

expects to make even smaller fingers and spaces using electron-beam lithography. In the present experiment, the team attached leads to the anvil base and then deposited xenon on the anvil by vapor deposition at 30 K in vacuum. Its thickness was typically 1000–2000 Å as measured by a quartz thickness monitor next to the diamond anvil.

One reason to run at 30 K is that the mechanical strength of xenon increases as the temperature is lowered, thus helping to keep the xenon in place.

The Cornell team found that the electrical resistance at 32 K dropped from 10^{13} ohms at atmospheric pressure to about 10^4 ohms at 330 kilobars with one method. A second method showed the resistivity had dropped to below 0.1 ohm-cm and possibly much lower. In 18 runs, some of the time the resistance dropped sharply, other times with a slight slope. Ruoff told us that he and Nelson can't say if they've seen a first-order transition or a continuous band-gap closing mechanism because it takes so long (weeks) to eliminate hysteresis effects in the experiment.

Sulfur. Comparing xenon with the earlier experiment he had done with sulfur, Ruoff noted that sulfur transformed to a metal at room temperature with the resistance curve having a substantial slope, indicating the effect was a continuous band-gap closing. In 1976, Lalit Chhabildas (Cornell) and Ruoff, using boron-carbide pistons, found⁴ the transition began at 175 kilobars; at about 275 kilobars, the resistance had dropped six orders of magnitude. According to Ruoff, this experiment did not achieve the fully metallic state of sulfur.

In 1977, at the Boulder International High-Pressure Conference Ruoff and Gupta, using the diamond indenter technique, reported² a resistance drop of 12 orders of magnitude at a pressure less than or equal to 350 kilobars; the calculated resistivity was 0.02 ohm-cm. At the same Boulder meeting, Francis Bundy of General Electric and Keh-Jim Dunn, who was formerly Ruoff's student and is now at GE, reported⁵ that sulfur transformed to a metal at room temperature and 475 kilobar; the resistivity was 0.03 ohm-cm.

Ruoff feels that all pressure scales in excess of 200 kilobars are open to question, that it will take several years to sort out the problem. So he feels that the Cornell and GE results are not in disagreement.

The General Electric experiments, done by Dunn and Bundy, use opposed diamond-tipped pistons, which are largely made of tungsten carbide. The very highly stressed regions near the tips are of strongly sintered diamond powder. Between the tapered flanks of the pistons is a button-shaped gasket of pyrophyllite stone (talclike). The GE experimenters put the specimen in a sample holder also

made of pyrophyllite. Typical specimen size is 0.06 cm long by 0.025 cm wide by 0.0025 cm thick. At each end is a gold electrode that makes contact with the piston.

The GE group measures the electrical resistance between the two pistons. A typical electrode resistance value is 0.2 ohms, Bundy told us, whereas typical values for the diamond indentors used at the Institute for High-Pressure Physics in Moscow are hundreds of thousands of ohms. The lower background resistance enables the GE group to follow resistivity values of the sample much lower. The Cornell group, Ruoff told us, has a background resistance of 6 ohms.

To calibrate their pressure and resistance measurements, the GE group uses materials such as iron-cobalt and iron-vanadium alloys, in which one can see the transition from face-centered-cubic to hexagonal-close-packed as the resistance increases sharply.

The entire apparatus is placed in a hydraulic press and is clamped in the loaded condition; then the apparatus is removed from the hydraulic press and lowered into a Dewar. Bundy notes that the pressure distribution in the region of the specimen is quite uniform in the GE apparatus. The stainless-steel clamp is temperature compensated so that the load on the specimen does not change during cool-down. Once 4.2 K is reached, the specimen is warmed slowly, and the resistance is monitored.

Bundy told us that in substances such as tellurium, selenium and silicon, they found that when they applied high pressure and lowered the temperature to that of liquid helium or lower, the resistance dropped abruptly from the normal to the superconducting state. However, for sulfur in its "metallic form," he said, the resistance behavior is different. The new GE results on sulfur were to be reported by Bundy on 22 March at the meeting of The American Physical Society in Chicago. For a pressure of 460–480 kilobars, the resistance first drops as the temperature is lowered, then levels out at 100–150 K, and then at still lower temperatures, the resistance increases—a result that surprised Bundy. At 12 K, there is an abrupt change in the rate of increase. At 4–5 K, the resistance increases again. By fitting the curve, considering the resistance of sulfur as consisting of two parts, one being metallic and one being semiconducting, if one subtracts the semiconducting part from the total resistance, there is a jog from 5 to 12 K of the metallic part. This jog is very reproducible, occurring in three runs, each lasting about 2 weeks. The jog looks like that of a smeared-out superconducting transition, Bundy said. However, the data could be interpreted as a structural transformation he noted.

