The limiting factor, however, will not be the absolute cost of hydrogen, but its cost relative to fossil fuels, and the price of these fuels is certain to climb steeply during the next 30 years. Another factor governing the cost of hydrogen, of course, will be credits obtained in the sale of byproduct oxygen.

The availability of relatively inexpensive hydrogen and oxygen in large quantities could bring about extensive changes in U.S. industry. Initially, during a transition to a hydrogen economy, they might be used in the production of other fuels. Coal gasification, for example, is expected to require about 1500 scf of hydrogen for every 1000 scf of methane produced. Most gasification proposals now envision production of this hydrogen from the coal itself, so the availability of alternative sources would greatly increase the amount of synthetic natural gas that might be produced from a given quantity of coal and extend the lifetime of coal reserves.

Petroleum refining uses increasingly large amounts of hydrogen to improve the quality of the products and to desulfurize the crude oil. By the year 2000, the American Petroleum Institute predicts a consumption of more than 600 scf of hydrogen per barrel of crude oil will be commonplace. Production of shale oil would require even more processing, and perhaps as much as 1300 scf of hydrogen per barrel.

Inexpensive hydrogen might also make it possible to produce synthetic fuels that are not derived from fossil sources. K. R. Williams and N. L. Campagne of Shell International Petroleum Company, London, suggest that it might be possible to make methanol or Fischer-Tropsch gasoline from atmospheric carbon dioxide for as little as 30 to 45 cents per gallon with low-priced hydrogen. Others have suggested that calcium carbonate would be a good carbon source for the production of these fuels.

Ammonia synthesis now accounts for more than 40 percent of hydrogen consumption, and the quantities of hydrogen required can be expected to increase as food demand rises. Hydrogen could also find wide use for the direct reduction of iron ore, particularly as supplies of coking coal become more expensive. Production of 1 ton of iron, the American Iron and Steel Institute estimates, would require some 20,000 scf of hydrogen.

The quantities of oxygen available as a byproduct of hydrogen production would be unprecedented. By weight, oxygen is currently the third largest industrial chemical produced in the United States—11.3×10^9 kilograms, or about 313×10^9 scf in 1971—but the quantities produced in a hydrogen economy would dwarf these figures. A wide variety of new or expanded uses for oxygen would thus be opened—or might, in fact, become necessary to bolster the economics of hydrogen production. Some of the oxygen might be used to support combustion in applications where atmospheric gases are not desirable, such as in coal gasification. Large quantities would also be used in the production of steel. An even larger market might be developed in the treatment of municipal sewage. But for now, however, the use of this oxygen remains the least-studied of all aspects of the hydrogen economy.

—THOMAS H. MAUGH II

Particle Physics: Many Results, Surprising Disclaimers

Research from a new accelerator facility at the European Organization for Nuclear Research (CERN) seemed to dominate the discussions at the 16th International Conference on High Energy Physics, a biennial meeting of scientists who study some of the smallest structures and most fundamental symmetries of nature. Two rather exciting new experiments reported from CERN may be additional evidence for granularity in the structure of the proton, a feature that was suggested by experiments at the Stanford Linear Accelerator Center about five years ago. Other experiments may signal changes in the accepted understanding of the structure of elementary particles. But the most surprising bits of news from the conference were the many reversals and retractions of previous results. The mood of the conference participants was optimistic; particle physics seemed to be progressing by increments on many fronts, with some backtracking, but certainly not lacking new ideas or creative experiments.

The conference, which was attended by 800 foreign and American physicists, was held at the site of the world's largest accelerator, the new National Accelerator Laboratory at Batavia, Illinois. The rough textures of the still unfinished buildings of the laboratory contrasted sharply with the cosmopolitan tone of the conference, at which the dinners were served with good wines and the day's discussions were followed by evenings with excellent chamber music and jazz. The scientific contributions from the new accelerator were restricted because it has not yet reached full-scale operation, but the conference participants seemed to find the early results, particularly from a small bubble chamber, provocative.

The list of reversals of previous experiments presented at the 1972 international meeting was fairly long. In the previous year many physicists had been puzzled because of the failure to observe decay of the long-lived K-meson into two muons in an experiment performed at Berkeley. This was particularly disturbing because it indicated that a rather basic principle of interactions, called unitarity, had been violated. Unitarity means that the probability of all decay modes, taken together, equals one. But in an experiment reported at the Illinois conference by David Nygren, William Carrithers, and associates at Columbia University, Brookhaven National Laboratory, and CERN, six examples of the decay in question were found, apparently enough to satisfy the unitary principle.

A heated controversy over another experiment that had been argued in round robin style at all the particle physics conferences of the last five years was apparently laid to rest. The debate started when a group at CERN reported that a meson thought to be a single entity, the A_2-meson, actually existed as two particles differing only slightly in their masses. Succeeding experiments yielded no evidence for a mass difference, however, and the rapporteur at the Illinois conference judged the preponderance of evidence in favor of a single meson after all.

