The Picture That Was Not Reversed

by Eugene Cowan

A three-part article that begins with the discovery of the positron, is followed by a commentary by physicist Richard Feynman and quotations from the scientific literature of the early 1930s, and ends with a few not-so-scientific items.

ON THE 2ND OF AUGUST 1932, a half-century ago, Carl Anderson peered through the small rectangle of a photographic film and caught the first glimpse of a new world, the world of antimatter. He saw what appeared to be a photographic negative reversed, a film viewed from the wrong side, and upside down as well. The picture showed the thin white trail left in a cloud chamber by a cosmic ray particle. Seen reversed, the trail could have been the track left by an ordinary fast moving negatively charged electron. This is the story of how that picture, which was *not* reversed, became the first clear view of particle-antiparticle symmetry — a symmetry that has since been extended to all known particles.

The story starts in the spring of 1930 when Carl was called to Dr. Robert Millikan's office to discuss a new apparatus to measure the energy of cosmic rays. In 1927, physicist Dmitrii Skobeltsyn had seen the tracks of cosmic rays appearing mysteriously in a cloud chamber used to study radioactivity. Millikan suggested that the cloud chamber could be placed in the field of a powerful electromagnet to measure the energy of individual cosmic rays. With this direction, Carl planned and built a unique apparatus.

The magnet coils consisted of lengths of copper tubing welded together to carry cooling water as well as electric current. An insulating braid was pulled on from the ends, inched forward, each advance more difficult than the last. After weeks of work and a basket full of worn-out cotton gloves, the tubing was wound into two coils around iron pole pieces. Additional iron to complete the framework brought the weight to nearly 2 tons. The heart of the apparatus was the cloud chamber, buried in the center of a small gap between the two coils and viewed through a hole in one of the pole pieces.

The cloud chamber was, and is, a temperamental tool, an instrument of amazing sensitivity that can make visible the path of a single moving electron. Delicate adjustments and unpredictable results make its use both art and science, and Carl did much to advance both. His method of adding alcohol to the water vapor in the chamber changed the previously faint trails to bright tracks that could be photographed. Even so, this required the momentary light of a powerful arc. A cloud chamber operates when a sudden expansion in volume cools a gas saturated with moisture. If conditions are precisely right, condensing droplets of fog form along the ion trail created by the motion of an invisible electron or other charged particle, leaving a visible track much as a distant unseen airplane leaves a visible vapor trail. In Carl's chamber the sudden expansion came when a movable piston forming the back of the chamber was released by a complicated mechanism, barely visible at the left side of the magnet in the picture at right. It was important to release the pressure quickly, and Carl designed a special system that permitted the piston to move suddenly into a vacuum, terminating with an explosive "bang." The loud "bangs" of this chamber's successors echoed through the cosmic ray laboratories at Caltech for the next 40 years, but none surpassed the speed of the original design.

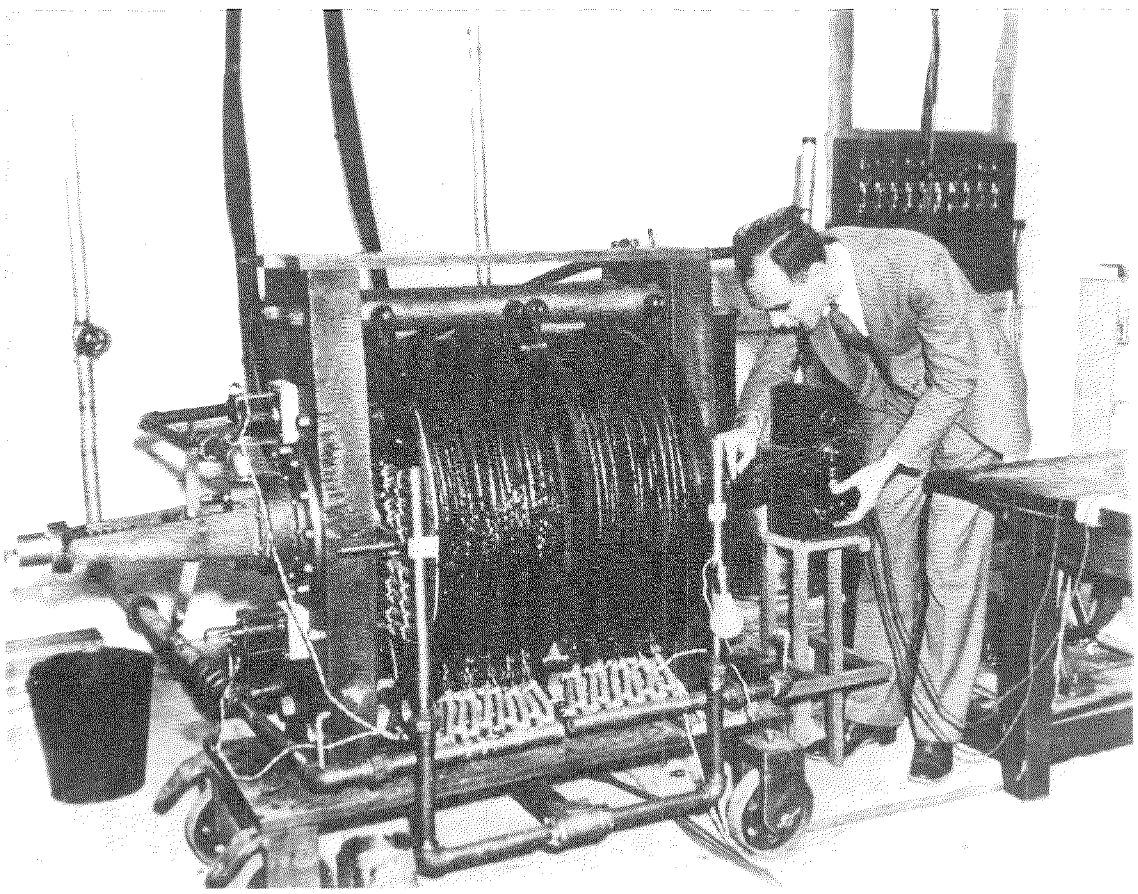
A glass window in the cloud chamber, opposite the piston, permitted photographs to be taken through a hole in the magnet pole piece (on the right in the picture). Two angles of view were needed for stereoscopic pictures, but there was room for only one camera lens to see the cloud chamber through the narrow hole. Carl's elegant solution — line the sides of the hole with mirrors. Effectively, the single lens became three.

