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Carl Anderson´s 1932 upward going positron

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Abstract

The 1932 discovery-photo of the positron track in Carl Anderson´s cloud chamber has been shown in numerous books and articles over the years. The 63 MeV positron strangely went *upwards* in the chamber, a fact not much discussed over the years. In his 1961 article about the early work on the positron and muon[1] Anderson writes: ”Curiously enough, despite the strong admonitions of Dr. Millikan that upward-moving cosmic-ray particles were rare, this indeed was an example of one of those very rare upward-moving cosmic ray particles.” However, no explanation about the origin of the upward going positron has been published. In this work we discuss different positron sources and give a detailed explanation of the likely origin of Anderson´s upward going positron.

Introduction

Carl Anderson (1905-1991) studied at the California Institute of Technology. For his graduate work he measured the space-distribution of photoelectrons and received his PhD in 1930 under Robert Millikan (often named the Chief). Millikan wanted him to stay at Caltech and measure high energy cosmic rays with a magnet cloud chamber. Anderson stayed at Caltech and constructed the powerful magnetic cloud chamber experiment, in operation from October 1931. At that time only two elementary particles were known, the electron and the proton. The aim of the experiment was to measure the energy spectrum, up to about 1 GeV, of secondary electrons produced in the atmosphere. Anderson was not familiar with Dirac´s work suggesting antiparticles. On August 2, 1932 came the surprise: the discovery of the positron.

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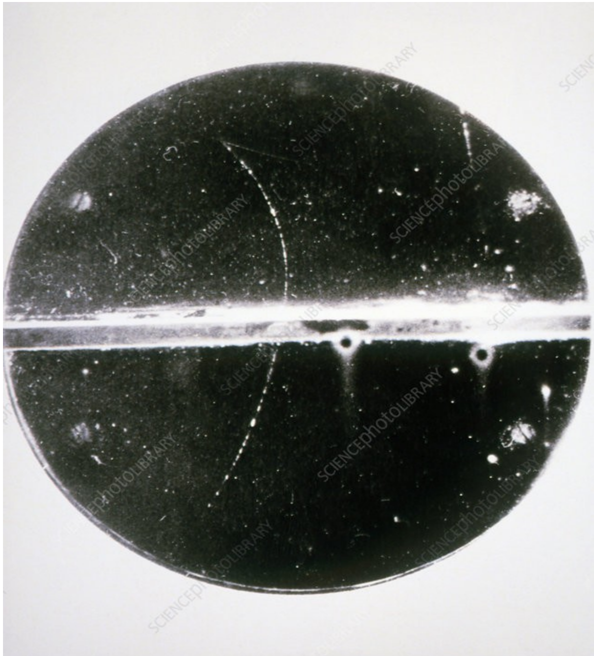
The cloud chamber photo below showing the positron track has been published in numerous books and articles over the years. It is probably, together with the X-ray photo from 1896 of the hand of Röntgen´s wife with a visible ring, the most well-known physics photographs.

Altbough showed so many times the following question has not been discussed or answered: what is the source of the 63 MeV positron? Here is the probable positron source discussed.



The discovery photograph of the positron, the positive version of the electron and the first antimatter particle to be discovered. The cloud chamber photo was taken in 1932 by Carl Anderson at Caltech. It shows the track of a positive particle that enters the chamber from below. The particle is known to be positive because of the way it bends in the chamber's magnetic field; it is proved to be moving up the picture because it loses energy and curves more in the magnetic field after traversing the 6 mm thick lead plate in the middle. But the track is too faint to be caused by a proton; it was exactly like an electron track; it had to be the predicted positron. Photo: Carl D. Anderson papers, Caltech Archieves, California Institute of Technology.

The magnet cloud chamber

Skobeltsyn was first to put a Wilson cloud chamber in a magnetic field in the 1920´s. He could show that cosmic rays are high energy particles [2]. In 1930 Millikan and Anderson, inspired by the work of Skobeltsyn, planned a magnet cloud chamber for cosmic-ray research. Particle energies should be measured using the curved cloud chamber tracks in a magnetic field. Anderson designed and constructed the cloud chamber magnet. The cloud chamber with a diameter of 16 cm and a thickness of 4 cm was placed in a powerful electromagnet with a field of up to 2.4 T. Operation began in October 1931.

Measurements by the droplet counting method of the magnitude of the specific ionization of the positive and negative electrons which occur with energies low enough to be appreciably curved in the magnetic field have shown that the mass and charge of the positive electron cannot differby more than 20 percent and 10 percent, respectively, from the mass and charge of the negative electron.

