A MATTER OF ENERGY LEVELS

The more energetically physicists probe into nature, the more complex and varied the phenomena become. Nevertheless, the end of the search may be approaching.

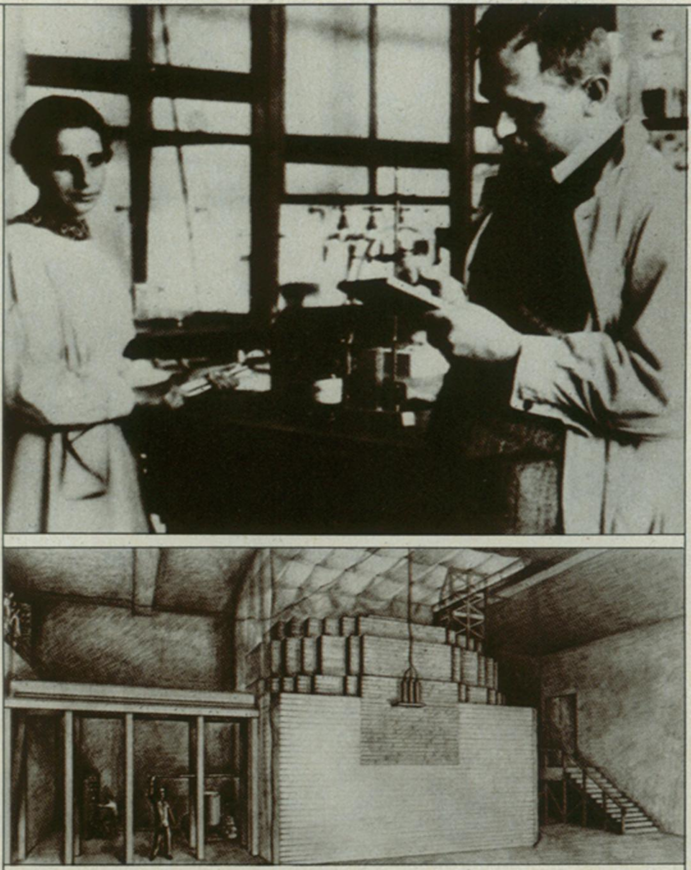
BY DIETRICK E. THOMSEN

Did God really say: "Let 100 particles bloom"? Or did He content Himself with: "Let there be light"? Whether they are primary or secondary to creation, the 100 (and more) particles exist. Physicists have fascinating ways of classifying them and explaining their relations with one another by using mathematical symmetry groups of various names and indicial designations. What is lacking is a satisfying philosophical description of their place in the over-all economy of things.

The 100 or so particles were not in the physics of 60 years ago. Physics in the 1920s had only two particles, the proton and the electron, and their roles in the structure of matter seemed quite evident. There was no particle physics then. Physics in those days was atomic physics.

In the early years they used the famous atomic model of Niels Bohr, who was the first to apply quantum mechanics successfully to a description of electron orbits in an atom. To be a physicist in those days, to be an atomic physicist anyhow, meant to be a spectroscopist —that is, one who sorts out energy levels. In 1982 a physicist is still a spectroscopist, but in the 1920s it meant the classic optical spectroscopy. The experimenter observed the light from an incandescent sample of some chemical element, and from the wavelengths found in it calculated the energy levels and orbits of the electrons in the given atom.

It was clear by 1922 that there were subtleties in the data not explained by the simple Bohr model. The key to these things was provided shortly thereafter by Samuel A. Goudsmit and George E. Uhlenbeck with the discovery of electron spin. Spin provided a new way for electrons to interact with their surroundings, making possible more numerous energy levels and a more subtle model of the atom. This change has been called the end of the old quantum mechanics and the beginning of the new, not only because it changed the model of the atom, but because it endowed particles with a new characteristic, spin. Spin, in particles, is not quite the same thing as spin in tops or planets. It was the first of many particle properties (quantum numbers) that correspond to nothing in the macroscopic world.



Lise Meitner and Otto Hahn (top) discovered nuclear fission at the Kaiser Wilhelm Institute in Berlin-Dahlem. The first fission reactor was built in Chicago in 1942 (bottom).

