the quantum behaviour of electrons is set in stone. But in his home town of Bristol, UK, his reputation is overshadowed by that of his fellow student at the Bishop Road School, Archie Leach — better known as the film star Cary Grant. On asking the Bristol Record Office for material about Dirac for his new book, author Graham Farmelo received the response: "Who?"

Danish physicist Niels Bohr described Dirac as "the strangest man". His extreme reticence, monosyllabic responses and repetitious statements are legendary. Six years elapsed before even close colleagues learned any of P. A. M. Dirac's forenames. When he came up with the equations of quantum mechanics, his weekly postcard home merely said, "Not much to report here." After solving a decades-old problem by creating Fermi–Dirac statistics later that year, the news once more was: "Not much to report." When he arrived at the relativistic quantum equation that describes the electron, he didn't even send a postcard. Even his colleagues were unaware of it.

In this elegantly written biography, Farmelo's meticulous research sheds considerable light on Dirac's personality and the circumstances behind it. Several members of Dirac's extended family developed acute depression, six committing suicide within a century, including his brother. His father was cold and authoritarian, his mother overweening — the description of her excruciating behaviour at the Nobel prize ceremony, haranguing journalists and officials on behalf of her idolized son, is pure entertainment. Dirac immersed himself in mathematics.

The received wisdom is that in producing his equation for the electron, Dirac 'discovered' the concept of antimatter in 1928, and four years later, Carl Anderson's discovery of the positron in cosmic rays validated Dirac's idea. But in Farmelo's account the reality is rather different.

Dirac's electron equation — declared "achingly beautiful" by physicist Frank Wilczek — described the spin of the electron, and caused

Paul Dirac predicted the anti-electron's existence, but did little to encourage others to hunt for it.

a sensation once people began to understand its unusual structure. However, it contained puzzling solutions in which the electron had negative energy. Dirac proposed that a vacuum is filled with a sea of negative-energy electrons. Any hole in this vacuum would appear as a positively charged, positive-energy particle. At first, he thought that this particle was the proton, until J. Robert Oppenheimer pointed out that if this were so, the electron and proton could destroy each other and matter would be unstable. Wolfgang Pauli was equally sceptical, remarking that anyone making a theory of matter should first apply it to the atoms of their own body. Pauli went on to prove that the positive particle must have the same mass as an electron, which was worrying because experimenters had not found any such particle. With the debate unresolved, many began to wonder if Dirac's equation might be wrong.

In 1931, Dirac referred for the first time to the 'anti-electron', remarking that it could not occur in nature owing to its immediate destruction by ubiquitous electrons. Although he commented that it could be made transiently in experiments, he was surprisingly circumspect, more concerned with the difficulties of detection than the inevitability of its existence. He made no suggestion as to how experimentalists might make it, or recognize it. He was away in the United States later that year when Robert Millikan gave a talk at the University of Cambridge, UK, showing Anderson's images of particle tracks from cosmic rays — including some that looked like those of electrons but which curved the wrong way in a magnetic field. No one associated these tracks with Dirac's holes.

By 1932, the holes had become a joke. At a meeting in Copenhagen, when Bohr lost his patience and confronted Dirac with: "Do you believe all that stuff?", he simply replied, "I don't think anyone has put a conclusive argument against it." Dirac no longer seemed to be strongly committed to the anti-electron; the absence of the particle was, Farmelo says, "sapping his morale". He even told Werner Heisenberg that he had ceased to believe in it.

On 2 August 1932, Anderson found his first clear single particle trail, now hailed in textbooks as the 'discovery of the positron'. This realization was far from clear cut, however. In a series of missed opportunities, no one seemed able to put two and two together to link Dirac's holes and Anderson's 'positron'.

Anderson published his positron paper in September 1932 in the journal *Science*. But remarkably, no one in Cambridge seemed to have read it. By that autumn, British physicist Patrick Blackett had his own images of positrons, and had even shown them in a talk with Dirac and Soviet physicist Peter Kapitsa in the audience. Dirac stayed silent. Kapitsa exclaimed

"Now, Dirac, put that into your theory! Positive electrons, eh!" Farmelo comments that Kapitsa "had spent hours talking with Dirac but had evidently not even heard of the anti-electron" and that Dirac simply replied "Positive electrons have been in the theory for a very long time". Yet there is no sense that Dirac was claiming anything, apparently convinced that the positive trails in the pictures were "a mirage". Farmelo sees Dirac as exhibiting "reticence taken to the point of perversity". His colleagues so mistrusted his abstract theory that they could not accept that it predicted new particles.

The first link between hole theory and the positron came from Blackett, who showed sensational images of electron–positron pair creation at a meeting at the Royal Society in London, saying that they "fit extraordinarily well with Dirac's hole theory". Immediately afterwards, journalists rushed to interview him. Meanwhile Dirac, who was lecturing in another room in the same building, was "unavailable for comment".

