Elusive Quarks: Hints of Two from a Stanford Experiment

Exotic physics discoveries have been announced frequently in recent years, only to evaporate upon closer examination. In 1975 a magnetic monopole burst upon the scene and then disappeared, and the same thing happened to a putative superheavy element in 1976. This year, three physicists from Stanford University have reported evidence of two particles with fractional charges—the telltale sign of a quark.

The latest discovery was directed by a physicist characterized as "one of the best pure experimentalists" in the country and it comes from a modern adaptation of the classical oil drop experiment with which R. A. Millikan first measured the basic charge on the electron. The new experiment is generally regarded as being of higher quality than the ones producing the monopole and superheavy element results, but it is nonetheless being subjected to the sort of careful criticism that is usually stimulated when a difficult and time-consuming search experiment turns up a small amount of positive data.

"Very provocative but not definitive" is the way one long-time quark hunter, Robert K. Adair at Yale University, assesses the fractional charge experiment. That experiment measured the net charge on eight niobium balls, each about one-fourth the size of a ball-point pen tip, and found that two of the eight carried one-third the electron charge. The incidence of two quarks in such a small sample (each ball has a mass of about 10^{-4} gram) was judged to be remarkably high by many physicists, who privately gave the experiment a 10 to 20 percent chance of eventually being confirmed. If verified, a Nobel Prize for the discoverers is considered to be a very good bet.

While there is no direct evidence that the fractional charge is a quark, "finding any fractional charge is quite an interesting thing in physics," says the senior member of the Stanford group, William M. Fairbank, "and I think the inference of the quark is the obvious one." Quarks are the building blocks of an elegant theory of subnuclear particles postulated by Murray Gell-Mann and George Zweig at the California Institute of Technology in 1964. Quarks would have either a $+2/3$ or $-1/3$ charge, and three of them would make up a proton or a neutron, adding up to an integral charge.

High-energy accelerator experiments have built up considerable evidence (particularly buttressed by the discovery of charmed particles) that pairs and triplets of quarks do indeed make up the elementary particles. But neither accelerator nor cosmic-ray experiments have so far been able to knock free any of the quarks that are presumably inside the elementary particles. Many physicists now favor the idea that quarks only come in aggregates. But if quarks were ever produced individually, for instance at the "big bang" in the early stages of the universe, they might be expected to attach themselves to an ordinary nucleus. Finding no other quark to pair with, the extra quark would produce an atom with a net fractional charge. The idea behind the Stanford experiment is to look for those free quarks that might be quietly residing in ordinary matter.

Superconducting Niobium Spheres

The Stanford team has been conducting its experiments, which are performed with a superconducting version of Millikan's oil drop apparatus, for 12 years. The famous Millikan experiment measured the charge on many small oil droplets and found that it was (almost) always a multiple of a basic unit—the electron charge *e*. Millikan measured the charge by putting the droplets between the plates of a capacitor and finding what electrical force (proportional to the charge) was necessary to offset gravity. In the 1960's, however, the quark searchers reread one of Millikan's papers and found that he had had some suspicious evidence of fractional charges himself. In the *Philosophical Magazine* in 1910 he wrote:

> In the third place, I have discarded one uncertain and unduplicated observation apparently upon a single charged drop which gave a value of the charge on the drop some 30 percent lower than the final value of *e*.

The original Stanford experiment was assembled by Arthur F. Hebard, who found one ball with a one-sixth charge that was later judged a spurious measurement and another with a one-third charge ($0.32 \pm .02$) that was judged too tentative to publish. The ball with the one-third charge was later destroyed when it was inadvertently wedged into a crack and flattened.

Starting in 1972, George S. LaRue rebuilt the apparatus to reduce the background forces that might mimic a fractional charge and made the measurements reported last week, which constituted his doctoral thesis. LaRue found one ball with a charge of minus one-third ($-0.331 \pm .070$) which subsequently lost its "quark," and another with a plus one-third charge ($+0.337 \pm .009$) which has been remeasured twice with the same result. LaRue plans to remain at Stanford, where he and Fairbank hope to conduct additional tests on as many as 100 balls. Hebard is now at the Bell Laboratories in Murray Hill, New Jersey.

The niobium balls in the Stanford experiment are only about 0.25 millimeter in diameter. They are much heavier than oil drops and therefore cannot be suspended with an electric field. Instead, a magnetic field is used to levitate the balls between the capacitor plates, and the charge is determined by observing small oscillations each ball makes when an alternating voltage is applied to the capacitor.

The immediate reason for using superconducting techniques in the Stanford experiment was to develop a force to offset gravity. Using liquid helium, the whole apparatus was cooled to 4.2°K, at which temperature the niobium ball becomes superconducting and floats on the magnetic field. Other experimeters, using iron rather than niobium balls, have performed similar experiments without supercooling, and some think the room-temperature methods are preferable.

Measured After 10 p.m.

Each measurement of charge takes several days or more, with all of the observations being made during the night (10 p.m. to 6 a.m.), when vibrations that might interfere with the ball's motion are at a minimum. When a ball is first inserted into the apparatus there may be as many as 10^5 charges on it. Each ball must be patiently neutralized by spraying it with particles from radioactive sources (there are movable β^- and β^+ emitters inside the chamber). Balls can be inserted and removed while the chamber is cooled, thus avoiding the need to recalibrate the apparatus in terms of the unit of electron charge for each measurement.