AIP Niels Bohr Library

Argonne National Laboratory

The atomic nucleus was not nearly so well studied during the 1920s as the shells of electrons surrounding it. A way into the nucleus powerful enough to reveal some of its structure was lacking until the first artificial accelerators— E. O. Lawrence's cyclotron and the electrostatic machines of John Cockcroft and E.T.S. Walton and of Robert van de Graaff.

In 1932 James Chadwick discovered the neutron, and nuclear physics as we know it began. The neutron had not been expected. The usual model of the atomic nucleus used before 1932 contained protons and electrons— enough protons to make up the observed weight plus enough electrons to cancel proton charges and give a net charge equal to the observed atomic number. The new model of the nucleus had only enough protons to make up the atomic number. The rest of the atomic weight was provided by neutrons, and there were no electrons identifiable as such.

The model called for the recognition of a new kind of force, or, as physicists would prefer to say, a new kind of interaction. In the earlier model, which has only electrically charged particles, well-known electric forces sufficed to bind the nucleus together. Electric forces do not grip neutral objects. With the neutron in the nucleus some other kind of force must do the binding. It was named the strong interaction for one of its most obvious characteristics.

On this basis physicists learned a great deal about the structure of the nucleus, but a complete understanding is still being sought. The dynamics of the nucleus are much more complex than those of atomic electrons and the detailed behavior of the strong interaction is very poorly known compared to that of electromagnetism.

Because of the strength of the strong interaction, large amounts of energy are stored in the bonds it effects. Physicists saw that if this energy could be released explosively, a very little bit of explosive would blow up a great deal. The key to doing this, that fission could be induced in certain nuclei by striking them with energetic neutrons, was discovered in 1938 by Otto Hahn and Lise Meitner, working in Berlin. It meant chain reactions might be possible.

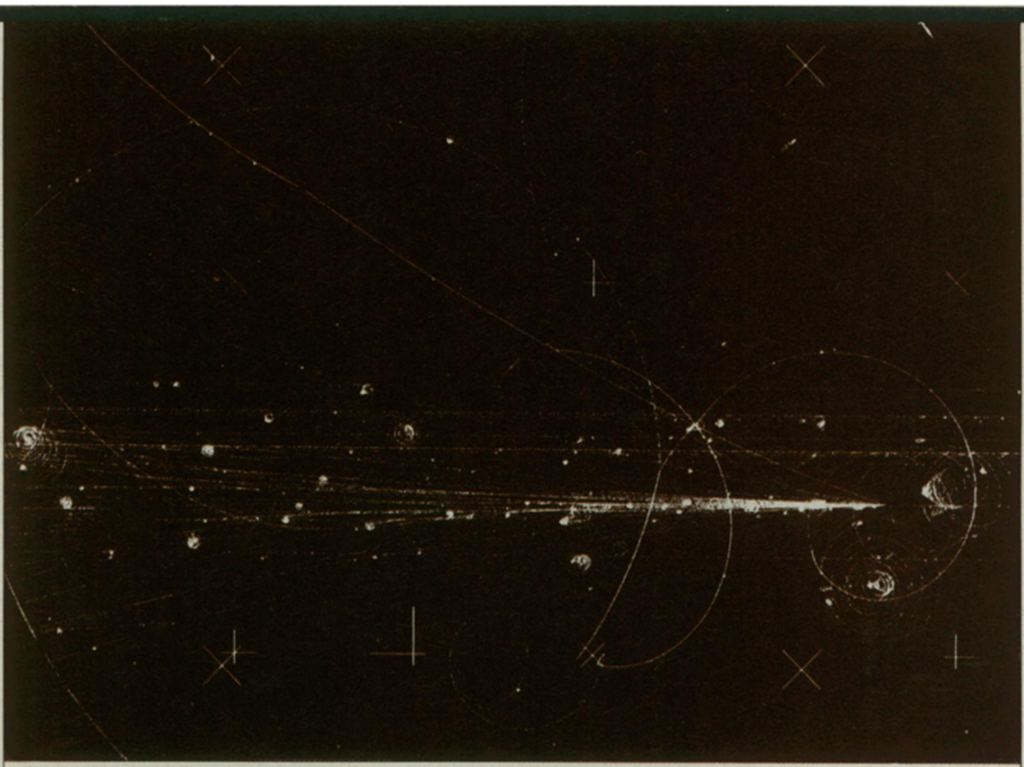
In one of history's ironies Meitner, who was Jewish, had been able to complete the series of experiments only because she was an Austrian citizen and so exempt from the German law requiring the dismissal of Jews from academic posts. In 1938 Germany annexed Austria, and Meitner came under the provision. She left at once for Sweden where she was to collaborate with her nephew Otto Frisch on the follow-up work and the famous Meitner-Frisch paper of 1939 that described nuclear fission for the scientific public. On the way she stopped in Copenhagen and told the news of induced fission to Bohr. Legend has it that she ran up the gangplank of a steamer on which Bohr was embarking for New York and imparted the information just ahead of the "all ashore" gong. She herself later said the encounter was not that dramatic.

