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A Biographical Memoir by

WILLIAM H. PICKERING

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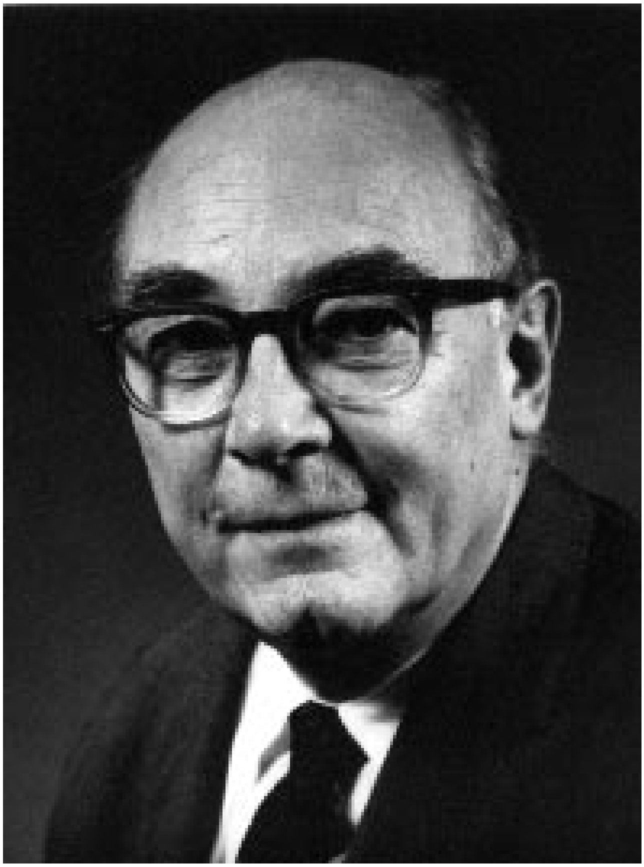

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Carl Anderson

CARL DAVID ANDERSON

September 3, 1905–January 11, 1991

BY WILLIAM H. PICKERING

BEST KNOWN FOR HIS discovery of the positive electron, or positron, Carl David Anderson was awarded the Nobel Prize in physics in 1936 at age thirty-one. The discovery of the positron was the first of the new particles of modern physics. Electrons and protons had been known and experimented with for about forty years, and it was assumed that these were the building blocks of all matter. With the discovery of the positron, an example of antimatter, all manner of theoretical and experimental possibilities arose. The Royal Society of London called Carl's discovery "one of the most momentous of the century."

Born on September 3, 1905, in New York City, Carl was the only son of Swedish immigrant parents. His father, the senior Carl David Anderson, had been in the United States since 1896. When Carl was seven years old, the family left New York for Los Angeles, where Carl attended public schools and in 1923 entered the California Institute of Technology. Caltech had opened its doors in 1921 with Robert A. Millikan, himself a Nobel laureate, as chief executive. Together with chemist Arthur A. Noyes and astronomer George Ellery Hale, Millikan established the high standard of excellence and the small student body that today continues to characterize Caltech.

Carl was an excellent student. Originally interested in electrical engineering, he changed to physics after attending a class with Professor Ike Bowen. In his junior year he was one of two students awarded the highly coveted travel prize for scholastic achievement. This prize consisted of a grant sufficient for two students to travel in Europe for six months, from March of their junior year to the following September, with an itinerary made up largely of their own choosing. Of the candidates considered for the prize, six were selected to attend a special class on the arts, history, and culture of Europe, given by John MacArthur, dean of freshmen. This was intended to help the winners plan an interesting trip. The chosen two spent most of their time visiting the prescribed round of museums and cathedrals, but they did get to meet scientists H. A. Lorentz and H. Kamerlingh-Onnes.

Carl graduated in 1927 in the option of "physics engineering." He received his Ph.D. magna cum laude in 1930 in the same option. His thesis on the spatial distribution of electrons ejected from gases by X rays, resulted in a *Physical Review* publication. (Caltech dropped the option "physics engineering" in 1931 and replaced it with "applied physics" in 1934.)

Millikan became Carl's graduate advisor. In those days graduate students had a great deal of freedom in their research. Consequently, Carl received very little direction from Millikan, but he advised Carl upon receiving his Ph.D. to get a National Research Council fellowship and go to some other school to broaden his experience. Carl applied to Compton in Chicago, but after being accepted, Millikan changed his mind and urged him to remain at Caltech for at least another year to study the Compton scattering of cosmic rays. Millikan thought that cosmic rays were primarily photons and this experiment would give him information on the energy of the radiation.

Carl had wanted to extend his X-ray thesis work to gamma rays. In this, fortunately, he agreed with Millikan's desire to work with cosmic rays, because, except for gamma rays from thorium C", these natural rays do not have enough energy to produce positrons.