According to Farmelo, Dirac later realized that he held responsibility for not having advocated that experimentalists should hunt for positrons, nor advising on how to detect them. Had he done so, the positron could have been discovered "in a single afternoon", as Anderson put it. When asked later why he did not speak out and predict the positron, Dirac said, "pure cowardice".

Nonetheless, Dirac on other occasions believed that he had predicted it, although not everyone agreed. Blackett said: "Dirac nearly but not quite predicted the positron." So much for history; today, Dirac's role in foreseeing the positron, and the mirror world of antimatter, was, as Farmelo describes it, "one of the greatest achievements in science".

Farmelo concludes *The Strangest Man* by analysing Dirac's singular character and genius. He makes a sound case that Dirac was autistic, and argues that his behavioural traits were crucial to his success as a theoretical physicist. Cambridge in the 1920s was the ideal environment for him: tolerant of eccentricity; college life providing for his every need; the rules of dining at High Table enabling a rigidly predictable form of social contact. These unusual circumstances enabled Dirac's special genius to flower. As to autism, this is thought to be caused by disrupted brain development, which can show up as irregularities in brain tissue. These can be visualized using positron emission tomography scans — the medical application of Dirac's antimatter. Irony indeed. ■

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The end of the invasion?

Invasion Biology
by Mark A. Davis
Oxford University Press: 2009. 288 pp. $55

Ascension Island in the South Atlantic Ocean is a good example of the changes that invasive species can wreak. Its volcanic mountain tops once hosted a monotonous carpet of ferns. But in 1843, botanist Joseph Hooker recommended that the bleak island be wooded by importing many new plants — what modern ecologists would see as a massive, human-mediated biological invasion. Surprisingly, this resulted not in ecological meltdown, but in the creation of a lush cloud forest. The forest traps mists, cycles nutrients and survives, generation after generation, without its species having evolved together. A study of this anomalous system is cited in Mark Davis's new book *Invasion Biology*. Why? Maybe because it is not so anomalous.

Invasion Biology starts out as a graduate-level text on how organisms brought far from their homes by humans can flourish, often at the expense of native species in the places they 'invade'. But on turning the pages, the book reveals itself to be an iconoclastic argument that much of the field's conventional wisdom is wrong, that biologists are more swayed by their emotions about invasive species than they care to admit, and that invasion biology as a field should be disbanded. Davis writes, "This may be the first time that an author has concluded a book, the title of which is the same as the discipline being reviewed, by recommending that participants consider abolishing their discipline."

Davis is not on the fringe. His arguments crystallize a rumbling of dissent recently heard among those who study invasive species. As he puts it, "There is little about biological invasions that make them so unique that a specialized subdiscipline need be sustained to study them."

Invasion biology began in earnest in 1958 when ecologist Charles Elton published his pioneering book, *The Ecology of Invasions by Animals and Plants* (see *Nature* **452,** 34; 2008). Elton saw species 'invasions' in the context of niches. In an intact, co-evolved ecosystem, every species will have a slightly different role, or niche, and often every niche will be filled. For example, predators eat herbivores; herbivores eat plants; some plants grow on wet soil and some grow on dry. When new species are introduced, the theory goes, they can get a foothold only by finding a vacant niche or by throwing out another species.

Niche theory gives rise to the diversity-invasibility hypothesis, which posits that the more species there are in an ecosystem, the more niches will be filled and the harder it will be for a new species to become established.

But the evidence does not bear this out. Many studies have failed to find any strong relationship between how diverse a place is and how easy it is to invade. Davis concludes that, despite its appeal and its "implicit affirmation of the value of diversity", the hypothesis is not true. In fact, the opposite may hold. In any ecosystem, each individual plant or animal has to get a foothold, irrespective of its origin. A seed does not care whether it is exotic or native when it lands on the ground, and neither do the surrounding species. The key insight is that there is nothing fundamentally different about exotics other than where they came from.


K. SCHAFER/ALAMY
Ascension Island: not all imported species are destructive.

Davis challenges other received wisdom, such as the idea that newcomers are more likely to compete with or predate on natives than help them flourish, and that introduced populations are unlikely to be genetically diverse. He refuses to exaggerate the differences between natives and exotics, or to see exotics as the enemy.

Elton's 1958 book was an expansion of a series of radio broadcasts aimed at the public. Davis speculates that this audience was the reason behind Elton's colourful, militaristic comparisons of "ecological explosions" with bombs. This may have sown the seeds of the current 'good-versus-evil' rhetoric of species invasion, with its talk of biological pollution, killer weeds and battling garlic mustard.

Davis is not a fan of such heated rhetoric. He feels that the dichotomous approach is not ecologically enlightening. Life is much messier, more dynamic and more complex, he says. He stuffs the book with examples of exotic species