Fermilab established the mass of the W particle to be 80.0 GeV—the world's most accurate measurement of this important Standard Model parameter.

Still undiscovered by end of the 1980's, however, were the elusive top quark (needed to fill out the third and final quark-lepton family) and the Higgs boson. According to Fermilab measurements, the top quark has to be heavier than 78 GeV, and indications are that it may be much more massive than that. If its mass is less than 200 GeV as expected, the top quark should eventually turn up at the Tevatron, which is the only collider in the world that can presently be used to produce it.

The Standard Model is a vast improvement over the situation that existed as late as the 1960's. It has withstood repeated experimental tests. But it is still too complex for most physicists, who seek to explain nature in the simplest possible terms, using only a few (if any) arbitrary parameters. Including the quark and lepton masses, there are at least 19 unexplained parameters in the Standard Model—a highly unsatisfactory situation.

For at least a decade, therefore, theoretical physicists have been trying to reach *beyond* the Standard Model. Based on little more than mathematical insight, they are attempting to predict how matter might behave and what particles might be discovered at energies above a thousand GeV, or 1 TeV, the current limit of existing accelerators. From previous experience at lower energies, they expect nature will reveal a common origin for the strong and electroweak forces, which would simplify matters enormously and help explain the complexity remaining today.

Perhaps the commonest path taken is the quest for what physicists dub a *grand unified theory,* or *GUT,* of the interparticle forces. Extending their Yang-Mills gauge theories, physicists have proposed that strong and the electroweak forces are, in turn, just two different low-energy manifestations of a single, grander unified force—two sides of the same coin. At the extremely high energies where this unity supposedly takes hold, estimated to be many trillions of GeV, these forces become one and quarks and leptons become indistinguishable from one another.

Because such energies are completely inaccessible at earthbound particle accelerators, experimenters have had to seek other, novel methods of testing grand unified theories. One way is to see if the proton decays. Long thought to be absolutely stable, the proton can decay according to GUTs because one of its quarks can change into a lepton through what physicists call a *quantum fluctuation.* The mean lifetime of a proton would still be incredibly long, however, perhaps a billion trillion times the age of the universe. The only feasible way to observe proton decay is to gather a lot of them—a thousand tons or more—in one place and wait patiently for a few to expire.

In the early 1980's experimenters around the world began to set up huge detectors in underground locations (to screen out cosmic rays, which can mimic the signals of proton decay) to search for such events. The largest and most sensitive of these underground experiments is built around a tank containing 8,000 tons of extremely pure water situated deep in a salt mine near Cleveland, Ohio. A collaboration of physicists surrounded the tank with over 2,000 phototubes, seeking to detect the faint flashes of blue light that would be generated in this water if a proton suddenly disintegrated.

In over 5 years of waiting and watching, they have recorded no such events, leading to the conclusion that the proton lifetime is greater than a million trillion trillion (or 10^{33}) years. This null result excludes the simplest grand unified theory. More complex GUTs, however, predict longer proton lifetimes that cannot be ruled out yet.

Grand unified theories make another prediction that can be tested by experiments. If they are true, then neutrinos are not massless particles as previously thought, but have a tiny mass. In such a case, the three known types of neutrinos can "*quantum oscillate*" one into another. A muon neutrino might become an electron neutrino, or vice-versa. So far, searches have turned up no conclusive evidence either for neutrino mass or for neutrino oscillations. But more sensitive searches are continuing in these areas, as much remains to be done. The quest for a grander unity has only just begun.

Whether or not grand unification holds true, however, the springboard that made these kinds of theories conceivable—the Standard Model—will certainly remain as one of the greatest intellectual achievements of this century.