Bohr proceeded to New York, and there, in lectures at Columbia University, imparted the news to the people who later drew up the famous letter to President Roosevelt that resulted in the Manhattan District Project. (By now it was early 1939.) In 1942 Enrico Fermi's first pile—a stack of fuel and control rods, hidden under the stands of Chicago's Stagg Field—showed that chain reactions really could be controlled. Fermi's pile led the way to practical power reactors, and, by way of fuel breeding, to practical bombs.

Particle physics pure and not so simple also got its start in the early 1930s with Wolfgang Pauli's postulation of the existence of the neutrino (it wasn't found until 1956) and Fermi's suggestion that yet another variety of force (known as the weak interaction or sometimes the universal Fermi interaction) was needed to explain its behavior. In the middle of the decade Hideki Yukawa worked out a theory of the strong interaction that called for the existence of an intermediary particle, one that was the embodiment of the force and carried its effect from neutron to proton or whatever.

Both the Yukawa particle (now called the pion and finally discovered in 1948) and the neutrino have a connection to the dynamics of the nucleus. The particle that was found during the search for the Yukawa particle has no such connection. It is the muon. When it was finally recognized *not* to be the Yukawa particle, nobody could think of what it was good for, and essentially nobody can yet. After the war the energies of particle accelerators climbed from a few hundred thousand volts to the millions, the billions, the hundreds of billions of volts. More and more things like the muon appeared: particles whose connection with palpable matter seemed tenuous at best; particles that were unstable, turning themselves into other particles and others again in a wild kaleidoscopic dance.

Physicists again turned spectroscopists. As they had done in the cases of the atom and the nucleus, they sought