Millikan had become interested in cosmic rays in the early 1930s. Cosmic radiation was first studied by Victor Hess in Austria, but was not well understood. To study the radiation Millikan organized three groups at Caltech, which were to use electroscopes, Geiger counters, and cloud chambers as tools. Carl Anderson handled the cloud chamber investigations. H. Victor Neher developed electroscopes. I was responsible for the Geiger counters. The Wilson cloud chamber is a short cylinder with glass end plates containing a gas saturated with water vapor. The pressure is dropped suddenly so that the gas expands and cools to a supersaturated state. If an ionizing particle has just passed through the chamber, there will be a trail of water droplets on the ions along its path. These droplets are photographed. The density of the droplets is a measure of the ionization produced and, therefore, of the nature of the ionizing particle. For inventing the chamber C. T. R. Wilson was awarded a Nobel Prize in 1927. Carl improved his own chamber by using a piston expanding into a vacuum to drop the pressure very rapidly and by using a mixture of water and alcohol in the chamber. Consequently, he obtained much better photographs than most other cloud chamber experimenters.

Anderson built his chamber on the top floor of the aeronautics building at Caltech, where there was adequate electric power to run the large electromagnet surrounding his chamber. The magnet provided a field of 25,000 gauss over an area 6 inches in diameter. Ionizing particles traveling across this field bend into circular paths. By measuring the curvature of the tracks in the chamber, he calculated the momentum of the particles causing the track and determined the polarity of the charge on the particle. To confirm the direction of travel of the particles, he placed a lead plate across the chamber. Particles passing through the plate emerged with lower than the initial energy, and therefore the direction of travel was confirmed.

At first, the cloud chamber expansions were randomly timed and many photographs showed no tracks. Later, Geiger counters were used to trigger an expansion after a counter recorded the passage of a particle. The result was a marked increase in useful data.

Early pictures showing tracks of cosmic ray particles were a surprise. The cosmic rays produced showers of particles both positively and negatively charged. The two polarities of track showed the same droplet density. If the particles were electrons and protons, the proton track would have been much denser, except at very high energies. This experimental result worried Anderson as well as Millikan. They even speculated that the positively charged particles were actually electrons traveling in the opposite direction. To settle this question Carl put the lead plate in his chamber. A particle passing through the plate loses energy and thus the direction of travel is uniquely determined.

In 1932 Carl recorded the historic photograph of a positively charged electron passing through the lead plate in the center of the cloud chamber. The change in curvature of the path on the two sides of the lead plate showed the direction of travel. It was definitely a positively charged particle. Surprisingly, the particle was traveling upward.

Several well known scientists, including Niels Bohr, were very skeptical of this result, but it was soon confirmed when P. M. S. Blackett and G. P. S. Occhialini published their data in the March 1933 *Proceedings of the Royal Society*.

They proposed that the positron appeared as one of a pair of positive and negative electrons produced when a gamma ray was converted into matter. The positron had a very short life before being absorbed by a collision with an electron, which produced two gamma ray photons of 511 kev energy each.

Anderson said that he discussed the problem of the formation and disappearance of the positron with J. Robert Oppenheimer and, in retrospect, was surprised that Oppie did not come up with this pair-production mechanism. He also commented that it was very difficult to understand Oppenheimer's answers to his questions. Later, when he talked with Richard P. Feynman, just the opposite was true. Feynman was clear and precise.

Anderson's positron and J. Chadwick's neutron, discovered and reported in the *Proceedings of the Royal Society* in 1932, were the first new fundamental particles. Chadwick also received a Nobel Prize in 1935, a year before Anderson. In a few years these discoveries led to the "zoo" of strange particles of modern physics.

Millikan had carried electroscopes and Geiger counters to various places so that he could use the earth as a giant magnet to analyze the energies of primary cosmic rays. Carl and his graduate student, Seth Neddermeyer, determined to follow Millikan's lead and take their cloud chamber to high altitudes and various latitudes. The cloud chamber was mounted on an old flatbed truck and, with great difficulty, driven to the summit of Pike's Peak. In fact, they were towed up most of the way. The two experimenters found evidence for a new short-lived particle intermediate in mass between the electron and the proton. This was originally called the mesotron, but is now known as the mu meson. Photographs taken in Pasadena and in Panama confirmed the existence of this new particle.

In the Depression days of the 1930s financing scientific research was difficult. The Pike's Peak trip was done on a shoestring. First they found a 1932 ton-and-a-half Chevrolet truck, which they purchased for $400. They then found a flat bed trailer and improvised a hitch. Some old packing cases were made into a housing for the equipment. Arriving in Colorado Springs, they had the motor overhauled and the clutch replaced. Even so, they couldn't quite make it to the toll gate up the mountain. The Pike's Peak Company towed them up, probably to clear the road.