The great power dissipated by the magnet coils was carried away by water circulated through the tubing that also carried the electric current. Part of the extensive water connection system appears at the bottom of the magnet in the picture. The magnet was designed to be powered by direct current from a large motor-generator with a rating of 425 kw — about 1/10 of the power used by the entire Caltech campus in the 1980s and many times the usual power needs of that day. The strength of the magnet field, which revealed the momentum of a cosmic ray by bending its path, was an important factor. Carl's magnet could sustain a continuous field of 17,000 gauss, which was greater than any of the later systems at Caltech patterned after it. At such levels the magnetic fields were no longer confined by the iron and could whisk a forgotten wrench from the floor and slam it into the magnet with a very large amount of force.

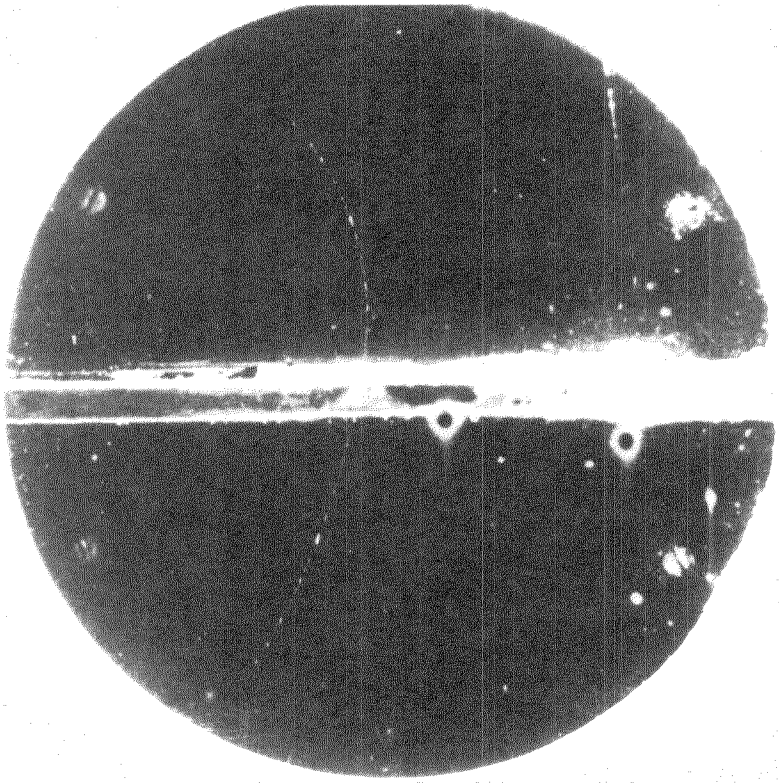
From the motor-generator set, which filled a small room in the depths of the aeronautics building (now Guggenheim Laboratory), heavy cables carried the power up to the roof, where the cloud chamber could be exposed to cosmic rays. The great penetrating power of these rays was not then known. Carl pushed the 425-kw generator to the limit and beyond, for brief periods as high as 600 kw, producing tremendous fields of over 25,000 gauss. Steaming water gushed from the magnet, bringing anxious reports of a vaporous liquid streaming from the campus across California Boulevard and down Arden Road.