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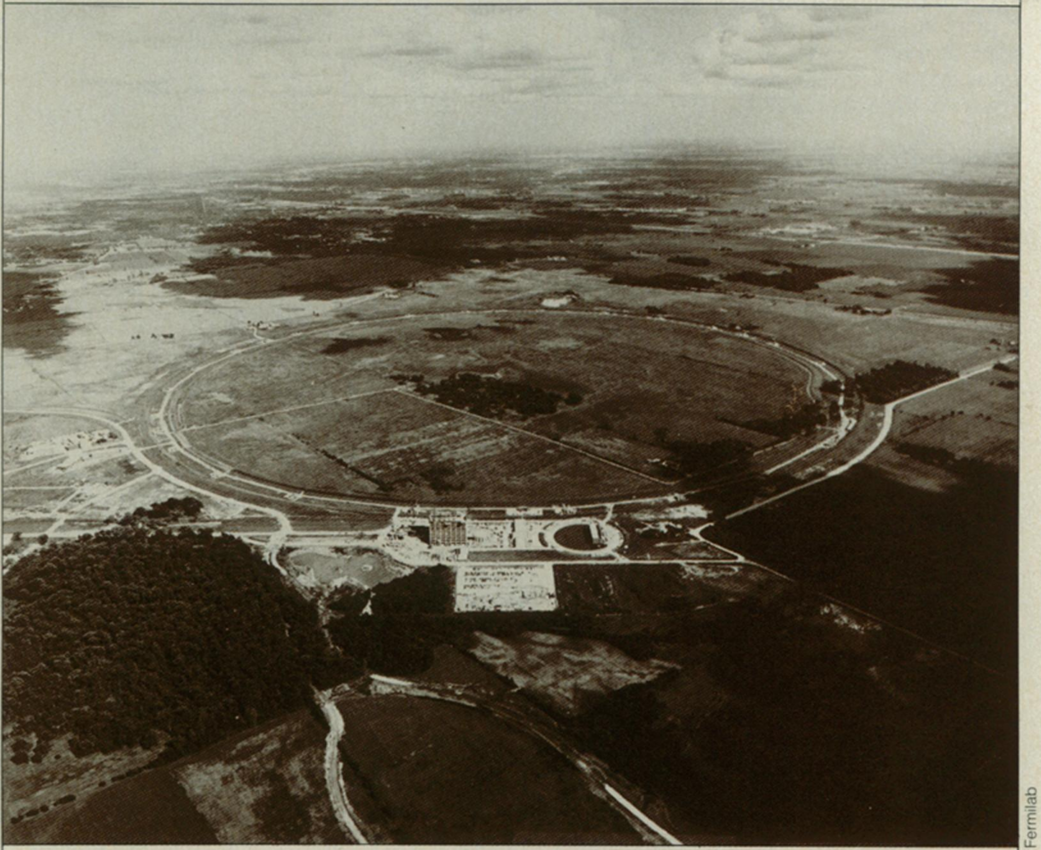

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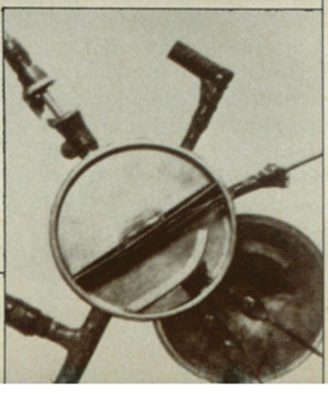
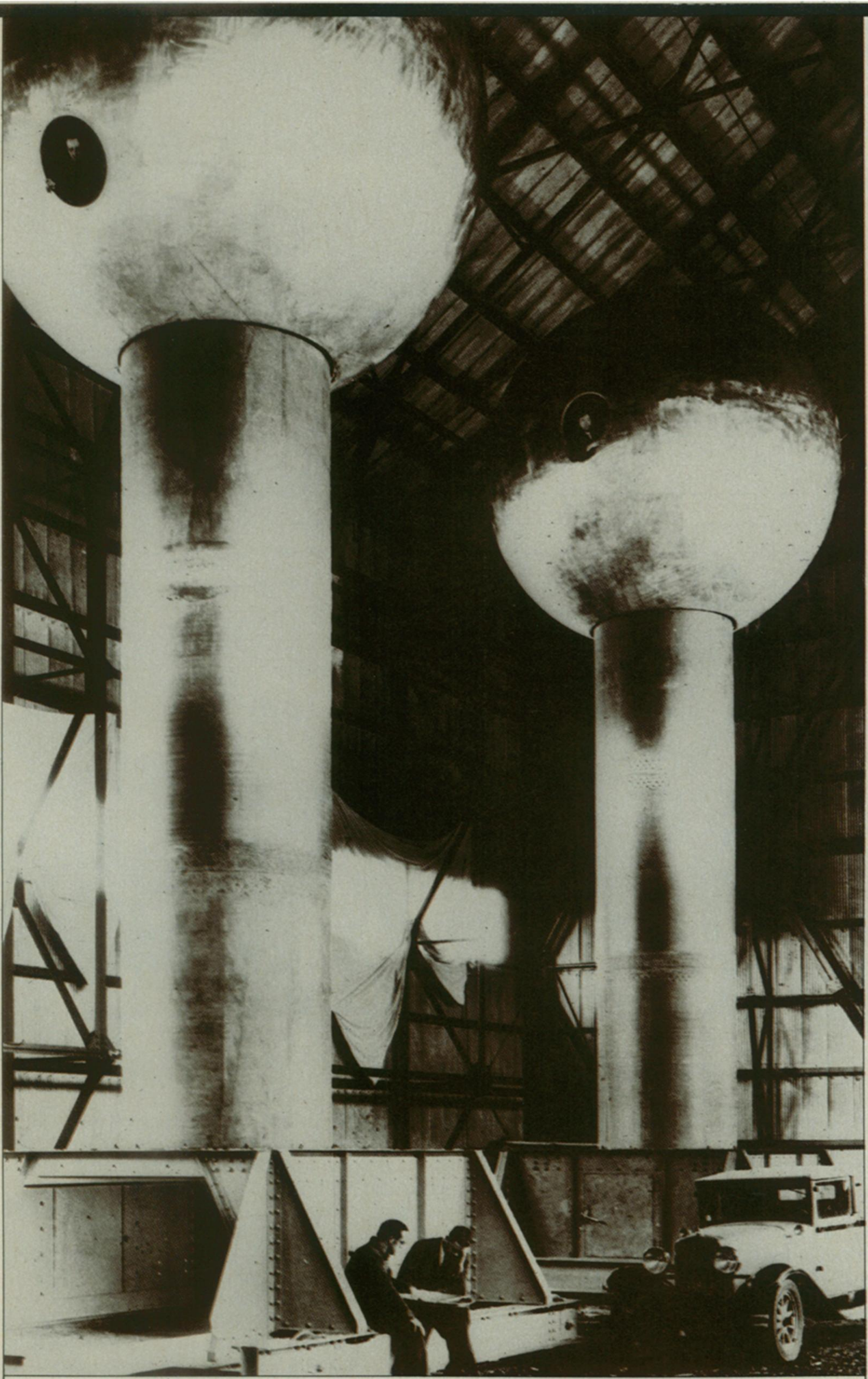