Subsequent to the finding of two fractionally charged balls, the Stanford group determined that there was "circumstantial evidence" that the method by which the balls were prepared for the experiment had affected the likelihood of finding a fractional charge. All the spheres were annealed at a high temperature for 18 hours to improve their superconducting properties. Fairbank and LaRue noticed that the five spheres that had been annealed on a niobium substrate had no fractional charges, but three that had been annealed on a tungsten substrate had charges of $+\frac{1}{3}$, 0, and $-\frac{1}{3}$. Fairbank estimates that during the annealing process, a niobium sphere could pick up about 10^{12} atoms of tungsten, which would migrate onto its surface. The implication is that if quarks have been found, they reside in the tungsten rather than the niobium. Each ball contains about 10^{17} atoms of niobium.

The tungsten connection is one aspect of the experiment that many physicists find implausible. Even if the quarks were attributed to niobium, the discovery of two in eight spheres gives an incidence of quarks many orders of magnitude greater than limits set by previous quark search experiments. If the quarks are attributed to the smaller number of tungsten atoms, then the measurement implies that there are 10^{11} quarks in every gram of tungsten. Could so many quarks go unnoticed? One point raised by critics is whether a tungsten atom with a quark would behave chemically like ordinary tungsten. Fairbanks points out, however, that most of the searches that put stringent limits on the existence of quarks were made in media that were lighter than tungsten (mass 184). There is also an argument in the literature of theoretical astrophysics that if quarks are trapped in nuclei, they are more likely to be in heavier nuclei.

The second implausibility that physicists find in the Stanford result is the fact that the negative fractional charge disappeared. Quarks would be bound so tightly in niobium that they could not be removed by chemical changes, according to the general opinion. If a quark was lost, it could only have occurred by dislodging a small speck of the ball that happened to contain the quark. The odds against dislodging the right speck of material would be extremely small unless the quark was on the surface of the sphere. Fairbank says this is one of the considerations that led them to wonder if the fractional charges might not have been transferred to the surface of the balls from the substrates used for annealing. In any event, the news that the "quark" could be lost so easily (the balls were delicately transferred in and out of the apparatus using a fine brush dipped in alcohol) caused a number of physicists who had been favorably disposed at first to be more skeptical.

Other experimenters have gotten data that appear to measure fractional charges with a high level of statistical significance, but have demurred from claiming a discovery until background effects were better understood. Klaus Ziock, at the University of Virginia in Charlottesville, found pseudo-evidence of quarks but could not eliminate background effects. He published the data, but did not claim evidence for quarks. The problem of systematic background effects is "the whole story" in this sort of experiment, says Ziock.

The most troublesome background problems are electric field nonuniformities that can be caused by crystalline inhomogeneities in the capacitor plates (the "patch" effect) and effects that would produce a dipole charge distribution on the ball (an uneven distribution of positive charges with respect to negative charges). Learning to reduce these effects is what takes years of work in such experiments, and "we think we understand all the electric and magnetic background forces," says Fairbank. "We are obviously cautious," he says, "but we wouldn't publish if we had not carefully considered all the alternatives."

Fairbank's reputation may account for the unusual degree of credence the experiments have been afforded. (Few physicists gave the monopole and superheavy element experiments better than a few percent chance of verification.) As the discoverer of the first quantization of magnetic flux and the mapper of many of the basic properties of liquid helium (^{3}He and ^{4}He), he is a highly respected experimentalist. Characterized as a "terribly clever guy" by his colleagues in the physics community, he is not known as one who by nature is conservative about publishing novel results.

If the Stanford announcement is correct, then many unsuccessful searches that have been made for quarks in myriad places—seawater, manganese nodules, and moondust—were misdirected. "I would be very pleased if quarks were discovered by Fairbank," says John P. Schiffer of Argonne National Laboratory, one of the unsuccessful quark searchers. But, says Schiffer, "I think he has a long way to go."—William D. Metz

Hormone Receptors: How Are They Regulated?

Many obese people have high concentrations of insulin in their blood but have normal concentrations of blood sugar, even though insulin should decrease blood sugar concentrations. Pregnant women produce a great deal of angiotensin II, which increases blood pressure, but they usually do not have hypertension. Some men have tumors that secrete enormous quantities of a hormone that stimulates testosterone production, yet they do not make abnormal amounts of testosterone. These are examples of a well-recognized process whereby certain hormones seem to lose their effectiveness after a period of time.

As of a few years ago, no explanation of this phenomenon was known. Recent research, however, shows that this lack of responsiveness is due not to faulty hormones but to changes in the target cells. All of these hormones must bind to specific receptors on the surfaces of cells before the cells respond to them. It now seems likely that many cells react to persistently high concentrations of certain hormones by changing their surface receptors so they bind fewer of those hormones. Although investigators speak of "lost" receptors, these receptors may be inactivated or may disappear from the cell surface.

Now that this effect has been documented, growing numbers of investigators are beginning to look for and find it in their studies of hormones. They are beginning to realize that hormones need not cause a loss or inactivation of their own receptors only; they may also affect receptors for other hormones.

These changes in the receptivity of cells to hormones are likely to be important control mechanisms. For example, they may prevent cells from overreacting to high hormone concentrations. They may also provide a way for hormones that act in sequence to amplify or diminish cellular responses to their successors. Investigators believe that an understanding of how hormones affect their own and other receptors may lead to new ways to treat certain diseases, such as insulin-resistant diabetes.

A few years ago, Jesse Roth, Ronald Kahn, and their associates at the National Institute of Arthritis, Metabolism, and Digestive Diseases discovered that cells of obese diabetics and other insulin-resistant patients, as well as obese people who have normal blood glucose concen-