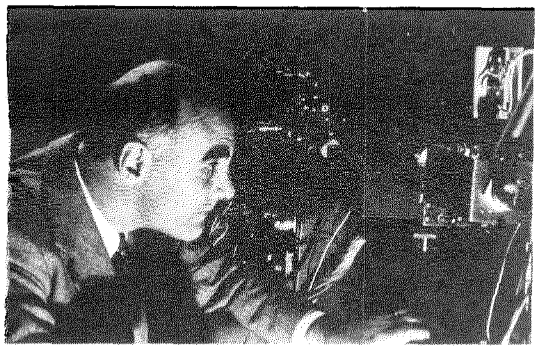


Unraveling the Particle Content of Cosmic Rays

by Carl D. Anderson

Most of the articles in this special issue of E&S *were written by colleagues of Carl Anderson. Each in its own way pays tribute to the 50th anniversary of the discovery of the positron and the later discovery of the mu meson. The most authoritative source of information about how it all happened, however, is Anderson himself. Below is an excerpt from a paper he prepared for an international conference of historians of science held at Fermilab in the fall of 1980. This paper, entitled "Unraveling the Particle Content of Cosmic Rays," will appear in its entirety in* The Birth of Particle Physics *by Brown and Hoddeson, to be published by Cambridge University Press.*

AT ABOUT THE END of 1929, when it became clear to me that I was likely to receive my PhD degree at Caltech in June 1930, I made an appointment to see Dr. Millikan. The purpose of my visit was to see if it were at all possible for me to spend one more year at Caltech as a postdoctoral research fellow. My reason for doing so was twofold: to carry out an experiment I had in mind and to learn something about quantum mechanics.

After a brief discussion with Dr. Millikan, in which I described the experiment and my desire to study quantum mechanics, he informed me that this would not be possible. The gist of his remarks was that, having had both my undergraduate and graduate training at Caltech, I was very provincial and should plan to continue my work at some other institution under a National Research Council fellowship, about the only fellowship available at that time for postdoctoral studies. Thus, I had no choice but to apply for the fellowship, and I wrote to Arthur H. Compton at the University of Chicago. I received a cordial reply and began planning for my sojourn at Chicago, an idea that appealed to me more and more as time went on.

One day I received a call from Dr. Millikan asking me to see him in his office. The gist of his comments on this occasion was that he wanted me to spend one more year at Caltech and build an instrument to measure the energies of the electrons present in the cosmic radiation. By this time, Chicago was clearly my first choice, and I used all the arguments that he had previously presented for not staying at Caltech. He replied that all these arguments were valid and cogent, but that my chances of receiving an NRC fellowship would be better after one more year at Caltech. He was a member of the NRC fellowship selection committee at the time.

Again, I seemed to have no choice in the matter. Without further ado I began work on the design of the instrument he had proposed for the cosmic ray studies. It was to consist of a cloud chamber operated in a magnetic field. This equipment, however, would require a very powerful magnetic field, for the cosmic ray electrons were expected to have energies in the range of at least several hundred million electron volts.

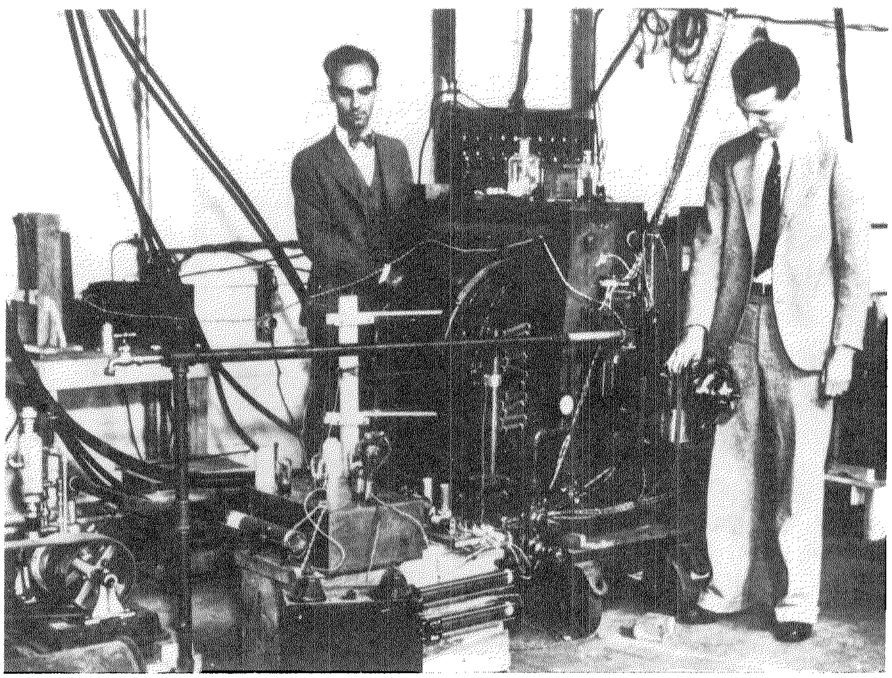
The first results from the magnet cloud chamber were dramatic and completely unexpected. There were approximately equal numbers of particles of positive and negative charges, in sharp contrast to the Compton electrons expected from simply the absorption of high-energy photons.

