of CP violation, Cronin and Fitch shared the 1980 Nobel prize.

A conservation rule that has never been knowingly violated—that seems to hold true in *every* interaction—is the conservation of electric charge. It is absolute. Nobody has ever observed charge spontaneously appear or disappear. To physicists the conservation of electric charge is proof of an abstract internal symmetry called *gauge invariance*. Loosely speaking, gauge invariance means that the laws of nature do not depend on the calibrations of our measuring sticks—their "gauges."

Both classical electromagnetism (the theory of electromagnetic force) and QED were long known to possess gauge invariance. The electromagnetic force, that is, originates from a charge that is absolutely conserved. In QED the force is carried from one charge to another by a spin-1 particle, the photon. Because QED had worked so well, allowing physicists to make very precise calculations accurate to many decimal places, physicists of the 1950's began to search for similar approaches, called *gauge theories,* to describe the strong and weak nuclear forces.

An early attempt along these lines was the work of Yang and Robert Mills, done at Brookhaven over the summer of 1954. They suggested that the strong force possessed a gauge symmetry and was borne from one hadron to the next by a *triplet* of spin-1 particles they designated B^+, B^-, and B^0—three analogues of the photon.

The analogy with QED and the requirements of gauge invariance meant, however, that these B-particles had to have zero masses like the photon, which posed a severe problem for the Yang-Mills theory. The strong force is a very short-range force, extending outward less than a trillionth of a centimeter. According to the so-called quantum-mechanical uncertainty principle, short-range forces are carried by massive particles. But allowing these particles to have a mass destroyed the beautiful gauge invariance of the theory. Yang and Mills could not surmount this problem, which continued to plague gauge theories for years.

Around this time there were increasing suggestions that the weak force was itself carried by two massive, spin-1 particles: the W^+ and W^-. Because the weak force had an even shorter range than the strong, the mass of these W's was thought to be at least 50 GeV—far too heavy to be produced by accelerators of the day.

In 1956 Julian Schwinger of Harvard University proposed that the Yang-Mills theory might be deployed to unify the theory of the electromagnetic force with that of the weak force. He thought the two forces might be different manifestations of the same fundamental force, much as electricity and magnetism are the two facets of electromagnetism. Schwinger suggested that the triplet proposed by Yang and Mills might actually be the W^+, W^-, and the neutral photon. By assuming the W's to have tremendous masses, he could explain why they acted only over short distances; hence the weak force only *appeared* to be very weak. But his theory foundered for the same reason as that of Yang and Mills: giving the W's a mass destroyed its desirable feature of gauge invariance.

During the 1950's physicists had made a good start in understanding the strong and weak nuclear forces, but by decade's end they still lacked a complete theory. In its stead they had determined a number of conservation rules that provided clues to the underlying symmetries (or lack thereof) of whatever laws of nature were operating on subatomic particles. But various attempts to model the strong and weak forces with QED-like theories had encountered severe difficulties.