Operation was often at night, when the power needs of the rest of the campus were small. The magnet was turned on, the cloud chamber compressed and made ready, but there was no way of knowing when a cosmic ray would arrive. To be visible it had to pass through the chamber in the brief fraction of a second it was sensitive after an expansion. A "trigger" was later devised by Blackett and Occhialini, but for these early operations Carl had to rely on chance. Over and over the cycle of the chamber was repeated — the blue-white flash of the arc light, the explosive "crack" of the chamber, and a tedious wait as the film was advanced and the chamber brought back to equilibrium. Night after night the cycle continued as the generator whirred and the brilliant flashes of the arc lit up the night sky over the campus. Thousands of pictures were taken, only a small fraction of which contained clear cosmic ray tracks. By the summer of 1931 the measured energy of cosmic rays had been pushed from 15 million electron-volts to 5 billion electron-volts.

In addition to the energy, the sign of charge,



The final apparatus of the magnetic cloud chamber appears in this photograph of December 1931 (released by the Associated Press under the confused headline "The Atom Cracking Machine"). Carl Anderson adjusts the handmade camera that records the tracks in the cloud chamber on 35 mm film. The entire design was simple and cleanly executed; note the cut leg on the camera stool. Above all, it worked.



This photograph shows the track of the first clearly identified positive electron. The particle was moving upward, determined by the greater curvature of the top half of the track compared to the bottom half, which corresponds to the decrease in energy as the particle passed through the lead plate. The direction of motion and curvature clearly require a positive charge, and the possibility of a proton is ruled out both by the density and length of the track, which correspond to a mass near that of an electron.

plus or minus, could be determined by whether the path curved to the left or to the right in the magnetic field, that is, *if* the direction of motion of the particle was known. That seemed to present no problem since almost all cosmic ray particles come downward from above with only a small chance of being deflected upward. Particles of positive and negative charge occurred with about equal frequency, the natural assumption being that they were protons and electrons, the only known charged particles. One important factor remained. "Slow" particles, traveling at less than 95 percent of the speed of light, made dense tracks if they were heavy. Information about both the velocity and energy of the particle revealed the mass. Many of the slow particles that curved to the right, indicating a positive particle (if going downward), were too light to be protons, and therefore were taken to be electrons going upward. Carl said to Millikan, "You wouldn't expect it, but there must be electrons that are going up." Millikan said that that was ridiculous; they couldn't be moving up — any appreciable number of them anyhow; they must be protons.

To settle the argument, Carl placed a lead plate inside the cloud chamber so that a track would be visible as it entered and left the plate. Since the curvature after leaving would be greater than before entering the plate, because the particle must lose energy in going through, there could be no question about the direction of motion. It was a straightforward solution that then became the obvious solution.

The day arrived, August 2, 1932. A graduate student, Everett Cox, climbed the steps to the darkroom in the penthouse atop East Bridge and developed the film. Carl peered through the viewer as he slowly rolled the film, frame-by-frame, to the picture. A lone cosmic ray track in the center of the picture passed through the lead plate and emerged, the direction clearly indicated by the increase in curvature. And it was going upward! By some quirk of cosmic fate, completely unrelated to its historic role, it was the rare exception — a cosmic ray going up. The important thing was that the direction of motion combined with the sense of the curvature determined the sign of the charged particle, and the smoothly curved path left no doubt that the charge was positive. The large curvature and light density clearly revealed a mass near that of an electron.

As Victor Neher [now professor of physics emeritus] recently recalled, Everett was really worried. Did the film somehow get reversed? Did it get turned upside down? Carl Anderson knew the picture was not reversed and that it could not be ignored. It was a positive electron!

The course of science veered, from that flip of the film, to a chain of antiparticle discoveries that in 50 years now finds every particle with an antiparticle, a complete symmetry. We now see the possibility that our universe of matter could as well be replaced by a similar universe of antimatter, where perhaps the discovery of the negatron would be announced, presumably to meet the same disbelief.