Soviet experiments on superconducting behavior in sulfur were done by two sep-

arate groups at the Institute for High-Pressure Physics, where L. P. Vereshagin led the high-pressure efforts until his death last year. In the 20 September 1978 issue of *JETP Letters* (Russian edition), E. N. Yakovlev and his collaborators and V. V. Evdokimova and I. G. Kuzemskaya independently reported finding such behavior.

Yakovlev, using an indenter with carbonado diamonds, finds a drop in resistance at 9.7 K resembling the GE result, Bundy noted, but with higher background resistance. He believes Yakovlev had 400–500 kilobar pressure.

Evdokimova and Kuzemskaya used cemented tungsten-carbide pistons and found that at 200 kilobars, sulfur underwent a superconducting transition at 5.7 K. —GBL

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Spin-dependent proton elastic scattering

Recent experiments with the Zero Gradient Synchrotron at Argonne have revealed startling differences in the way protons of different spins scatter elastically. A group from the University of Michigan and Argonne National Lab led by Alan Krisch has found that for protons polarized normal to the scattering plane, elastic scattering at large momentum transfers is about four times more probable for spins parallel than anti-parallel.

The latest experiments were discussed at the 1979 Orbis Scientiae conference on 16 January. Last year the group had already seen¹ the beginning of this dramatic increase at $P_{\perp}^2 = 4.2$ (GeV/c)², where the ratio of spin-aligned to spin-opposed cross sections is a bit less than 2. The recent improvements in the intensity (up to 3×10^{10} protons per pulse) and polarization (up to 71% at a beam momentum of 11.75 GeV/c) of the ZGS beam made possible an extension of the experiment to high transverse momentum transfers. By observing scattering at 90° and at the maximum beam energy the group was able to obtain data² up to $P_{\perp}^2 = 5.09$ (GeV/c)². These energies are the highest that can currently be obtained from the ZGS, Krisch told us, and he has suggested that during its last month of operation the synchrotron's energy be raised so that one can see if the strong spin dependence continues to higher energies. That way

the ZGS could die "with a bang, not with a whimper."

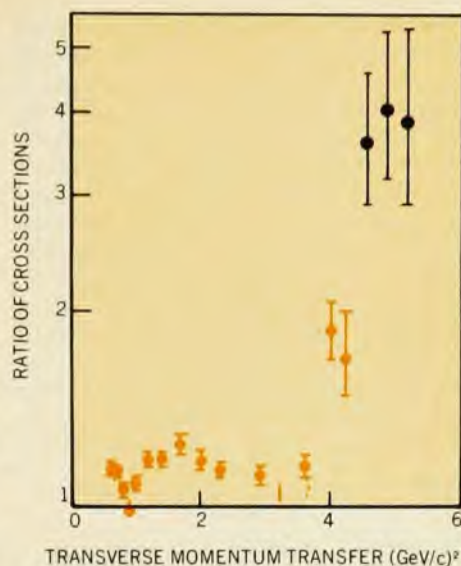
The polarized proton target consists of beads of ethylene glycol doped with potassium dichromate. The beads are maintained at 0.5 K in a magnetic field at 25 kG; however, because of radiation damage, they slowly lose their nuclear polarization, and must be annealed every few hours and replaced twice a week. In this way the group was able to keep the target polarization at an average value of 65%. The mechanism for polarizing the protons involves a temporary spin-pairing between a proton from ethylene glycol with a polarized electron from a chromium atom. (At 0.5 K the electrons are 99.5% polarized.) An rf field of the appropriate frequency induces what is, in effect, a hyperfine transition in the temporary pair, thus transferring the electron polarization to the protons. The group monitored the proton polarization in the target with nmr techniques. To monitor the beam polarization they measure the left-right asymmetry in the p-p elastic scattering from a hydrogen target placed in the beam before the polarized target.

At the ZGS the polarized beam is produced from a thermal beam of hydrogen atoms. A Stern-Gerlach magnet focusses atoms with electrons in one spin state, defocussing those in the other, and an rf field then transfers the polarization to the protons via a hyperfine transition. The atoms are then ionized and sent to the accelerator. Although the protons are normally polarized transverse to the beam, they can, with further manipulation, be polarized along the beam direction.