Their troubles were just beginning. They had an old Cadillac engine generator set that wouldn't produce adequate power at 14,000 feet. When they took the generator down to Colorado Springs to be fixed, the Chevrolet truck broke down because the repair work had not been done properly. However, as luck would have it, a new Chevrolet test truck appeared, which was being monitored on a trip up the mountain. It carried as a passenger a General Motors vice-president, who stopped to inquire about the scientist's problem. He then very kindly had the truck towed up the hill and subsequently replaced the engine free of charge. But their troubles weren't over. They couldn't afford to pay the $2.50 per night for the six-week stay in the shed on top of the mountain, so they bought a Chevy Roadster for $50 and stayed at a road crew bunk house half way down the mountain. They were obviously two dedicated scientists and they were first-class experimenters. During their month and a half on Pikes' Peak they took about 10,000 photographs.

Shortly before America entered World War II, Compton contacted Anderson and invited him to be the director of what soon became the atomic bomb project. Compton suggested he choose Oppenheimer as his assistant. Anderson turned him down because he felt that he lacked the necessary administrative experience, and because of concern for his mother who was in ill health.

During World War II, Carl remained at Caltech and joined physicists Charles Lauritsen and Willie Fowler on the Caltech artillery rocket project for the Navy. This project was to develop a solid propellant rocket with enough accuracy to deliver an artillery barrage from a simple launch platform. Anderson was primarily concerned with problems associated with launching the rockets from aircraft. By the end of the war, these rockets were being produced by Caltech in very large numbers, and were launched from ships in several Pacific island landings. The aircraft version that Carl helped develop was used against submarines, which had been detected by magnetic sensors.

Carl's student, Seth Neddermeyer, who had received his Ph.D. in 1935, left to join the staff of the University of Washington. He later left the university and went to Los Alamos to work on implosion technology for the atomic bomb.

In 1944 Carl traveled to the Normandy beachhead to observe the use of Caltech rockets under battlefield conditions. He spent a month in France and helped install rockets on Allied aircraft. The reports of the rocket's effectiveness were excellent.

In 1947 Anderson received support from the Office of Naval Research to fly cloud chambers in two B-29 airplanes. Data were collected at the maximum height the aircraft could attain. New information about the decay of primary cosmic ray particles was obtained, including a photograph of the disintegration of a mu meson. However, problems of installing and operating the equipment on this aircraft inhibited their work. Carl felt they should have spent more time on physics and collected more data on the strange particles. Later, Carl with Professor Robert Leighton and some Caltech graduate students made observations with an improved apparatus at an altitude of 10,000 feet in the White Mountains of northeastern California.

Anderson's work with cosmic rays in the 1930s and 1940s was important for the development of modern particle physics. Other physicists in Europe and the United States using both cloud chambers and photographic emulsions collected data that confirmed Anderson's results and added additional particles to the physicist's "zoo."

The theoretical physicists set the stage. Paul A. M. Dirac postulated the "anti-electron" in 1928 and received the Nobel Prize in 1933. Hideki Yukawa required the existence of a heavy, short-lived particle for his theory of the nucleus, and for this theory he received the Nobel Prize in 1949. For a time Anderson's "mesotron" was assumed to be the Yukawa particle, but it turned out to have too long a lifetime and to be too light. Anderson was not actually searching for Dirac's anti-electron. Its discovery was a complete surprise. However, once the positron and the neutron were known, the search for additional particles was guided by speculations of the theoretical physicists.

Today experimental work in particle physics is done almost exclusively with large particle accelerators. These machines now produce energies in the same range as primary cosmic rays. Also, the machines produce large energy fluxes on demand, so that they are much more useful than the natural cosmic rays.

Caltech elected not to enter the very large machine race, so that Carl found his research area preempted by others. Caltech needed Carl for other tasks. He was appointed chairman of the freshman admissions committee and chairman of the division of physics, mathematics, and astronomy from 1962 until his retirement in 1970.

Carl's parents divorced shortly after the move to Los

Angeles, and Carl found himself helping to support the family. In retrospect, he said that he was amazed that his mother was able to do so well on so little money. Money was so short that he had to borrow $500 from Millikan to make the trip to Sweden for his Nobel Prize.

Carl married Lorraine Bergman in 1946. It was her second marriage. Her three-year-old son Marshall David was immediately adopted by Carl. Another son, David Anderson, was born in 1949. Marshall is now a computer mathematician and David is an engineer. The Anderson family lived in San Marino, not far from Caltech. Lorraine passed away in 1984.