As Oppenheimer related later, "Pauli thought it was nonsense; you find that in the relativistic part of his handbook article. Bohr not only thought it was nonsense, but was completely incredulous when he came to Pasadena." Rutherford remained unconvinced until Blackett and Occhialini had published similar work in February 1933. R. H. Fowler then wrote the following letter to Millikan:

> Dear Millikan,
>
> I have just had a letter from Rutherford which contains some of Blackett's work which may interest you and Anderson. It is that they have capitulated on the question of positive electrons and agree with Anderson that *there are present* in large numbers among the tertiary or quartinary (or whatever they are) ionizing particles seen in a Wilson photograph of the Cosmic ray effects *particles of positive charge and electronic mass.* I have few details. But I take it that Blackett has collected so many photographs of such

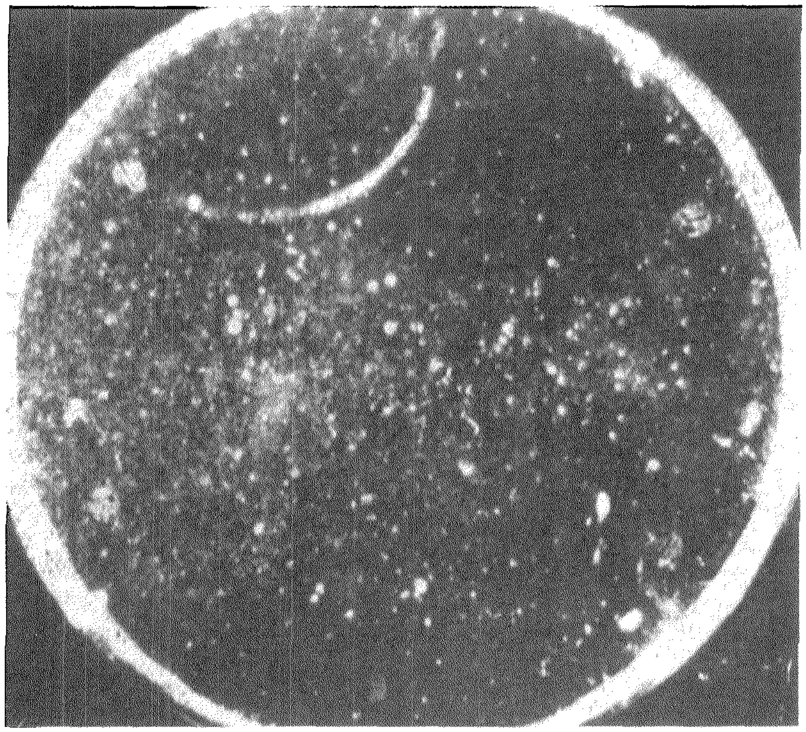
tracks as those earlier ones of Anderson that he can no longer resist this devastatingly interesting conclusion. Blackett's photos will come out in P.R.S. in March.

I have a lecture to deliver
Yours sincerely,
R. H. Fowler

Viva CalTech and Cav. Lab.

The relation between the discovery of the positron and Dirac's relativistic theory of 1929, by which it might have been predicted, can be traced through the direct quotes from the formal scientific literature that begin on page 11. The Dirac theory foresaw the possibility of a positive electron, but it played no part in the actual discovery. Although the discovery was unexpected, it was not a chance upturning of a gold nugget. Careful planning and skillful work had found a path to the whole lode. The picture at right shows the heavy curved blob of a cosmic ray track, not greatly different from thousands. In the eye of an acute observer it can have been made neither by an electron nor by a proton — only by a particle of intermediate mass. That particle left its track in Carl Anderson's cloud chamber in 1931. In the world of that time, made only of electrons and protons, there was no room for another particle. This picture was published later, in 1939, by Seth Neddermeyer and Carl Anderson with the caption that it was consistent with a mass between 150 and 200 times that of an electron. Seth was Carl's first graduate student. He arrived at about the time the magnet cloud chamber was completed and stayed after graduation through the exciting experiments on Pikes Peak, when they found room in the world for another particle, the μ meson whose track is pictured above.

By 1936, the year the Nobel Prize was awarded for the discovery of the positron, the growing list of elementary particles read e^-, p, n, e^+, μ^+, and μ^-, half of them discovered in Carl Anderson's cloud chamber. The neutron was discovered by Chadwick shortly before the discovery of the positron in the same year, 1932. That was the year of the beginning, the beginning of particle physics. There comes a time in the affairs of science to mark beginnings, a time to look backward, back half a century to the day when the evidence for antimatter hung by a slender trail of vapor, and the world's knowledge of antiparticles lay in the thoughts of Carl Anderson as he stared at the picture that was not reversed.



***A** particle of mass intermediate between an electron and proton left this heavy, curved track in Anderson's cloud chamber in 1931, a time when the existence of such particles was still unsuspected. This was later established to be the particle now called the mu meson.*

RICHARD P. FEYNMAN, the Richard Chace Tolman Professor of Theoretical Physics and Nobel Laureate, was tracked down in Mexico and asked to comment for this article on the history of the relationship of Dirac's 1929 theory to the discovery of the positron. Quotes (chronologically by submission date) from the scientific literature that he refers to, along with other relevant citations, follow Feynman's remarks.

