

## Recent Developments in Particle Physics

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When I received my B.S. degree in 1932, only two of the fundamental particles of physics were known. Every bit of matter in the universe was thought to consist solely of protons and electrons. But in that same year, the number of particles was suddenly doubled. In two beautiful experiments, Chadwick showed that the neutron existed (1), and Anderson photographed the first unmistakable positron track (2). In the years since 1932, the list of known particles has increased rapidly, but not steadily. The growth has instead been concentrated into a series of spurts of activity.

Following the traditions of this occasion, my task this afternoon is to describe the latest of these periods of discovery and tell you of the development of the tools and techniques that made it possible. Most of us who become experimental physicists do so for two reasons: we love the tools of physics because to us they have intrinsic beauty, and we dream of finding new secrets of nature as important and as exciting as those uncovered by our scientific heroes. But we walk a narrow path with pitfalls on either side. If we spend all our time developing equipment, we risk the appellation of "plumber," and if we merely use the tools developed by others, we risk the censure of our peers for being parasitic. For these reasons, my colleagues and I are grateful to the Royal Swedish Academy of Science for citing both aspects of our work at the Lawrence Radiation Laboratory at the University of Cali-

fornia—the observations of a new group of particles and the creation of the means for making those observations.

As a personal opinion, I would suggest that modern particle physics started in the last days of World War II, when a group of young Italians, Conversi, Pancini, and Piccioni, who were hiding from the German occupying forces, initiated a remarkable experiment. In 1946, they showed (3) that the "mesotron," which had been discovered in 1937 by Neddermeyer and Anderson (4) and by Street and Stevenson (5), was not the particle predicted by Yukawa (6) as the mediator of nuclear forces, but was instead almost completely unreactive in a nuclear sense. Most nuclear physicists had spent the war years in military-related activities, secure in the belief that the Yukawa meson was available for study as soon as hostilities ceased. But they were wrong.

The physics community had to endure less than a year of this nightmarish state; Powell and his collaborators (7) discovered in 1947 a singly charged particle (now known as the pion) that fulfilled the Yukawa prediction, and that decayed into the "mesotron," now known as the muon. Sanity was restored to particle physics, and the pion was found to be copiously produced in Ernest Lawrence's 184-inch cyclotron, by Gardner and Lattes (8) in 1948. The cosmic ray studies of Powell's group were made possible by the elegant nuclear emulsion technique

they developed in collaboration with the Ilford laboratories under the direction of C. Waller.

In 1950, the pion family was filled out with its neutral component by three independent experiments. In Berkeley, at the 184-inch cyclotron, Moyer, York *et al.* (9) measured a Doppler-shifted  $\gamma$ -ray spectrum that could only be explained as arising from the decay of a neutral pion, and Steinberger, Panofsky, and Steller (10) made the case for this particle even more convincing by a beautiful experiment using McMillan's new 300-Mev synchrotron. And independently at Bristol, Ekspong, Hooper, and King (11) observed the two- $\gamma$ -ray decay of the  $\pi^0$  in nuclear emulsion, and showed that its lifetime was less than  $5 \times 10^{-16}$  second.

In 1952 Anderson, Fermi, and their collaborators (12) at Chicago started their classic experiments on the pion-nucleon interaction at what we would now call low energy. They used the external pion beams from the Chicago synchrocyclotron as a source of particles, and discovered what was for a long time called the pion-nucleon resonance. The isotopic spin formalism, which had been discussed for years by theorists since its enunciation in 1936 by Cassen and Condon (13), suddenly struck a responsive chord in the experimental physics community. They were impressed by the way Brueckner (14) showed that "Y-spin" invariance could explain certain ratios of reaction cross-sections, if the resonance, which had been predicted many years earlier by Pauli and Dancoff (15), were in the 3/2 isotopic spin state, and had an angular momentum of 3/2.

By any test we can now apply, the "3.3 resonance" of Anderson, Fermi *et al.* was the first of the "new particles" to be discovered. But since the rules for determining what constitutes

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The author is professor of physics at the University of California, Berkeley. This article is the lecture he delivered in Stockholm, Sweden, January 1969, when he received the Nobel Prize in physics. It is published here with the permission of the Nobel Foundation and will also be included in the complete volume of *Lectures on Nobel Prizes 1968* as well as in the series *Nobel Lectures* (in English) published by the Elsevier Publishing Company, Amsterdam and New York.

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