

STRONGLY INTERACTING PARTICLES

Presenting an account of recent developments in high-energy physics. These particles that respond to the strongest of the four natural forces no longer seem "elementary." They may be composites of one another

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Only five years ago it was possible to draw up a tidy list of 30 subatomic particles that could be called, without too many misgivings, elementary. Since then another 60 or 70 subatomic objects have been discovered, and it has become obvious that the adjective "elementary" cannot be applied to all of them. For this reason the adjective has been carefully avoided in the title of this article. There is now a widespread belief among physicists that none of the particles with which this article is mainly concerned deserves to be singled out as elementary.

What is happening has happened before in physics: the old way of looking at things, which was adequate for perceiving order in a limited number of observations, finally proved cumbersome and inadequate when the accuracy and range of observation increased. This happened with the Ptolemaic scheme of epicycles for describing the motions of the planets. Much the same thing occurred early in this century when spectroscopists, studying the light emitted by excited atoms, found a profusion of discrete wavelengths that were at total variance with the wavelengths predicted by classical electrodynamics. The spectroscopists accumulated so much empirical information, including sets of "selection rules" governing the permissible states of excited atoms, that it finally became possible in 1926 for Werner Heisenberg, Erwin Schrödinger and others to formulate a new mechanics—quantum mechanics—capable of predicting most of the states of matter on the atomic and molecular scale.

A similar situation may exist today in particle physics. The great unifying invention analogous to quantum mechanics is still not clearly in sight, but the experimental data are beginning to fall into striking and partly predictable

patterns. What can be said to summarize the vast amount of particle information now available?

First of all, there is a clear distinction between strongly interacting particles, such as the neutron and proton, and other particles. The neutron and proton are known to interact through the strong, short-range nuclear force, which is responsible for the binding of these particles in atomic nuclei. All particles discovered to date participate in this strong interaction except the photon (the particle of light and other electromagnetic radiation) and the four particles called leptons: the electron, the muon (or mu particle) and the two kinds of neutrino.

Another striking property of the strongly interacting particles is that none of them has a small rest mass. Rest mass is the mass that a particle would have if it were motionless; this is the minimum mass the particle can have. It is now common to express this mass as its equivalent in energy, rather than in units of the electron's mass, as was often done in the past. The lightest strongly interacting particle is the pion (or pi meson), which has a mass with an energy equivalent of some 137 million electron volts (Mev). In contrast, the mass of the electron is about .5 Mev and that of the photon and the neutrinos is believed to be zero.

