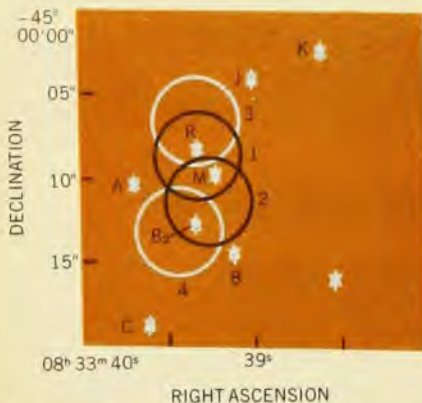




**Stars in the neighborhood of the Vela pulsar.** The radio position established by Miller Goss et al. (ref. 2) is labelled "R"; the other lettered positions follow Barry Lasker's scheme (ref. 3). Astronomers at the Anglo-Australian Telescope detected optical pulses within the areas shown as circles 1 and 2, but not in circles 3 and 4. This figure, adapted from reference 1, retains the shear distortion introduced by the TV monitor.

be observed for more than a short time from the major northern-hemisphere observatories. Photographs taken two years ago at the Cerro Tololo Interamerican Observatory in Chile showed several "candidate" stars close to the radio position.<sup>3</sup> None of these stars appeared to be emitting pulsed optical radiation.

The optical observations with the AAT allow the possibility that one of the stars photographed by Barry Lasker and his colleagues at Cerro Tololo (Lasker's "star M") may be the Vela pulsar, and the AAT group now locates M at the coordinates  $\alpha = 08^{\text{h}} 33^{\text{m}} 39.22 \pm 0.03^{\text{s}}$ ;  $\delta = -45^{\circ} 00' 10.1 \pm 0.3''$  (1950). Observations went on for a total of about ten hours, at four positions. At only two of these positions—

one centered at the new radio position and the other, about 3 arc sec away, near star M—were optical pulses detected, and these pulses were slightly more intense at the position with M closer to the center of the aperture.

For the Vela pulsar, pulsation has now been observed at optical, gamma-ray and radio frequencies. The optical and gamma-ray pulses are both double; that is, two of these pulses occur for each radiofrequency pulse. These radio pulses occur every 89 millisecond, the third shortest period known for any pulsar. The optical components are separated by  $22 \pm 2$  millisecond (with the second pulse somewhat stronger) and the first of these appears  $20 \pm 2$  millisecond after the radiopulse. The optical peaks are centered symmetrically between the two gamma-ray peaks, which are themselves 35 millisecond apart in time; that is, although the pulses do not themselves coincide, their midpoints do.

Now that more than one pulsar has been optically identified, what can we expect from the theorists? Which pulsar model will be buttressed by the new data, and which will have to be revised? A closer examination of the relative radio and optical intensities, pulse phases in the various wavelengths, and so on should yield good new checks on different theoretical models for neutron-star magnetospheres.

—MSR

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## High-conductivity graphite compounds

The measurement of high electrical conductivity in a synthetic metal at room temperature was one of many observations discussed at the Conference on Intercalated Compounds of Graphite held in La Napoule, France last month. Although these compounds have been studied—largely by chemists—for some 40 years, physicists have recently taken a renewed interest in them because they offer the potential for technological applications as well as the opportunity to explore electronic and other properties of materials of variable dimensionality.

A striking property of graphite intercalation compounds is their greatly enhanced basal-plane conductivity compared to that of the original graphite. This property was first studied starting in the early 1960's by A. R. Ubbelohde and his colleagues at Imperial College, London<sup>1</sup> and by Gerhard Hennig at Argonne

National Laboratory,<sup>1</sup> but only recently have conductivities of practical significance been reported.

A team from the University of Pennsylvania consisting of Geoffrey M. T. Foley, Claude Zeller, E. Robert Falardeau and F. Lincoln Vogel announced at the March APS meeting in San Diego that they had measured a conductivity  $6.3 \times 10^5$  (ohm cm)<sup>-1</sup> comparable to a value of  $6.29 \times 10^5$  (ohm cm)<sup>-1</sup> for silver.<sup>2</sup> The measurements were made on near-single-crystal samples of graphite intercalated with arsenic pentafluoride, a compound first reported by a group at the Hebrew University of Jerusalem.<sup>3</sup> The conductivity was measured by a contactless rf induction technique. The conductivity from optical reflectance data on the same compounds, which was consistent with the direct measurements of conductivity, were presented at the same

meeting by Lawrence Hanlon and John E. Fischer, also of Pennsylvania.

