From a Theoretical Object to an Observed Particle: The Case of the Positron

Workshop BEYOND THE STANDARD MODEL

Bologna, October 2, 2006

"***J. J. Thomson*** discovered the ***electron***. Numerous are the books and articles in which one finds it said that he did so ***in 1897***…"

"Who", "What", "When".

"… I cannot quite agree."*

*Abraham Pais, *Inward Bound – Of Matter and Forces in the Physical World*, Clarendon Press, 1986, p. 78. Hereafter IB.

What: something whose existence had been predicted?

"In 1892 he [Lorentz] had published his first paper on the atomistic interpretation of the Maxwell equations in terms of charges and currents carried by fundamental particles. In 1892 he called these particles simply 'charged particles'; in 1895 he called them 'ions' […] only in 1899 he called them 'electrons'."

Zeeman (1896) "raised the question of whether his effect could be explained by Lorentz' theory of electromagnetism". Lorentz considered the case of an "ion" bound by harmonic forces within an atom and subject in addition to the [Lorentz] force K. In Zeeman's first experiment only a broadening of the spectral lines was observed. That was however sufficient to make a rough estimate of e/m.

Pais, IB, p. 76.

What: properties of the object discovered

- Photoelectric ejecta and beta rays are electrons (ca. 1899)
- Spin: Goudsmit and Uhlenbeck (1926)
- Electron diffraction: Davisson and Germer, G. P. Thomson (1927)
- Anomalous magnetic moment: P.Kush and H. M. Foley (1947)

…

The positron: the first antiparticle to be predicted and discovered

Dirac’s equation: difficulties with negative energy states:

“Let us assume ... that ... all the states of negative energy are occupied except perhaps for a few of very small velocity” * (occupation being one electron per state, according to the exclusion principle).

Imagine that one such negative energy electrons is removed, leaving a hole in the original distribution. The result is a rise in energy and in charge by one unit. This hole acts like a particle with positive energy and charge.**

*P.A.M. Dirac, “A Theory of Electrons and Protons”, Proc. Roy. Soc. A **126**, 360, 1929. - **Pais, IB, p. 349.

What

“We are ... led to the assumption that the holes in the distribution of negative energy electrons are the protons”. *

“At that time ... everyone felt pretty sure that the electrons and the protons were the only elementary particles in Nature”.**

*P.A.M. Dirac, *op. cit*., p. 363.

**P.A.M. Dirac, in *History of twentieth century physics*, Academic Press, 1977, p. 140.

General information: Pais, IB, p. 351.

February 1930 - Robert Oppenheimer: the theory allows for the process proton and electron going into two photons. A hydrogen atom could spontaneously annihilate into radiation: "[This] gives a mean life of ordinary matter of ten to the minus ten seconds".*

Weyl, 1930: "...according to the [hole] theory the mass of the proton should be the same as the mass of the electron."**

*R. Oppenheimer, Phys. Rev. **35**, 562, 1930.

**H. Weyl, *Gruppentheorie und Quantenmechanik*, 1st edn, Hirzel, Leipzig, 1928 (1930).

May 1931 - Dirac: “A hole, if there were one, would be a new kind of particle, unknown to experimental physics, having the same mass and opposite charge of the electron”. *

*P.A.M. Dirac, Proc. Roy. Soc., A **133**, 60, 1931.

Who and when …

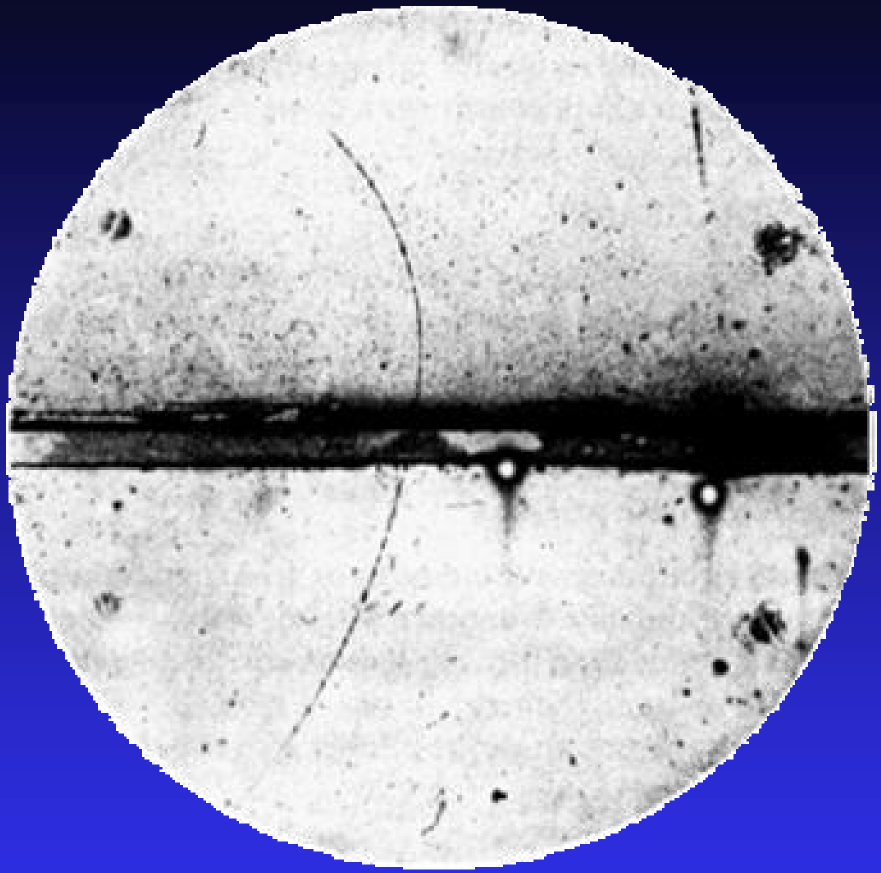
Carl Anderson (ca. 1931) had built a cloud chamber with the highest magnetic field then in existence (up to 25 000 gauss). Before long he detected curious tracks in his chamber with a curvature that indicated positive charge if they were moving downward, negative if upward.*