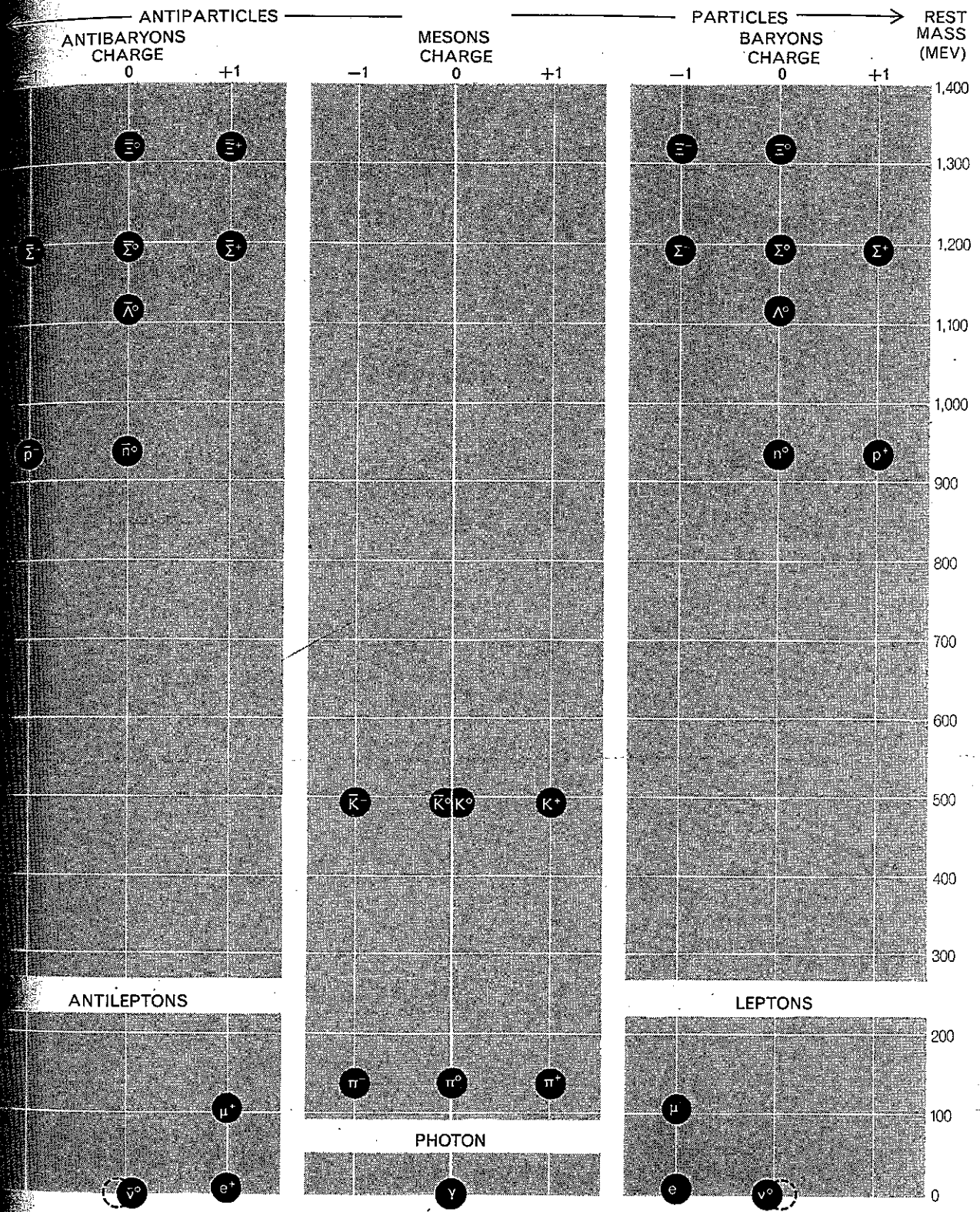
A third general observation is that the recent proliferation of particles has so far occurred almost exclusively among the strongly interacting particles. Although this proliferation came as a surprise to physicists, a precedent for this state of affairs can be found in ordinary atomic nuclei. It is well known that all compound nuclei, from the nucleus of deuterium (heavy hydrogen) to those of the heaviest elements, can exist at a variety of energy levels, comprising a "ground" state and many excited states.

These levels, which can be detected in several ways, indicate different degrees of binding energy among the component nucleons (neutrons and protons) in the nucleus. The binding energy, of course, is an expression of the strong nuclear force.

It is now clear that the nuclear force can similarly give rise to numerous states among those strongly interacting particles sometimes designated elementary. The lower states are "bound," or stable; the higher states are only partly bound, or unstable, decaying in a tiny fraction of a second. The result is that all strongly interacting particles exhibit a spectrum of energy levels with no sharp upper limit.

Since the leptons do not participate in strong interactions, it is not surprising that their spectrum of states, beginning with the massless neutrino and apparently terminating sharply at the muon, with a mass of 106 Mev, bears no resemblance to any known dynamical spectrum. In recent years physicists have learned much about the simplicity and regularity in the properties of leptons, but they have learned nothing of why these particles exist.

In the following discussion we shall begin by considering the place of the strong force in the hierarchy of four forces that seem to underlie all the operations of the physical universe. Next we shall describe a new nomenclature that assigns each of the strongly interacting particles to one of a small number of families, each characterized by a distinctive set of properties. One group of these families embraces the baryons, which in general are the heaviest particles; a second group consists of mesons, the first members of which to be discovered were lighter than the baryons. The new naming system will require a brief review of the seven quantum num-



BARYONS
 SIGMA
 LAMBDA
 NEUTRON
 PROTON
 MESONS
 KAON, OR KAON
 PION, OR PION
 LEPTONS
 MUON, OR MUON
 ELECTRON
 NEUTRINO

THIRTY PARTICLES of 1957 consisted of 16 baryons and antibaryons, seven mesons, six leptons and antileptons and the photon. (Baryon, meson and lepton respectively signify heavy, medium and light particles.) The strongly interacting particles, which respond to the strong, or nuclear, force, are in color. Particles shown in black do not respond to this force. It is the former that have proliferated in the past half-dozen years, as shown on the next two pages. In the same period the number of

leptons and antileptons has increased by only two. It is now known that there are two kinds of neutrino instead of one, each with its own antiparticle (indicated by broken lines next to the two particles known in 1957). One other neutral and massless particle is believed to exist but is not shown here: the graviton, the carrier of the gravitational force. The hypothetical carrier of the weak force, also not shown, should have a considerable mass and one unit of electric charge. Evidence for it is now being sought.