Even larger conductivities had been reported a year earlier by the Penn group at the March APS meeting in Atlanta but results had been received with some skepticism. There, Vogel reported experiments made on composite wires that consisted of a powdered graphite core intercalated with antimony pentafluoride encased in a thin copper sheath.<sup>4</sup> Doubts were raised over the poorly characterized composition of the core and over the interpretation of the data. This earlier experiment used a dc four-point resistance method to determine the conductivity. Subsequent bridge measurements on the same intercalate—antimony pentafluoride—but diffused into a different form of graphite—highly oriented pyrolytic graphite rather than the drawn wire—have found conductivities only about one third that of copper.<sup>5,6</sup> However, the Penn group feels that the anisotropy in the resistivity is so high that the bridge method is inappropriate for measuring the conductivity of these compounds. Jimmy Gan and Vogel reported in La Napoule the results of more recent experiments, which they feel substantiate the existence of high conductivity in graphite intercalated with antimony pentafluoride.

Industry may well be interested in a high-conductivity substitute for copper, especially one that might be lighter, cheaper and more free of resource constraints. Graphite compounds might potentially offer some of these advantages, but many problems remain to be solved before they can be considered for use in commercial electrical wiring. The compounds must be well encapsulated to prevent exposure of the superacid intercalants, which are corrosive and unstable in air. They must have high tensile strength and must be designed to form good electrical and mechanical connections. Clearly it is premature to judge either their technological potential or their economic viability.

While industry ponders the application of intercalated graphite compounds, scientists may ponder the cause of their high conductivity. Intercalation of graphite, the diffusion of atomic and molecular species into the interstices of the lamellar host, results in compounds that have widely varying properties. The approximately 60 species known to intercalate can be divided into two general groups, those that act as electron donors (for example, alkali metals) and those acting as acceptors (halogens, acids, etc.). A long and widely held hypothesis is that the enhanced conductivity results from an increase in free carrier density, which accompanies a transfer of charge between the donor or acceptor intercalate layer and the graphite. The high conductivity can be achieved with lower carrier concentrations than those for normal metals

because of the relatively high mobilities of the carriers.

At Penn and elsewhere not only the conductivity but a whole range of interesting properties of graphite intercalated compounds are studied by a variety of techniques. For example, at MIT's Center for Materials Science and Engineering, researchers led by Mildred and Gene Dresselhaus have undertaken such studies as magnetoreflexion, Raman scattering, infrared spectroscopy and electron diffraction to gain insight into the electronic, structural and lattice properties of these materials. Of particular interest is the unique intralayer and interlayer ordering of these compounds. The MIT group has access to the Francis Bitter National Magnet Laboratory for high-field experiments.

Several features of intercalated compounds might explain the interest in them. According to Frank DiSalvo of Bell Labs, the possibility of intercalation offers chemical degrees of freedom. An experimenter can alter the material in a controlled way by the insertion of a particular intercalate in specific amounts between layers and observe how the properties change as a function of the amount and type of intercalate. Larry Ebert, a chemist at Exxon, points out that they are quasi two-dimensional structures and constitute bulk surfaces for measurement of any properties that depend on a large surface area. Both men mentioned to us the possible application of these compounds to high energy density batteries.

—BGL

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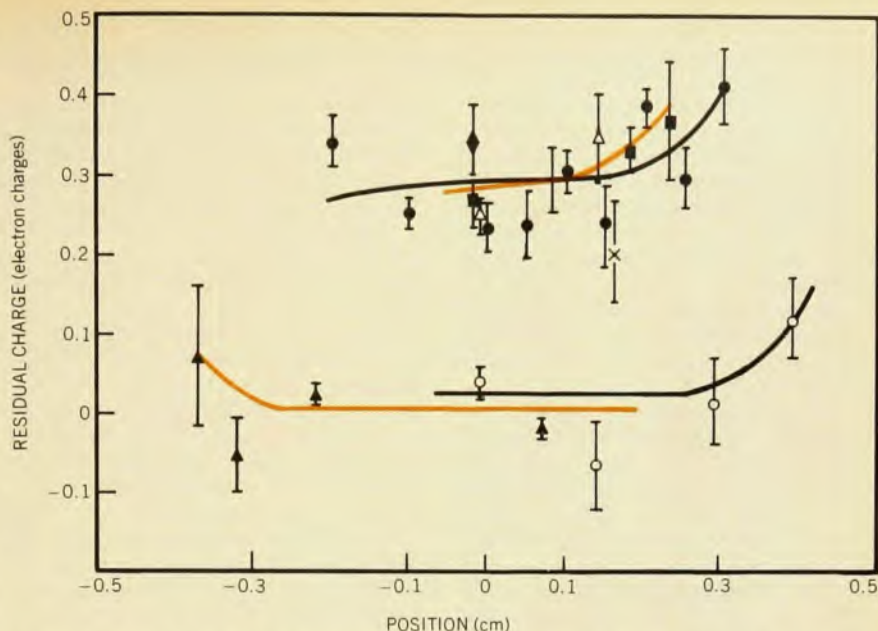
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## Quarks