It was, of course, important to provide unambiguous identification of the unexpected particles of positive charge, and this could best be done by gathering whatever information was possible on the mass of the particles, inasmuch as the photographs clearly showed that in all cases these particles carried a single unit of electric charge. Experimental conditions were such that no information as to a particle's mass could be ascertained except in those cases in which the particle's velocity was appreciably lower than the velocity of light, which was true for only a small fraction of the events. Only a few of the low-velocity particles were clearly identified as protons.

As more data were accumulated, however, a situation began to develop that had its awkward aspects, in that practically all of the low-velocity cases involved particles whose masses seemed to be too small to permit their interpretation as protons. The alternative interpretations in these cases were that these particles were either electrons (of negative charge) 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 (i.e., that these particles were upward-moving negative electrons). This led to frequent, and at times somewhat heated, discussions between Professor Millikan and myself, in which he repeatedly pointed out that everyone knows that cosmic ray particles travel downward, not upward, except in extremely rare instances, and that therefore these particles must be downward-moving protons. This point of view was very difficult to accept, however, because in nearly all cases the specific ionization of these particles was too low for particles of proton mass.

To resolve this apparent paradox, a lead plate was inserted across the center of the chamber in order to ascertain the direction in which these low-velocity particles were traveling and to distinguish between upward-moving negatives and downward-moving positives. It was not long after the insertion of the plate that a fine example was obtained in which a low-energy lightweight particle of positive charge was observed to traverse the plate, entering the chamber from below and moving upward through the lead plate. Ionization and

Robert A. Millikan (right above) visited Anderson at Pikes Peak in the summer of 1935. The cog-wheel railway car and engine in the background transported tourists up the mountain. Below, Anderson and Seth Neddermeyer with the magnet cloud chamber in which the tracks of both positrons and muons were discovered.



curvature measurements clearly showed this particle to have a mass much smaller than that of a proton and, indeed, a mass entirely consistent with an electron mass. 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 them.

Soon additional instances of lightweight positive particles traversing the plate were observed; in addition, events in which several particles were simultaneously emitted from a common source were observed. Clearly, in both types of cases the direction of motion was known, and it was therefore possible to identify the presence of several more lightweight positive particles whose mass was consistent with that of an electron but not with that of a proton — in short, the positron.

It has often been stated in the literature that the discovery of the positron was a consequence of its theoretical prediction by Paul A. M. Dirac, but this is not true. The discovery of the positron was wholly accidental. Despite the fact that Dirac's relativistic theory of the electron was an excellent theory of the positron, and despite the fact that the existence of this theory was well known to nearly all physicists, including myself, it played no part whatsoever in the discovery of the positron.

During the months that followed the discovery of the positron, my graduate student, Seth Neddermeyer, and I accumulated much more data and at least for a while believed the bulk of the high-energy particles to be electrons about equally divided between positive and negative charges. But doubts soon began to develop, and it was only through the discovery of the meson that these doubts were finally resolved.

The discovery of the meson, unlike that of the positron, was not sudden and unexpected. Its discovery resulted from a series of careful, systematic investigations all arranged to follow certain clues and to resolve some prominent paradoxes that were present in the cosmic rays. A principal aim of our experiments was to identify the penetrating cosmic ray particles. They had unit electric charge and were therefore presumably either positive or negative electrons or protons, the only singly charged particles known at that time.

There were difficulties, however, with any interpretation in terms of known particles. These particles seemed, in fact, to be neither electrons nor protons. We tended, however, to lean toward their interpretation as electrons, and we "resolved" the paradox in our informal discussions by speaking of "green" electrons and "red" electrons — the green electrons being the penetrating type, and the red the absorbable type that lost large amounts of energy through the production of radiation.

In the summer of 1936 Neddermeyer and I were quite firmly convinced that all the data on cosmic rays as known at that time nearly forced on us the conclusion that the penetrating sea-level particles could be neither electrons nor protons and must therefore consist of particles of a new type.

Evidence for the existence of new particles of intermediate mass was first presented in a colloquium at Caltech on November 12, 1936; but perhaps the first reference in the "literature" to the new particles was the last sentence in my Nobel lecture on the positron delivered in Stockholm on December 12, 1936. In the more than 40 years since the delivery of that address I have received no reaction at all from it; so I will quote that sentence here: "These highly penetrating particles, although not free positive and negative electrons, will provide interesting material for future study." □