The Michigan-Argonne group used a double-arm spectrometer to measure the angle and momentum of both the forward and recoil protons. By varying the currents in the spectrometer magnets and occasionally reversing the target magnetic field they were able to obtain data for a large range of transverse momentum transfers without moving the counters.

The Michigan-Argonne polarized target can be polarized only vertically, so Krisch and his collaborators measured the spin dependence of elastic scattering for the four possible spin-up, spin-down combinations of beam and target. For transverse momentum transfers in the range 1 to 3 (GeV/c)² the group found considerable spin-orbit coupling and some spin dependence, but both parameters diminished above 3(GeV/c)². For $P_{\perp}^2 > 4(\text{GeV}/c)^2$, however, the spin-spin correlation increases dramatically, while the spin-orbit coupling remains small.

The interpretation of these results will depend considerably on whether the observed behavior continues to higher values of $P_{\perp}^2$ than the 5.09(GeV/c)² Krisch's group has been able to obtain. Another group at Argonne, led by Akihiko Yokosawa, has used a different polarized proton target to measure the polarization



Ratio of differential cross sections for elastic proton scattering with spins of beam and target protons aligned parallel and anti-parallel. Both spins are normal to the scattering plane. Beam momentum is 11.75 GeV/c; the most recent data are in black. (Figure from ref. 2)

effects for spins in the scattering plane.³ These experiments were done for values of $P_{\perp}^2$ less than 3(GeV/c)² and display a considerable amount of structure. These data, as well as earlier data on the total cross sections from Yokosawa's group, have been interpreted by some theorists as indicating a di-proton resonance, and the Yokosawa group therefore has been spending much of its efforts on a search for that resonance. If such a resonance is confirmed, it is an exciting development. Gerald Thomas, a theorist at Argonne, told us that σ_T data are especially interesting for helping to elucidate whatever internal structure the proton has. Yokosawa's group has recently begun taking data to extend their experiment to higher energies, so that they will be able to look for further effects of the possible di-proton resonance and for longitudinal spin effects comparable to those found by Krisch's group for transverse spins.

The momentum dependence of differential cross sections is, in a sense, the Fourier transform of the spatial structure of the scattering particles. In that sense, the high- $P_{\perp}$ scattering probes the deep internal structure of the proton. Most proton-proton scattering data show a very steep drop at low $P_{\perp}$ and a much slower decrease at high $P_{\perp}$, with a transition region exhibiting various kinds of complex behavior. At large $P_{\perp}$ one is presumably seeing some relatively "hard," small scattering centers, Krisch told us, and the asymmetric scattering may be attributable to some spin dependence of the scattering of these hard constituents of the proton. Just what these constituents are and whether one can draw any conclusions about quark-quark scattering from the results is not yet clear. Thomas said that preliminary quark models can

provide reasonable fits to the Yokosawa group's data, but that the asymmetries found by Krisch's group are much larger than the models predict.

Future experiments may provide further data to resolve the problems. At present, the polarized proton beam at the ZGS makes these experiments possible. The ZGS is now planned to close on 1 October, 1979. When it closes, no comparable facilities will be available. At this time it seems feasible to provide polarized proton beams for other accelerators, and in fact, a 3 GeV polarized-proton beam source is under construction at Saclay and planned to open in about a year. There is a proposal and design study for providing a polarized beam for the 33-GeV Alternating Gradient Synchrotron at Brookhaven, a proposal to provide a polarized-beam capability at Fermilab, and Japan is considering a polarized beam source for the KEK 12-GeV accelerator.

—TVF

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High-flux neutron source for fusion studies

In all of the fusion reactors currently under active consideration, an intense flux of 14-MeV neutrons will bombard the inner walls of the reactor. One expects a 14-MeV neutron flux of about 10¹⁴/cm² sec. This is an order of magnitude below the typical flux in fission power reactors, but the much more energetic neutrons from the deuterium-tritium fusion reaction can generate significantly different kinds of damage to the materials of the reactor.

The detailed nature of the damage done by such an energetic neutron flux is a major unknown in studies of the engineering feasibility of fusion reactors. In the absence of a working fusion test reactor, until now one has had to make do with 14-MeV neutron sources delivering a maximum flux less than 2 × 10¹²/cm²-sec. With such a limitation on available neutron sources, it would take more than 50 years to simulate the damage suffered by a test material in one year of real reactor time.

With the opening of a new Department of Energy facility at the Lawrence Liver-