Lawrence Berkeley Laboratory

The variety of phenomena in particle physics is well symbolized by this picture from Fermilab's 30-inch bubble chamber showing 26 charged particles produced in a single interaction (top). Fermilab's synchrotron, buried under the large white circle (middle), one of the two largest circular accelerators in the world, makes a sharp contrast with its tabletop ancestor, the first successful cyclotron (bottom at right).



Among the first successful linear accelerators was the first van de Graaff machine, built at MIT *in 1933 (left).*

National Museum of History and Technology, Smithsonian Institution

for principles of symmetry and pattern to bring some order out of this subatomic fireworks display. The patterns that seem to work are those of the unitary symmetry groups, which arose in geometrical research and have to do with the possible permutations of different geometric figures. They seem equally useful for the permutations and changes among subatomic particles. A particle's place in the patterns determined by these symmetry groups and the role it plays in the changes and permutations that these theories analyze is determined by its quantum numbers, which are its particular set of properties (and which include the spin first discovered 60 years ago). The first great success of the method, pioneered by Murray Gell-Mann and George Zweig, was to predict the existence of the omega-minus particle, discovered in 1962.

The beauty of these symmetry groups is that if you start with a small one, you can find a bigger one that includes the one you had first plus a lot of other things. To many this seems the way to go to find a unified description of all of physics. Already a significant part of that unification, the putting together of the phenomena controlled by electromagnetism and those under the weak or Fermi interaction, has been accomplished. It is largely the work of Steven Weinberg, Abdus Salam and Sheldon Lee Glashow. They and others are busy at work on a total unification, a so-called Grand Unified Theory (GUT). If a GUT is ever reached we will presumably know how all things, the one hundred particles and everything else, relate to one another, but unless we find some role for the hundred particles in palpable matter, creation will still seem extravagant: Why make all this variety of phenomena to come down in the end to the familiar triad, proton-neutron-electron? □

The largest present linear accelerator, the Stanford Linear Accelerator (left), is two miles long. It is shown here before the addition of storage rings at the near end.

Stanford Univ.