continued from page 17

Y. Han and Yoichiro Nambu (University of Chicago), and by Jogesh Pati (University of Maryland) and Abdus Salam (International Centre for Theoretical Physics) does not postulate quark confinement; it involves interger charged quarks.

Gell-Mann told us that if fractional charges are being observed, one would have to conclude that quark confinement is only approximate, "unless one finds some weird, alternative explanation." If it is only nearly true, this could happen in two ways: One, "the strong interaction



**Measured residual charge as a function of position** for runs in which no correction for dipole moments needed to be made. Symbols are for ball 6C (solid circles, upper black line), with magnetic field reversed (open triangles), with field of 1000 V/cm (cross); for ball 6D (solid squares, upper colored line) with field of 1000 V/cm (solid diamonds); for ball 7C (open circles, lower black line); for ball 8D (solid triangles, lower colored line). Figure adapted from ref. 4.

by itself wouldn't quite go to infinity—it would come down again, so that the quarks could emerge." Or, two, "quantum chromodynamics or whatever the correct theory of quarks and gluons is, would confine but there would be some extremely weak interaction, which would somehow change the situation, and allow quarks to escape." Gell-Mann says one has to take the Stanford experiment fairly seriously, "But I'd like to see more evidence."

The Stanford experiment is a variation of the classical oil-drop experiment done by Robert A. Millikan, in which the force of gravity on an oil drop was balanced by the electrostatic force. In experiments over many years, Millikan reported convincing evidence against fractional charge, although in 1910 he wrote<sup>1</sup> in the *Philosophical Magazine*, "I have discarded one uncertain and unduplicated observation, apparently upon a singly charged drop, which gave a value of the charge on the drop some 30 percent lower than the final value of  $e$ .... The single observation mentioned above was probably on such a drop [a singly charged and very small drop of water or alcohol], but it was evaporating so rapidly that I obtained a poor value of  $e$ ." (A study of the early dispute over fractional charge and of Millikan's lab notebooks has been made<sup>2</sup> by Gerald Holton of Harvard; he told us that anyone convinced of the existence of fractional charges even less than  $\frac{1}{3}$  could have found support in Millikan's data.)

**Unlike Millikan**, the Stanford experimenters look for fractional charge on a much more massive object ( $10^7$  times greater) to improve the probability of

finding one. They balance gravity by floating a superconducting niobium ball on a magnetic field. The ball, 0.25-mm in diameter, has a mass of  $9 \times 10^{-5}$  grams and has  $5 \times 10^{19}$  nucleons. It oscillates along the magnetic field with a frequency of  $0.8 \text{ sec}^{-1}$ . Experiments are done between 10:00 pm and 6:00 am. The experimenters applied an alternating square-wave voltage at the natural resonant frequency and observed with a SQUID detector the change in amplitude of the ball as it was driven.

A radioactive source is used to increase or decrease the number of electrons until the net charge is almost exactly balanced. Then one electron at a time is added or subtracted to measure the difference between the number of electrons and protons. In 1970 Fairbank and Hebard reported at the Kyoto low-temperature conference that one ball had a charge of  $(0.32 \pm 0.02)e$  (PHYSICS TODAY, May 1971, page 17). Later measurements yielded  $(0.159 \pm 0.009)$ . In retrospect, Fairbank feels the problem with those experiments was in determining the background forces that could mimic a fractional charge.

When LaRue took over from Hebard, he rebuilt the apparatus and made some significant changes. In the new apparatus a ball can be measured, brought back to room temperature, a new ball inserted and then the first ball can be returned for further observation without raising the temperature. To obtain effective fractional charge as a function of position, LaRue can now move the capacitor plates up and down with respect to the ball, maintaining the same spacing between