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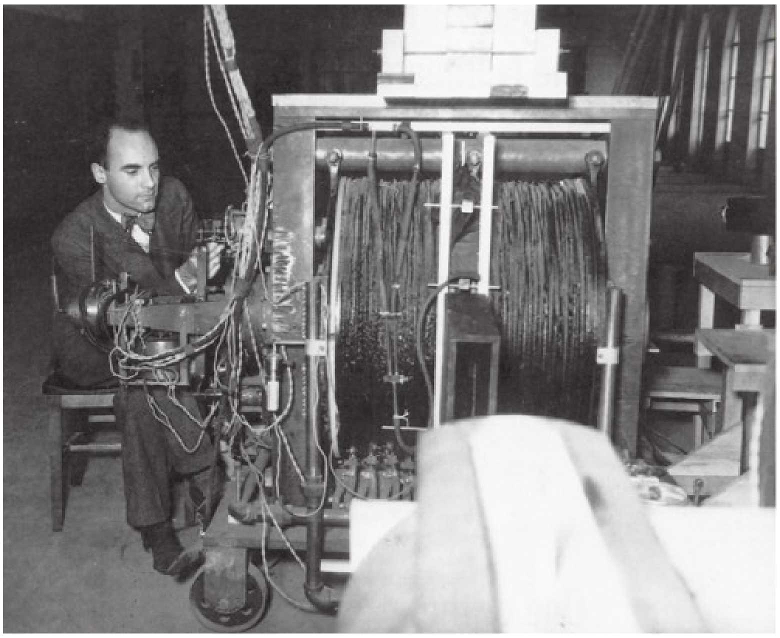


Carl Anderson at the magnet cloud chamber. The 800 turns of 1 cm Cu-tubing carried both an electrical current of up to 1600 A and cooling water, 150 litres per minute. A dc generator in the basement of the Aeronautics building (today Guggenheim building) at Caltech delivered up to 600 kW giving a strong magnetic field of up to 2.4 T. In front of Anderson the camera is visible. *Photo: Carl D. Anderson papers, Caltech Archieves, California Institute of Technology*

The 6 mm lead plate

When the magnet cloud chamber came into operation in October 1931 photos showed many positive particles whose mass seemed to be too small to be protons. At the time only protons and electrons were known. Anderson recalls [3] :

> “...these particles were either ordinary electrons moving upward, or some unknown lightweight particles of positive charge moving downward. In the spirit of scientific conservatism, I tended at first toward the former interpretation, namely, that these particles were upward-moving negative electrons. This led to frequent discussions between the Chief and myself, in which he repeatedly pointed out that cosmic ray particles travel downward, and not upward, except in extremely rare instances, and that these particles must be protons.“

To resolve his apparent paradox, Anderson inserted across the center of the cloud chamber a 6 mm lead plate, an experimental ingenuity. Particles passing through the plate would loose energy and the direction, upward or downward, could be determined.

The discovery

In the evening of August 2, 1932, the well-known photo of the 63 MeV positron was obtained. Anderson writes in his Log book: ”Track 75. Thru Pb showing energy change or double ejection”. Ionization measurements clearly showed the particle to be of low mass compared to a proton and with an energy of 63 MeV loosing 40 MeV in the lead plate exiting with an energy of 23 MeV. Anderson published his discovery in Science on 9 September 1932 [4]. His result was first met with skepticism but the existance of positive electrons, or positrons, was later confirmed by Blackett and Occhialini at the Cavendish Laboratory in the spring of 1933 [5].

In his 1932 discovery paper Anderson discusses possible interpretaions of the cloud chamber track [4]:

(1) a positive particle of small mass penetrates the lead plate and loses about two thirds of its energy; or
(2)two particles are simultaneously ejected from the lead, in one direction a positive particle of small mass, in the opposite direction an electron; or
(3) an electron of about 20,000,000 volts energy penetrates the lead plate and emerges with an energy of 60,000,000 volts, having gained 40,000,000 volts energy in traversing the lead; or
(4) the chance occurrence of two independent electron tracks in the chamber, so placed as to give the appearance of one particle traversing the lead plate.

Carl Anderson received the 1936 Nobel Prize in physics "for his discovery of the positron". The prize was shared with Victor Hess for the discovery of cosmic radiation [6].

Comment by Luis Alvarez 1967

An interesting comment was made by Luis Alvarez (Nobel Prize physics 1968) in an interview by C. Weiner 1967 [7]. When visiting Caltech in 1934 Carl Anderson told Alvarez that when he observed the positron track, the first thing he thought was that students had made a joke reconnected the wires to the magnet and reversed its polarity! But looking at photos just prior to the positron track and just after that it was clear that no one could have disconnected the magnet.

Upward positron of 63 MeV?