Pais, IB, p. 352.

"Everybody knows that cosmic rays go downward". Particles moving downward cannot be protons: "… a proton should have one and a half or two times the ionization, or something like, that would be clearly seen on the photograph".

So that he got the idea of putting a lead plate across the centre of the chamber "the point being that if (for example) the particle travels downward and passes through the plate it will have lost energy so that its track will be curved more sharply on the downward side". *

*C. D. Anderson, interview with C. Weiner, June 30, 1966 (general reference: Pais, IB, p. 352).



Anderson proposed that the positive charged particle was ejected from the nucleus of a nearby atom by a cosmic ray impact.

“It seems necessary to call upon a positively charged particles having a mass comparable with that of an electron”.

… ***what***: had Anderson discovered Dirac's particle?

"Yes, I knew about the Dirac theory ... But I was not familiar in detail with Dirac's work. I was too busy operating this piece of equipment to have much time to read his papers ... [Their] highly esoteric character was apparently not in tune with most of the scientific thinking of the day .,.. The discovery of the positron was wholly accidental". *

*C. D. Anderson and H. L. Anderson, in *The Birth of Particle Physics*, Eds. L. M. Brown and L. Hoddeson, p. 131 (general reference: Pais, IB, p. 352).

February 1933: paper by P. M. S. Blackett, G. P. S. Occhialini: Anderson “remarkable conclusion” is reaffirmed, namely that “some of the tracks must be due to particles with a positive charge but whose mass is much less than that of a proton”.

December 1933: reviewing all the experimental data Blackett expressed himself strongly in Dirac’s favour:

“These conclusions as to the existence and the properties of positive electrons have been derived from the experimental data by the use of simple physical principles. That Dirac’s theory of the electrons predicts the existence of particles with just these properties gives strong reasons to believe in the essential correctness of the theory”.

M. De Maria, A. Russo, The Discovery of the Positron, Riv. Stor.Sci., 2 (2), 1985, 237-286, p.p. 268, 279.

*How experiments end**

"The sunset, refracted through the dust and droplets kicked up by all that has happened, recounts in compressed form the whole story of the day. The end of an experiment resembles this sunset, recapitulating in a human context ***the encounter of the reason with the world***".

*Peter Galison, University of Chicago Press, 1987, p. 278.

What good is the discovery of a new particle?

When the Prime Minister asked of a new discovery,

"What good is it?",

Faraday replied,

"What good is a new-born baby?"

However …

It was one of Faraday's electromagnetic devices, legend has it, that prompted his remark to the curious prime minister who failed to grasp its utility:

“But, after all, what use is it?”

Faraday replied,

“Why sir, there is the probability that you will soon be able to tax it.”

N.B.: The anecdote should be considered apocryphal, however, because it isn't mentioned in any accounts by Faraday or his contemporaries (letters, newspapers, or biographies) and only popped up well after Faraday's death.

PET

Positron
Emission
Tomography

Seeing inside our body:
the brain at work

And the future?

"We continue to be inward bound; the heroic period to be discussed is open-ended. Some believe its closure to be imminent. It could be, however, that writing of its history now is like writing of the French Revolution after the Bastille was stormed".*

"If, then, it is true that the axiomatic basis of theoretical physics cannot be extracted from experience but must be freely invented, can we ever hope to find the right way? […] I answer without hesitation that there is, in my opinion, a right way, and that we are capable of finding it. ***Our experience hitherto justifies us in believing that nature is the realization of the simplest conceivable mathematical ideas***". **

*Pais, IB, p. 3
**Einstein, "On the method of theoretical physics",Herbert Spencer Lecture, Oxford, 1933, Clarendon Press.