The Search for Fractional Charges

by Robert McKeown

CARL ANDERSON'S *discovery of the positive electron — the positron — validated by the mid-1930s the Dirac theory that every particle in nature has its antiparticle. It also reinvigorated the interest of physicists in these smallest constituents of ordinary matter — neutrons and protons (which form atomic nuclei) and electrons. In the years since an almost endless series of pairs of elementary particles have been found, but in 1964 Caltech physicists Murray Gell-Mann and George Zweig introducted a new concept. They proposed that two of those particles — neutrons and protons — are composed of subunits called quarks.

Today this view is very well established experimentally and is the basis for our present theories of the fundamental particles, in spite of the fact that no one has ever isolated a quark nor found a free quark in nature. In fact, current theories maintain that quarks exist only in certain combinations that correspond to the observed particles and thus cannot be isolated. The proton is a combination of three quarks, while the neutron corresponds to a different configuration of three quarks. Of course, just as the electron has an antiparticle (the positron), the quarks have antiparticles called antiquarks. Various configurations of quarks and antiquarks have been observed, but they are not arbitrary — only the particular combinations allowed by theory are seen.

One property of the allowed combinations is that the particle that results will have "integral charge." It was first demonstrated by Millikan that particles possess electric charge in multiples of the fundamental unit, e. The proton has charge +e and the electron −e. Quarks, however, have the peculiar property that their charges are multiples of ⅓e, so that they have "fractional charge." Most experimental attempts to isolate quarks or find free quarks utilize this special property as a signature. Many searches for other fractional charges have been attempted, but most concentrate on looking for charges that are ± ⅓e or ± ⅔e. They include cosmic ray experiments, surveys of bulk matter (such as lunar rocks), and efforts to observe production of fractionally charged particles in high-energy accelerators. Until recently all these experiments yielded negative results. (The observation of a fractional charge, incidentally, does not necessarily imply that an isolated quark has been found. Other fractionally charged particles may exist in nature, and their discovery would be just as significant as the discovery of a free quark.)

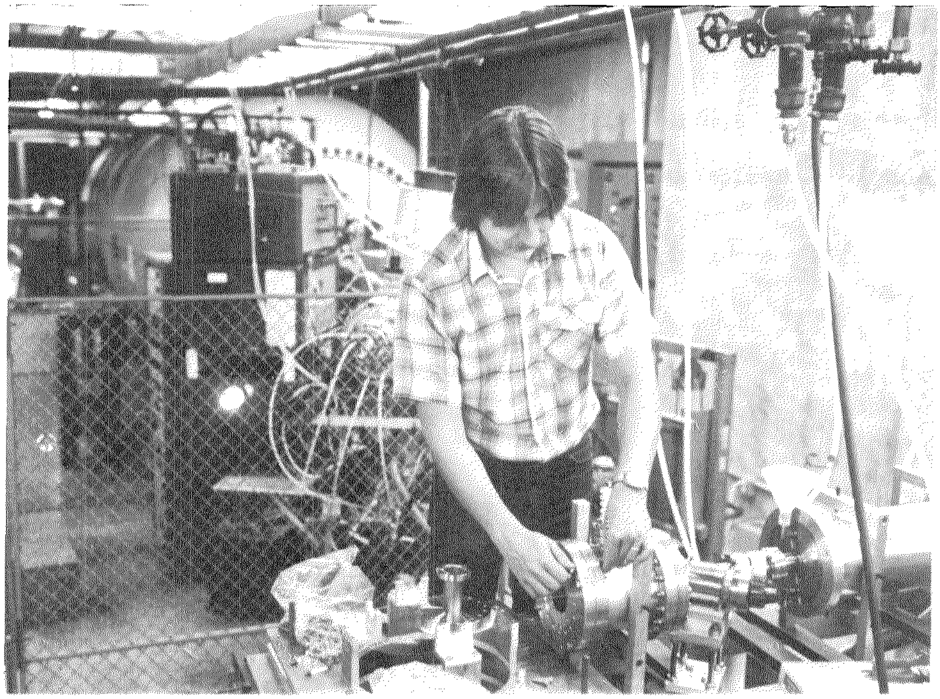
During the last few years, Stanford University Professor W. Fairbank and his collaborators have been running an experiment that consistently indicates the presence of fractional charges that are multiples of ⅓e. Their experiment is analogous to Millikan's famous oil-drop experiment to determine the charge of the electron, except that they use superconducting niobium spheres levitated by magnetic fields. (Millikan used charged oil droplets.) The charge on a niobium sphere is measured by observing the motion of the sphere under the influence of an applied electric field. Of course, all that can be measured is the total charge on the sphere; the fractional charge (or charges) may reside anywhere in or on the sphere.

No other experimental effort has reproduced or corroborated this result, although none has duplicated the experimental conditions of the Stanford experiment. Similar measurements on iron spheres by a group in Italy give null results. Zweig has pointed out, however, that the fractional charges may have unique chemical properties that cause them to concentrate only in certain materials. Nevertheless, the experimental results to date indicate that if free fractional charges exist in nature they are very rare. We could expect to find only one in about 10^{18} normal atoms of material. Several additional experiments are in progress that attempt to verify the result obtained by Fairbank.

One of those experiments is being readied here at Caltech in the Kellogg Radiation Laboratory by a group that includes Charles Barnes, professor of physics, and me, plus research fellows B. H. Cooper and J. H. Thomas, and graduate students Richard Milner and Raymond Rau. The technique to be used in our search involves extracting the fractionally charged particles from the host material (niobium, for example) by eroding the material with an ion beam. The charged particles that are ejected in this process (including the fractional charges) will be injected into an electrostatic tandem accelerator and accelerated by several million volts. The energetic particles will then be electrostatically deflected into a particle detector where they will be counted and identified by their energy and amount of deflection. This technique allows determination of the charge of the detected particles without regard for their mass, which is unknown. The detection of fractional charges with this apparatus would also allow measurement of other properties, such as their mass, as well as collection and concentration of these particles for study or technological application.

A variety of materials can be searched with this method, although the initial effort will concentrate on niobium. In fact, it will be possible to search the actual niobium spheres used in the Stanford experiment. The Caltech experiment is designed to detect fractional charges at the concentration level indicated by the Stanford results, and a niobium sphere of the size used in the Stanford experiment can be searched in less than an hour using the accelerator techniques to be employed at Caltech. The apparatus for the Caltech experiment is now under construction, and measurements should begin in early 1983.

Perhaps, even as Robert Millikan determined the charge of the electron and Carl Anderson proved the existence of the positive electron, we will be able to find a fractional charge and thus take one more step in the understanding of the fundamental constituents of matter in our universe. □



Looking for charged particles in the 1980s involves considerably more sophisticated equipment than Carl Anderson's magnet cloud chamber of the 1930s, as these photographs indicate. Above, Robert McKeown assembles instruments being prepared for an experiment in search of free fractional charges. In the background is the high-current, high-resolution 3-MV tandem accelerator recently installed at Caltech that will be used in the experiment. The control panel for the accelerator is shown below.