Muon decay $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$ $E_e \leq 53$ MeV

Pair production $\gamma \rightarrow e^+ + e^-$

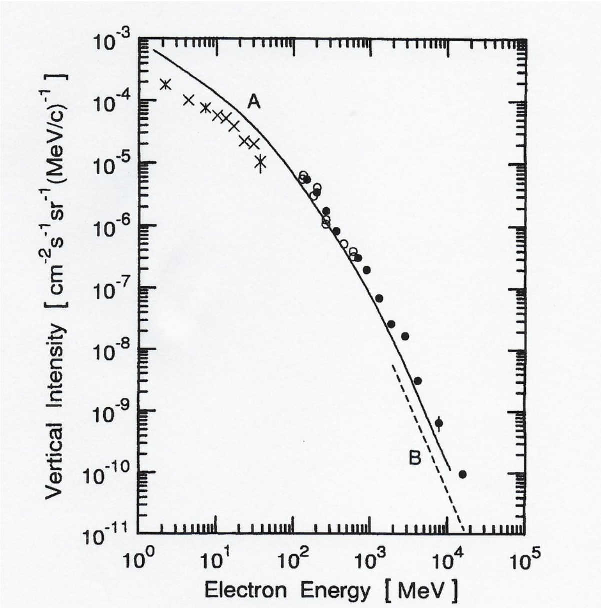
Pion decay $\pi^+ \rightarrow \mu^+ + \nu_\mu$ ($E_\mu = 4$ MeV) $\pi^+ \rightarrow e^+ + \nu_e$ (10^{-4}) $\pi^0 \rightarrow e^+ + e^-$ (10^{-7})

Downward positron bent upwards in the magnetic field

The decay processes and the pair poduction are all very improbable. A downward positron bent upwards in the field seems more likely.

Flux of downward positrons at sea level

Early measurements (1960´s, 1970´s) of the sea level flux of electrons and positrons are summarized in the book by Grieder [8]. Theoretical energy spectra using experimental data has been published by Daniel and Stephens 1974 [9]. The electron component of seal level cosmic rays was measured in the range 0.1-2 GeV by Golden et al. 1995 [10]. A recent analytical model, PARMA model, gives spectra for electrons and positrons in agreement with older experimental results and with an electron/positron ratio of about 1 at 100 MeV [11]. The Particle data group [12] gives the integral vertical intensity for electrons plus positrons above 10 and 100 MeV as 30 and 6 m^{-2} s^{-1} sr^{-1} .



Energy spectra of electrons plus positrons at sea level. Line A is the calculations by Daniel and Stephens [9], B represents early measurements. From Grieder [8].

Positron flux in Anderson´s magnet

With a magnetic fielid of 1.5 T the radius of curvature for a 63 MeV positron is about 14 cm and the radiation energy loss is small. The opening between the solenoids is about 2 cm and with a height of about 25 cm the opening area for cosmic positrons is about 50 cm^2. From Anderson 1933[13]

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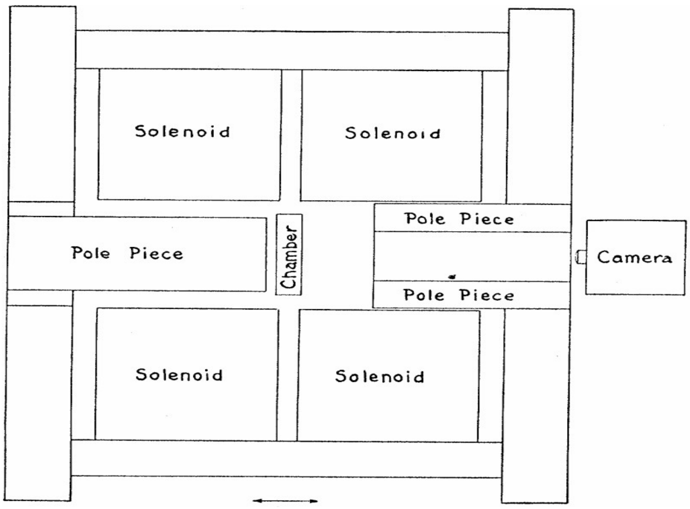

Magnet layout, from Anderson 1933 [13]. The chamber has a diameter of 16 cm and a 4 cm width. The opening between the solenoids, 27 cm height, is 2 cm. The sensitive time of the chamber is about 10 s per exposure.

The sea level flux of positrons in the energy range 50-100 MeV is about 10 $m^{-2}s^{-1}sr^{-1}$. With a sensitive time for the cloud chamber of about 10 s the positron flux in the magnet is about 5 sr^{-1} for each photo. The conclusion is that Anderson´s 63 MeV positron is a cosmic ray downward positron being bent upwards in the magnetic field.

Conclusion

Anderson´s 63 MeV positron is a cosmic ray downward positron being bent upwards in the magnetic field.

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