

The Quantum Hall Effect—in Pentacene?

Organic materials have long held promise as possible inexpensive semiconductors in field-effect transistors (FETs) for electronic circuits. No one, however, had dreamed that one might use them to create a two-dimensional gas of electrons or holes and with it to study fundamental electronic behavior. Thus, Bertram Batlogg of Bell Laboratories, Lucent Technologies, stunned an audience at the March Meeting of the American Physical Society in Minneapolis by showing textbook curves of the fractional and integer quantum Hall effects and of an apparent metal-insulator transition—all seen in FETs made with tetracene and pentacene (chains of four and five benzene rings, respectively).

To make these measurements, Batlogg, J. Hendrik Schön, Steffen Berg, and Christian Kloc (all of Bell Labs) created their FETs by growing very pure single crystals of tetracene and pentacene, covering them with insulating layers and adding gates atop the insulator. A source and drain were connected to either end of each crystal. When a positive (negative) voltage was applied to the gate in one of these FETs, electrons (holes) were attracted to the interface between the crystal and the insulator. The resulting charge layer had all the hallmarks of the two-dimensional electron (or hole) gases known to form in silicon or gallium arsenide devices traditionally used to study such phenomena as the quantum Hall effect.

To manifest the quantum Hall effect or the metal-insulator transition, the charges in a sample must have a sufficiently high mobility, a measure of the ease with which charges can move through the material. That means the organic crystals must be as free as possible of impurities that scatter or trap the charges. At temperatures of 1–2 K, the Bell Labs FETs had mobilities as high as $100\,000\text{ cm}^2/(\text{V}\cdot\text{s})$ for holes, as good or better than most inorganic devices.

At room temperatures, Batlogg said, the Bell Labs crystals had mobilities better than those reported so far for tetracene and pentacene, either in bulk or thin-film form. Because the crystal mobilities are high for both electrons and holes, the Bell researchers reported in February¹ on the potential of these devices as ambipolar field-effect transistors, which can be switched from hole-based to electron-based by reversing the polarity of the gate voltage. A practical device would have to be made from pentacene thin films, and Batlogg told us that their pentacene thin films perform at room temperature almost as well their bulk crystals.

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Reference

1. J. H. Schön, S. Berg, Ch. Kloc, B. Batlogg, *Science* **287**, 1022 (2000).

size of the fireball's volume at thermal freeze-out by examining how the bosonic correlation of final-state pions decreases with increasing distance in momentum space. That's important for estimating the fireball's energy density. The volume, in the SPS experiments, turns out to be comparable to that of a Pb nucleus. And from the transverse-momentum distributions of final-state particles of different masses, the experimenters conclude that the fireball is expanding at more than half the speed of light.

Chiral restoration

The lattice gauge calculations suggest that another phase transition—the restoration of chiral symmetry—should occur simultaneously with the deconfinement transition. In the approximation that all the quarks are massless, the QCD Lagrangian is perfectly symmetrical between left- and right-handed fermion couplings. (*Chiros* is Greek for hand.) In the vacuum ground state, this symmetry is spontaneously broken. Some QCD calculations predict that one manifestation of chiral symmetry restoration in a

quark-gluon plasma should be a temperature dependence of the mass of the ρ vector-meson resonance that would severely broaden the observed resonance. And indeed, the sharp ρ resonance one would ordinarily see in the invariant-mass spectrum of emerging e^+e^- pairs is smeared out almost to invisibility in the Pb-Pb runs at the SPS. But once again there's an alternative explanation: One could argue that it's just ordinary collision broadening in a very dense hadronic medium.

"There is no question that all these exciting observations constitute a quantum jump in our understanding of matter at extremely high temperatures and densities," Heinz summarized. "But the evidence is not yet enough to prove, beyond reasonable doubt, the creation of a quark-gluon plasma."

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References

1. <http://cern.web.cern.ch/CERN/Announcements/2000/NewStateMatter/>
2. Proc. Quark Matter 99, Nuclear Phys. A, **661** (1999). ■

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