Let me summarize what I think the history of the thing is from looking at the papers. In December 1929 Dirac got a theory of his negative energy states; that they were filled and that there would be, then, holes (unfilled states) in them; that the holes would act like positive charges; and that they would be, perhaps, protons.

I think, judging the times, that there must have been an immediate tendency to suggest that they were protons; there was, of course, a strong conservatism and desire to avoid inventing new particles. Nowadays, when we have so many particles, we don't see why they resisted it. But I can appreciate the times, I think, and they didn't want to make the world complicated — it was supposed to be *simple*, with protons and electrons. So he thought they were protons. The fact that the mass was different was slightly disturbing, but there was an asymmetry which he *thought* existed. That was because of the interaction between the electrons. All the electrons in a negative energy state, he thought, would be interacting, and the interactions were a big complication that he couldn't see through and that, presumably, in some way gave the extra mass.

Two months later, in February 1930, Oppenheimer questions the idea that they're protons, and suggests that if the masses *were* different, due to interaction or something, there would be a lot of difficulties produced in the theory (the theory wouldn't give the right formulas for scattering of light by electrons, and so on), and he suggests that all the negative energy states are full and that there are two kinds of particles — electrons and protons — and they're not related to each other. As far as I can tell by reading it, he does not clearly or explicitly predict positrons. He says *all* the negative energy states are full; he does not discuss the possibility of the Dirac holes actually being produced or existing. It's not explicitly stated that there *should be*, definitely, a new particle of mass equal to that of the electron. He states only that the holes of Dirac could not be protons.

In March 1930, Dirac calculated quite accurately the annihilation rate of electrons and protons and therefore, presumably, the rate of production if they could be made. His calculations showed that it would be very, very high, and he was, of course, bothered by this. This demonstrated again, more directly, that protons couldn't be the holes. But the formulas were available for these things ahead of time, before Anderson's experiment, even though these calculations were not actually used until after the positron was discovered.

In a paper on magnetic poles the next year Dirac says some very explicit things. In the first place, the fact that the holes had to have the same mass as the electron had been demonstrated in a formal way by Weyl, who apparently thought the idea so obvious that he didn't bother to publish it except in his book about quantum mechanics in 1931. (Early in 1929 Weyl had also already suggested that the negative energy states of the Dirac theory were somehow related to protons. Dirac then modified Weyl's idea in his 1929 paper inventing the hole theory — that the negative energy states that were not occupied were protons.) Oppenheimer, as well as Weyl, had pointed out that if there *were* holes, they would have to have the same mass. I suspect that both Oppenheimer and Weyl were simply saying at this time that the holes couldn't be protons — not that the holes *were* some other particle. They just felt that there was still a difficulty, that they didn't know what the holes were.

But in this paper in May 1931, Dirac explicitly discusses the reality of holes. Of these papers it's the earliest one in which he really *believes* that holes are going to be there, that they can be made experimentally, and he discusses an experiment that he says is very, very difficult. (He wanted to hit two gamma rays together.) But he talks about the reality and the possibility of producing them. Of course, by that time he knew that they would have the same mass as an electron.

Over a year later, in September 1932, Anderson finds them experimentally, which, of course, clears up a lot of difficulty. I think that it's during that year between May 1931 and September 1932 that Dirac proposed the reality of the holes — that is, the positrons, or "anti-electrons," as he called them — but that many other people, including Pauli and Bohr, thought it was nonsense. Oppenheimer, in his later recollections, says that he doesn't think he thought of mechanisms to produce pairs before Anderson and that he had no opinion as to whether the holes really could be made. But I think Dirac really *believed* that they could be made.

As to the influence that discovering the positron had on theoretical physics, it's pretty obvious that the idea of the holes as positrons — the mass the same as the electron — was considered a possibility by Dirac and a great difficulty by other people, because there weren't any positrons. It's always wonderful how experiment throws away the cobwebs and straightens everything out and decides it all very nicely. Where many people were worrying, now they're all satisfied.

Dirac did say (in the 1931 paper) that the idea that there would be antiparticles for particles was much more general than just for the electron and the positron and comes from the problem of wedding together relativity and quantum mechanics. One of the reasons is that there was no way to avoid the two solutions of a square root. The formula for the energy of a particle is the square root of the momentum squared plus the mass squared, and that square root has two signs. So there would be negative energies. He was very clever in filling those negative energy states and inventing the hole theory to get rid of them. But he saw that there would be a general problem, that there's no way around that plus and minus sign for *any* particles. In classical physics the sign didn't give any difficulty, because once you started with a positive sign, its continuity didn't permit you to jump to the negative sign. But the quantum mechanics has discontinuous transitions with the emission of photons possible, and therefore you couldn't get rid of the minus sign. So I guess that very early everybody knew (after Anderson, of course, made it easy for everybody to believe it) that relativity and quantum mechanics went together to produce the need for antiparticles. I think, on the part of Dirac, who was one of the few who really believed his own theory, this was a rather brilliant prediction in the face of the conservatism with which he originally started — that there shouldn't be too many new particles. I think it is quite dramatic to invent or to discover the need for another particle by theoretical argument and then have experiment demonstrate its reality for all to see.

