2. THE PARTICLE ZOO

Physicists of the 1950's tried to understand the burgeoning list of subatomic particles by classifying them according to their discernible properties and interactions. In the absence of convincing theories of the strong and weak forces, such a taxonomical approach made good sense. It was like zoology before Darwin: animals had to be grouped into phyla, genera, and species before an evolutionary paradigm could unify the entire kingdom.

A distinguishing feature of subatomic particles is whether or not they feel the strong force. Electrons, for example, do not. If you shoot an electron across the bow of an atomic nucleus, it will be diverted from its straight-line path by the electromagnetic forces exerted by the protons and neutrons inside; it might even catch a whiff of the weak force, too. But the strong force that locks the nucleons together has no direct effect upon the electron. The same is true of the neutrino, which doesn't even feel the electromagnetic force. Only the weak force can perturb its path.

Particles like the electron and neutrino that do not feel the strong force are known as *leptons*, from the Greek word meaning small or light. Compared to the proton, these are two exceedingly light particles. But leptons need not necessarily be so light; indeed, we shall soon encounter a lepton that is heavier than the proton. The single defining characteristic of a lepton is the simple fact that it is oblivious to the strong force.

During the 1950's particles that felt the strong force began to be known collectively as *hadrons*, from the Greek word for thick or heavy. Protons, neutrons, and pions are all hadrons because they interact with one another by the strong force. So are their more exotic cousins—the kaons, lambdas, sigmas, and xis mentioned in the previous chapter.

There was another subatomic particle known by the 1950's, the *muon* (pronounced "mew-on" and denoted μ). It had turned up in cosmic rays in the 1930's and been mistaken for Yukawa's hypothetical carrier of the strong force. That would have made it a hadron. But experiments during and after World War II proved that this new particle interacted with matter far too feebly to be a hadron. In fact, the muon has all the same properties as the electron except for the fact that, at a mass of 106 MeV, it is about 200 times heavier.

Muons are therefore classified as leptons. They survive for a few microseconds, a long time in the subatomic world, before decaying into an electron or positron (depending on their charge) plus a neutrino and an antineutrino. Along with neutrinos, muons are the principal decay products of the somewhat heavier pions. Because they are long-lived, penetrating particles, muons are a major component of the cosmic-ray debris that eventually reach the Earth's surface.

Until 1956 nobody had ever seen a neutrino directly. Its existence had been inferred from theoretical arguments, and sensitive measurements of pion and neutron decays showed that *something* very light and neutral was indeed spiriting energy away. (A neutron, once isolated, decays to a proton after about 12 minutes.) But because neutrinos interact with matter so feebly, these ghostly particles had never left visible traces in detectors.

During the 1950's, however, nuclear reactors funded by the AEC emerged as a copious source of neutrinos, which also are produced in radioactive decays of atomic nuclei like uranium. In 1956 two physicists from the Los Alamos National Laboratory (located in New Mexico) buried thousands of gallons of cadmium chloride solution next to the giant Savannah River reactor in South Carolina. With trillions of neutrinos speeding through the huge volume every second, a few occasionally collided in the solution and made flashes of light that were identified as due to neutrinos.

Producing controlled beams of neutrinos for research, however, took a few more years. In 1952, the same year that the Cosmotron began operations at the Brookhaven National Laboratory, three physicists there had developed a new accelerator technique known as *strong focusing*. This ap-