6. THE SEARCH FOR UNITY

High-energy physicists try to describe the universe with the utmost economy. They seek the smallest possible set of fundamental bricks out of which to build matter and the fewest different kinds of mortar that can bind them together. Ideally they would prefer to use only one kind of mortar and a few different bricks, one force acting among just a few elementary particles, as the basis of all existence. The quark model was a major success in this regard; out of a scant three particles, all the teeming variety of hadrons could be built.

By the 1950's it had become clear that there were *four* forces acting upon subatomic particles: electromagnetism, the strong and weak nuclear forces, and gravity. Although such a situation is not bad—4 is far better than 40—it was not good enough for certain physicists, who began to search for deeper connections between these forces. They wanted to know whether two of these forces might be just different manifestations of a single, fundamental force.

Such a quest was hardly radical. In the late 1600's Isaac Newton had accomplished such a "unification" when he showed that apples fell to earth—and moons and planets remained in orbit—because of a single universal force called gravity. Almost two centuries later, the Scottish physicist James Clerk Maxwell achieved a similar unification when he demonstrated that electricity and magnetism were but two facets of the same phenomenon, called electromagnetism. Maxwell's four equations, which predicted the existence of electromagnetic waves (of which light is just one form), supply the theoretical underpinnings of the electronic and communication technologies that are central to modern life.

Recent attempts at unification employed the gauge theory approach that had been eminently successful in describing electromagnetism. In a gauge theory the force on a particle is due to some kind of charge that is absolutely indestructible—like electric charge. As mentioned earlier, Julian Schwinger tried to apply the gauge theory of Yang and Mills to form a unified theory of the weak and electromagnetic forces. It was an audacious idea, because these two forces appear *very* different in practice. Thousands of times feebler than electromagnetism, the weak force extends only over extremely short distances, and does not conserve parity.

Schwinger's attempt ran into severe difficulty, however, when he tried to endow the two weak-force-carrying W particles with mass—which was necessary because short-range forces are usually carried by massive particles. When he tried to graft a mass onto these particles, the desirable gauge invariance of the theory broke down, and infinite quantities began to crop up in his calculations. This "problem of mass" continued to be a source of frustration to physicists working on gauge theory.

One such physicist was Sheldon Glashow, who as Schwinger's graduate student at Harvard, had participated in the attempts to unify the theories of weak and electromagnetic forces. Sympathetic to his mentor's ideas, he was also cognizant of their shortcomings. Working in Copenhagen in 1960, he skirted some problems by postulating a neutral force-carrying particle called the Z in addition to the two W's. Together with the photon, they formed a hypothetical family of four spin-1 vector *bosons* that carried both the weak and electromagnetic forces. By an appropriate choice of masses, Glashow's theory portrayed both a short-range, parity-violating weak force and a long-range, parity-conserving electromagnetic force. But because he had inserted the masses of the vector bosons into the theory in a seemingly arbitrary manner, infinities again cropped up in calculations.

In the early 1960's, theorists were becoming interested in *broken* symmetry. An idea borrowed from solid-state physics, broken symmetry means that the equations describing a physical system remain symmetric even though their physical manifestations—the subatomic particles and the forces between them—do not. The members of the spin-0 meson octet, for example, have fairly different masses ranging from 135 to 550 MeV even though they are all close relatives. Perhaps the symmetry