The main effect of the discovery was, of course, to clear the air, to make it wonderfully dramatic that this theory of Dirac's (which was fitting all the numbers so well in spite of the apparent difficulties of those holes) was a true prediction. That was what the experimental discovery said. But most people didn't have the guts to go along with it as Dirac had. So I would say that Dirac really predicted the positron.

Dirac and Oppenheimer, 1935.

December 6, 1929, P. A. M. Dirac, *Proceedings of the Royal Society,* A126 (1929-30), pp. 360-365, "A Theory of Electrons and Protons."

"We are therefore led to the assumption that *the holes in the distribution of negative-energy electrons are the protons.*"

"In this way we can get over the three difficulties mentioned at the end of the preceding section. We require to postulate only one fundamental kind of particle, instead of the two, electron and proton, that were previously necessary."

February 14, 1930, J. R. Oppenheimer, *Physical Review,* 35 (March 1, 1930), pp. 562, 563, "On the Theory of Electrons and Protons."

"If we return to the assumption of two independent elementary particles of opposite charge and dissimilar mass, we can resolve all the difficulties raised in this note, and retain the hypothesis that the reason why no transitions to states of negative energy occur, either for electrons or protons, is that all such states are filled."

March 26, 1930, P. A. M. Dirac, *Proceedings of the Cambridge Philosophical Society,* 26 (1930), pp. 361-375, "On the Annihilation of Electrons and Protons."

"According to these ideas, when an electron of positive energy makes a transition into one of the unoccupied negative-energy states, we have an electron and proton disappearing simultaneously, their energy being emitted in the form of electromagnetic radiation."

1931, H. Weyl, *Gruppentheorie und Quantenmechanik,* 2nd ed. (English translation), p. 263.

"The quantum jump of an electron between positive and negative energy levels, which was so undesirable in the Dirac theory as formulated in the previous section, now appears as a process in which an electron and a proton are simultaneously destroyed and as the inverse process. The assumption of such an occurrence, for which our terrestrial experiments offer no justification, has long been entertained in astrophysics, as it seems otherwise extremely difficult to explain the source of the energy emitted by stars.

"However attractive this idea may seem at first it is certainly impossible to hold without introducing other profound modifications to square our theory with the observed facts. Indeed, according to it the mass of a proton should be the same as the mass of an electron (so long as it is invariant under interchange of right and left); this hypothesis leads to the *essential equivalence of positive and negative electricity under all circumstances — even* on taking the interaction between matter and radiation rigorously into account."

May 29, 1931, P. A. M. Dirac, *Proceedings of the Royal Society,* A133 (1931), pp. 60-72, "Quantised Singularities in the Electromagnetic Field."

"It was shown that one of these holes would appear to us as a particle with a positive energy and a positive charge and it was suggested that this particle be identified with a proton. Subsequent investigations, however, have shown that this particle necessarily has the same mass as an electron and also that, if it collides with an electron, the two will have a chance of *annihilating one another much too great to be consistent with the known* stability of matter.

"It thus appears that we must abandon the identification of the holes with protons and must find some other interpretation for them. Following Oppenheimer, we can assume that in the world as we know it, *all,* and not merely nearly all, of the negative-energy states for electrons are occupied. A hole, if there were one, would be a new kind of particle, unknown to experimental physics, having the same mass and opposite charge to an electron. We may call such a particle an anti-electron. We should not expect to find any of them in nature, on account of their rapid rate of recombination with electrons, but if they could be produced experimentally in high vacuum they would be quite stable and amenable to observation. An encounter between two hard γ-rays (or energy at least half a million volts) could lead to the creation simultaneously of an electron and anti-electron, the probability of occurrence of this process being of the same order of magnitude as that of the collision of the two γ-rays on the assumption that they are spheres of the same size as classical electrons. This probability is negligible, however, with the intensities of γ-rays at present available.

The protons on the above view are quite unconnected with electrons. Presumably the protons will have their own negative-energy states, all of which normally are occupied, an unoccupied one appearing as an anti-proton. Theory at present is quite unable to suggest a reason why there should be any differences between electrons and protons."

September 1, 1932, C. D. Anderson, *Science,* 76 (September 9, 1932), pp. 238, 239, "The Existence of Easily Deflectable Positives."