All of Carl's professional career was at Caltech. He was a teaching fellow (1927-30), research fellow (1930-33), assistant professor (1933-37), associate professor (1937-39), and a full professor (after 1939). He retired in 1970 and in 1976 was made the Board of Trustees professor of physics emeritus.

In 1936, when he was awarded the Nobel Prize, he was an assistant professor. He shared the Nobel Prize with Victor Hess, who had first measured cosmic radiation in 1912. They each received about $20,000—a princely sum in 1936. Carl used half of his money to cover his mother's medical expenses and invested the balance in California real estate.

In his Nobel lecture Carl described how he obtained his first cosmic ray tracks in 1931. A preliminary report published in 1932 indicated that energies in excess of a billion electron volts were involved, and that approximately equal numbers of positives and negatives appeared in these cosmic ray showers. Even the relatively low energy positives, those with energy less than 500 mev had the same ionization track density as the negatives.

By putting a 6-mm lead plate across the center of the cloud chamber he settled the question of the direction of travel of the particles, and also allowed a measure of the energy loss in passing through the plate. The key photograph had a positive particle entering the plate with 68 mev and leaving it with 28 mev. Had this particle been a proton its range in the gas of the chamber would have been at least ten times smaller than the actual path.

Anderson's data from his Pike's Peak and Panama experiments encouraged him to conclude his Nobel lecture as follows:

> These highly penetrating particles, although not free positive and negative electrons, appear to consist of both positive and negative particles of unit electric charge, and will provide interesting material for future study.

Within a few months it was obvious that a new particle with mass intermediate between electron and proton was needed to explain the data.

Carl enjoyed teaching, and enjoyed research as an individual effort. He was not interested in being part of a large team. His Nobel Prize, of course, exposed him to many calls for public appearances and speeches. He did not enjoy this exposure.

Other awards he received included the Gold Medal of the American Institute of the City of New York (1935), the Elliott Cresson Medal of the Franklin Institute (1937), the Presidential Certificate of Merit (1945), and the John Ericsson Medal of the American Society of Swedish Engineers (1960). He received honorary degrees from Colgate University (1937), Temple University (1949), and Gustavus Adolphus College of St. Peter, Minn. (1963).

Elected to the National Academy of Sciences in 1938, Carl was chairman of the Physics Section from 1963 to 1966. He was a fellow of the American Physical Society and a member of the American Philosophical Society, the American Association for the Advancement of Science, the

American Academy of Arts and Sciences, Sigma Xi, (president, 1947-48), and Tau Beta Pi.

Carl was not particularly interested in politics, although he did sign a petition prepared by Tommy Lauritsen of the physics department against the testing of hydrogen bombs. About ten faculty members signed, but the Caltech administration officially stated this was not Caltech policy. Apparently, there were no repercussions against any of the signatories. Carl's graduate student Seth Neddermeyer may have registered as a communist at one time, but neither Carl nor Seth played an active role in any political campaign or movement.

Outside of his professional interests Carl was most interested in automobiles and auto racing. He was also a radio ham (call sign W6KGR). He listed his recreations as "tennis, mountains, desert, music." He was a member of the Twilight Club, a social club for Pasadena leaders.

In 1962 President Kennedy held a White House dinner for Nobel laureates, and Carl attended. He was honored to be seated at a table with the Swedish ambassador's wife on his right, Mrs. Ernest Hemmingway on his left, the President next to Mrs. Hemmingway, and Mrs. George Marshall on the President's right. Carl recalled the President's comment that this was the greatest gathering of talent at a White House dinner since Thomas Jefferson dined there alone. The dinner was on the same day that Linus Pauling had picketed the White House. In the reception line Mrs. Kennedy commented to Pauling that she wished he wouldn't picket, because when that happened Caroline would ask, "What has Daddy done wrong now?"

The period from 1930 to 1940 was a very fruitful one for particle physics. Not only were new fundamental particles discovered, but they also induced radioactivity and, of course, nuclear fission. Studies of natural radioactivity and of cosmic rays showed the complex nature of the atomic nucleus. Bombarding the atom with high-energy particles or photons broke up the nucleus and produced new nuclei. By 1940 most of the great collection of stable and unstable nuclei that we now know had been found .

In retrospect Anderson's achievement was due in part to R. A. Millikan's intuition that the study of cosmic rays was important and that Anderson had the experimental ability to build a superior cloud chamber. The intellectual climate at Caltech encouraged the young physicist. This was still the period when physics was being done with "love and string and sealing wax." Brilliant scientists with very little money or other support were pushing back the frontiers of physics and in the process giving us new concepts of the world. Anderson's "anti-matter" was the first step that led to an understanding of the atomic nucleus.

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