Quark theory seems to be falling apart

In the early 1960's physicists stood in need of a theory to sort some order out of the chaos of "elementary" particles they were discovering. Physicists had expected that nature would stop with the proton, the neutron, the electron and perhaps a few field quanta. They were unprepared for the plethora of particles that was appearing, and they needed some way to systematize it.

The way came. Sometimes called the Eightfold Way or the quark hypothesis, it had its genesis in ideas conceived by Murray Gell-Mann and George Zweig. (The two were working in the same physics department and had virtually the same idea simultaneously, but neither found out about the other's thought until later.) The developed theory uses the mathematical discoveries of Sophus Lie, who showed how patterned groups of related objects (in the cases of interest to physicists, multiplets of eight or ten) could be generated by combining three basic entities in various ways.

Physically the fundamental entities are called quarks, and they have some unusual properties, most strikingly either one-third or two-thirds of the amount of electric charge usual for particles. Putting them together in various permutations generates the class of particles called hadrons. Hadrons are those particles that respond to the strong force that binds atomic nuclei together; leptons are those that do not. The theory applies only to hadrons, but since there are only four known leptons (the electron, the muon and two kinds of neutrino), having a theory that arranged the hadrons was considered a real giant step.

The theory was quite successful. It predicted the future like a good theory should. There was a famous hole in one of the patterns that called for the existence of a then unknown particle. In February 1964 the discovery of that particle, the omega-minus, was announced. It had the properties predicted by the theory. And the theory reigned supreme.

But now, in the cold gray dawn of 1974, the theory seems to be coming unraveled. Ironically it was a series of experiments that gave further success to the theory that led to the present series of experiments that is making trouble for it.

This part of the story begins in the late sixties. Experimenters noted that in certain collisions of electrons and protons, the electrons seemed to be bouncing off constituent bodies inside the proton rather than the whole proton. These constitutents were at first named partons to prevent an identification with quarks before more was known about them. But as more and more experiments indicated their existence, physicists began to think of partons as quarks, and the results began to be looked on as more evidence in favor of the quark theory.

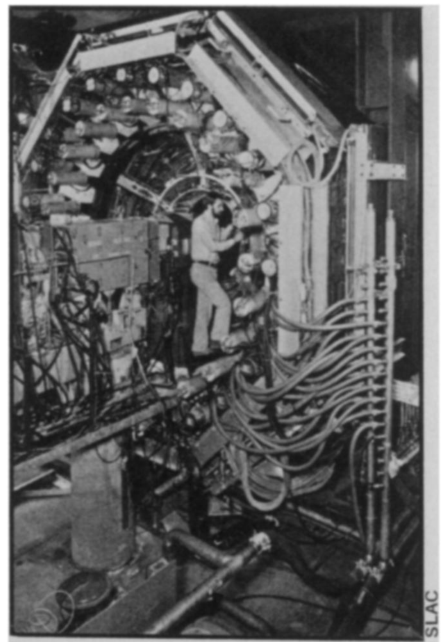
But satisfaction tempts fate, and fate has zapped the particle physicists. It was done by experiments in electron-positron storage rings. Electron-positron collisions in the rings produce a lot of other particles, including hadrons. The detailed dynamics of this hadron production is similar to what happens in the electron-proton collisions, so physicists had confidently expected that a series of electron-positron experiments would yield further confirmation of the quark theory. Instead they came out flatly contrary.

The latest of these experiments was done at the SPEAR storage ring of the Stanford Linear Accelerator Center and reported at a meeting of the American Physical Society in February by Burton K. Richter. It was preceeded by experiments at the Adone storage ring in Frascati, Italy, and at the now defunct Cambridge Electron Accelerator in Cambridge, Mass.

Late last summer, as the Stanford experiment was being set up, the hand was beginning to write on the wall. Some of the data from the other experiments were already in, and it didn't look good for the quark-parton theory. The original quark theory predicts the ratio of hadrons to muons produced in the electron-positron collision to be two-thirds. The ratio is supposed to remain constant no matter what amount of energy goes into the interaction. By varying the theory to endow quarks with extra properties called "color" (physicists are running out of words to describe abstractions with), one can raise the ratio to two, but it still must stay constant.

Early results were showing somewhat higher ratios and also a tendency for the ratio to change with energy. At the time some physicists were thinking the discrepancies might be due to structure within the parton, and as we reported from Stanford then, some people there were hoping they might see some such structure. Instead they seem to have drawn a blank with regard to the partons themselves.

In the Stanford and Cambridge results, the ratio of hadron production to muon production definitely goes higher than the numbers allowed by quark theory, and it definitely seems to rise with energy, reaching numbers as high as seven when the energy is five billion electron-volts. Another contradiction is the total cross section (probability) for the production of hadrons in the electron-positron collisions. It was supposed to fall as the energy rose, in inverse proportion to the square of the energy. Instead it remains virtually constant, at least up to energies of five billion electron-volts.



Detector array for Stanford experiment.

Thus there is a serious dilemma. Physicists have one set of experiments that shows evidence for parton-quarks, and another set that does not. Theoretical and experimental effort are now necessary to reconcile the difference or to come up with a theory that transcends it.

Meanwhile there is a corollary problem raised by the electron-positron experiments. Hadrons and leptons appear to behave in such completely different ways that physicists often speak of two basic kinds of matter: hadronic and leptonic. People who philosophize about physics make a great deal of this.

But the absence of scaling in the electron-positron experiments casts doubt on this distinction. Scaling refers to the pattern of the particles that come out of one of these collisions. If the particles assume a pattern that remains constant as the energy of the experiment changes, we say scaling exists. Scaling appears in the electron-proton scattering experiments, but not in the electron-positron experiments. Its absence leads one to wonder how fundamental is the difference between hadronic and leptonic matter. It was this point that led the CERN COURIER to entitle a report on these results, "All the world's a hadron." Well, perhaps it is. And perhaps a solution to the total problem will come from meditating on that point. □