"The interpretation of these tracks as due to protons, or other heavier nuclei, is ruled out on the basis of range and curvature.

"*The specific ionization is close to that* for an electron of the same curvature, hence indicating a positively charged particle, comparable in mass and magnitude of charge with an electron."

September 10, 1932, R. M. Langer, *Science,* 76 (September 30, 1932), pp. 294, 295, "The Fundamental Particles."

"The present theory of the electron seems to lead inevitably to an electron with negative energy and — with the help of the assumption due to Dirac that the negative energy states are almost filled — to a positive electron of the same mass."

". . . the electron and the Dirac magnetic pole are the fundamental particles."

February 7, 1933, P. M. S. Blackett and G. P. S. Occhialini, *Proceedings of the Royal Society,* A139 (1933), pp. 699-727, "Some Photographs of the Tracks of Penetrating Radiation."

". . . it is necessary to come to the same remarkable conclusion that has already been drawn by Anderson from similar photographs. This is 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.

"The existence of positive electrons in these showers raises immediately the question of why they have hitherto eluded observation. It is clear that they can have only a limited life as free particles since they do not appear to be associated with matter under normal conditions. It is conceivable that they can enter into combination with other elementary particles to form stable nuclei and so cease to be free, but it seems more likely that they disappear by reacting with a negative electron to form two or more quanta. This latter mechanism is given immediately by Dirac's theory of electrons."

February 28, 1933, C. D. Anderson, *Physical Review,* 43 (1933), pp. 491-494, "The Positive Electron."

"It is concluded, therefore, that the magnitude of the charge of the positive electron which we shall henceforth contract to positron is very probably equal to that of a free negative electron which from symmetry considerations would naturally then be called a negatron."

June 9, 1933, J. R. Oppenheimer and M. S. Plesset, *Physical Review,* 44 (1933), pp. 53-55, "On the Production of the Positive Electron."

"This is what we should expect from the pairs, which should lose practically all of their kinetic energy in passing through matter, and in which the anti-electron near the end of its range should combine with an electron with the radiation of two quanta of about a half-million volts."

February 2, 1934, P. A. M. Dirac, *Proceedings of the Cambridge Philosophical Society,* 30 (1933-34), pp. 150-163, "Discussion of the infinite distribution of electrons in the theory of the positron."

Footnote: "As this theory was first put forward, *Proc. Roy. Soc.,* A126, p. 360 (1930) and *Proc. Camb. Phil. Soc.* 26, p. 361 (1930), the holes were assumed to be protons, but this assumption was afterwards seen to be untenable, since it was found that the holes must correspond to particles with the same rest mass as electrons. See *Proc. Roy. Soc.,* A133, p. 61 (1931)."

November 20, 1963, oral interview (unpublished) of J. R. Oppenheimer by Thomas S. Kuhn, Archive for the History of Quantum Physics.

Oppenheimer: I must have seen Dirac's note on electrons and protons shortly after it came out. I think that year (1929-30) I went first to Berkeley and came at Christmas time to Pasadena. My recollection is that I saw this in Pasadena. I guess the following note, or actually paper, on radiative transitions had something about the annihilation. You could then ask "what did I think?" Well, obviously I thought that the proton system and the electron system were separate and in normal experience one had only the one sign of charge. I don't think that I thought about mechanisms which would produce pairs until the Anderson thing. I think that I had no opinion as to whether this conclusion of the theory would be borne out. This may seem odd because if they could be annihilated they certainly could be produced, but it isn't the first time and it wasn't the last that one wondered really whether detailed balancing was right. This happened with the strange particles too, of course, and with the new meson and so on. It's always been right, and I think it's probably one of the few things that will continue to be, but I would just say that puzzlement was it. I talked to Anderson about it —

Kuhn: Before the positron?

Oppenheimer: Sure, and he talked to me, but I didn't encourage him to think that this was a good experiment, and he didn't look for positrons because there might be a place for them in a theory of whose general rightness no one was at all sure. Pauli thought it was nonsense; you find that in the relativistic part of his handbook article. Bohr not only thought it was nonsense but was completely incredulous when he came to Pasadena. It wasn't until — not that he'd seen the picture — that helped — I could explain to him how naturally the pair production would have to come out if this was a correct view at all that he became convinced. He left Pasadena convinced that it was a consequence of the hole theory and that this was genuine progress. I think there was a World's Fair in Chicago, and he went there, and when he talked about it he talked about having become convinced of this. That I think went on in Pasadena not least because there was a beautiful photograph but primarily because he hadn't thought about relativistic theory and changing particle numbers and all such things, and it was reassuring to him that the framework was there and that if there were troubles with it they were no worse than the troubles with light quanta in the hydrogen atom. They were the same kind of pushing a theory beyond what the traffic was good for.