Another experiment that had been closely watched because it was possible evidence for a new particle was apparently in error. Jack Keuffel and associates at the University of Utah had found an anomalous distribution of muons in an abandoned silver mine under the Wasatch Mountain Range that could not be accounted for by normal processes. The experiment was taken as possible evidence for the long sought intermediate vector boson, the particle which would, if found, be the mediator of the weak interaction, just as the photon and pion are the mediators of the electromagnetic and strong interaction forces. However, Keuffel recently repeated the experiment and decided that his earlier analysis of the muon distributions had been in error; as it stands now there is no evidence from his experiment for an anomalous effect, or for an intermediate vector boson.

Several hundred mesons with extremely short lifetimes are known, but according to C. Lovelace of Rutgers, who summarized the situation, there has been a net decrease in the number of strongly interacting mesons (baryon resonances) since the previous international conference. Specifically, experiments that indicated the existence of the A_1-meson now appear doubtful, and the existence of the E-meson is also in question. Such reports prompted Murray Gell-Mann from Caltech to question whether meson experiments need to be repeated every few years to see if the particles are still there. He postulated a new law: Mesons decay if they haven't been mentioned lately."

Reversals are to be expected in any field of science, particularly in one with experiments as tedious and complex as the typical research projects in high-energy physics, but new findings are the only hints to the future directions.

In two experiments particularly noted at the conference it was found that very many pions were emitted perpendicular to the paths of colliding proton beams of the CERN Intersecting Storage Rings. The fact that so many particles were emitted at right angles to the original path may be additional evidence for granularity in the proton substructure, or may be evidence that some new particle is produced and then decays with pion emission. Because a new particle (such as an intermediate vector boson or a heavy lepton) from equally energetic beams would be produced at rest in the laboratory, observation of the pions at 90 degrees to the beam path would be more likely than usual, and could explain the large flux. The experiment detecting neutral pions was directed by Rodney Cool of Rockefeller University, Leon Lederman of Columbia, and Luigi DiLella and Emilio Zavattini of CERN. A similar experiment with the Intersecting Storage Rings detecting charged pions was performed by Marcel Banner and associates from Saclay, Center d'Etudes Nucleaires, France.

Other experiments, particularly electron-proton collisions producing many secondary particles, seemed to some physicists to signal the germination of qualitatively different ideas about the structure of strongly interacting particles (such as protons).

The concept of scaling, the property whereby the likelihood of a reaction depends on the energy in a particularly simple way, still seems to be viable. For reactions initiated with electrons, neutrinos, or gamma rays, scaling is expected because the "particle" has no size. Scaling is not so obvious for particles with measurable sizes, but it appears to be holding reasonably well at the high energies available from CERN. For the first time, in Illinois, it was suggested that scaling of a rather different sort, involving individual products in a complex reaction, may be a valid concept.

In theories of elementary particles, the greatest recent advance is generally acknowledged to be the development of models which synthesize the electromagnetic and weak interactions, such as the work of Steven Weinberg of the Massachusetts Institute of Technology and Benjamin W. Lee of the State University of New York at Stony Brook. Although all the theories proposed so far have enough limitations so that, in the words of Murray Gell-Mann, "they are not beautiful," he considers the prospects for further development bright.

New Facilities with Colliding Beams

The number of outstanding experiments from CERN reported at the Illinois conference suggested that the future experiments of high-energy physics may be performed more and more frequently with two beams colliding head-on rather than with one beam hitting a stationary target. Although the energy of each beam in the Intersecting Storage Rings at CERN is only about 28 billion electron volts (Gev), the energy available in a head-on collision is equivalent to what a 2000-Gev beam would release hitting a stationary target. Of course, a scientist performing a colliding beam experiment might have to wait a very long time to find any rare particles because particles of the two beams collide very infrequently, so experiments with single beams may be better for searching out such suspected but still undiscovered entities as quarks, magnetic monopoles, intermediate vector bosons, and heavy leptons.

But the frontier of particle physics research seems to move inexorably toward greater energies, which can be reached much more economically with colliding beam machines. The shift toward colliding beam experiments was clear in the planning for new machines talked about in Illinois. Robert Wilson, director of the National Accelerator Laboratory, announced that he is planning a proposal for a small storage ring (8 Gev) to intersect with the main ring, so that experiments with 200 Gev of available energy will be possible. (The energy available now with a stationary target is about 26 Gev.) Major planning has been under way for about a year for two larger storage ring projects on the East and West Coasts. The machines that will be proposed by a West Coast collaboration (Lawrence Berkeley Laboratory and Stanford Linear Accelerator Center) would have the capability of producing proton-electron collisions with an energy at least equivalent to that of a fixed 2000-Gev proton accelerator, proton-positron collisions of the same energy, or positron-electron collisions of considerably lower energy. The most likely acronym for this three-ring project is PEP (proton-electron-positron). The East Coast planning group, at Brookhaven National Laboratory, is expected to propose two intersecting rings of protons, each ring with the energy of the National Accelerator Laboratory (200 Gev).

There are a number of technical questions about the feasibility of improving the collision rate in intersecting beams, but it appears that the proposals for the next generation of particle accelerators will all follow the trend that was started with colliding electron beams at Stanford and most notably exemplified by the colliding proton rings of CERN. Whether or not the proposals in the United States will be funded, particularly whether two major proposals could be funded in the same decade, appears to be much less certain.

—William D. Metz