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The Picture That Was Not Reversed

by Eugene Cowan

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The quotations on pages 11 and 12 from the scientific literature indicate the flavor as well as the facts of the era of the discovery of the positron. And at the end of this article are three short items — not from the scientific literature — that show another aspect of doing science.

I have put this story together as a scientist who spent 25 years listening to the whir of generators and the bang of cloud chambers in the laboratory started by Carl Anderson. With Robert Leighton, myself, and others the work continued after 1945 along Carl's path. The light of the arc became the blinding flash of Xenon tubes, and the "bang" of Carl's chamber deepened to the "boom" of a walk-in monster. The thousands of pictures multiplied a hundredfold, and the world of elementary particles came into closer view as the years fell behind. And we faced the path ahead. Now we turn to face about. Words from the Fowler/Rutherford letter echo across the 50 years. Viva Caltech! And we answer back. Viva Carl Anderson! □

Googly-Antigoogly

THE TASK of naming new particles has occasionally stimulated some flights of unexpected fancy in 20th-century physicists. Carl Anderson stuck to a rational approach, however, when, six months after its discovery, he suggested the name "positron" as a contraction of positive electron. He added that from symmetry considerations the electron should really be called the "negatron," but 40 years of usage was too much to overturn, and the electron remained to pair with the positron.

It might have been worse. A British physicist with a classical bent suggested that the positive electron be called the "oreston," since Orestes was the brother of Electra. Another sports-minded British physicist wanted the name "googly," from the peculiar hop of a cricket ball when it curved in the wrong direction. Physicists escaped, perhaps only by months, the fate of attending symposia on googly-antigoogly annihilation.

Practical Applications

NO ONE can possibly quantify the benefits to mankind of the great discoveries of science. Even when those benefits are direct, however, their application often awaits other discoveries. Hundreds of years lie between Gilbert's 16th-century discovery of magnetic forces and the electric power of the 20th century. Isaac Newton died in 1727, and his equations ride with every airplane that flies today.

Things may be speeding up, though. After less then 50 years, Carl Anderson's discovery of the positron made possible a new medical technique (called PET for positron emission tomography) that allows physicians to examine the brain and body in ways never before possible. They can now view metabolic changes in the activity of the organ under examination — seeing an actual picture of the changes in the brain when, for example, a loud noise becomes soft music. They can also watch blood flow and metabolism in the heart and blood vessels, which may lead to a better understanding of the mechanisms of heart attacks and strokes.

The PET scanner works because positrons consist of antimatter. In studies with this instrument, a subject is injected with some biochemical (glucose, for example) that is tagged with a short-lived radioactive substance that emits positively charged particles — positrons. Since the positron is an anti-electron, when it meets an electron (which is negatively charged) in the body's cells, the two particles completely annihilate each other. In the process, they produce two gamma rays moving in directly opposite directions with an energy corresponding to the mass of the destroyed particles (according to Einstein's equation $E = mc^2$). These gamma rays can be detected by a scanning device. Collected and translated into color-coded images, the resulting patterns indicate the intensity of metabolic activity — that is, the rate of consumption of tagged biochemical — in whatever organ is under scrutiny.

No Matter

BACK IN the 1950s the *San Francisco Chronicle* published an article about antimatter that evoked a response in the form of a poem from physicist Harold Furth. In January 1967 *E&S* reprinted an excerpt from the *Chronicle* story and the entire poem in an article written by Murray Gell-Mann, now Robert Andrews Millikan Professor of Theoretical Physics at Caltech and Nobel Laureate. With permission from both Furth and *The New Yorker* (in which the poem originally appeared), we once more offer these items as our final word on antimatter — at least for this special issue of Caltech's magazine.

PERILS OF MODERN LIVING

A kind of matter directly opposed to the matter known on earth exists somewhere else in the universe, Dr. Edward Teller has said . . . He said there may be anti-stars and anti-galaxies entirely composed of such anti-matter. Teller did not describe the properties of anti-matter except to say there is none of it on earth, and that it would explode on contact with ordinary matter.

–San Francisco Chronicle

Well up beyond the tropostrata
There is a region stark and stellar
Where, on a streak of anti-matter,
Lived Dr. Edward Anti-Teller.

Remote from Fusion's origin,
He lived unguessed and unawares
With all his antikith and kin,
And kept macassars on his chairs.

One morning, idling by the sea,
He spied a tin of monstrous girth
That bore three letters: A.E.C.
Out stepped a visitor from Earth.

Then, shouting gladly o'er the sands,
Met two who in their alien ways
Were like as lentils. Their right hands
Clasped, and the rest was gamma rays.*

—Harold Furth