Physical Sciences

Dietrick E. Thomsen and Stefi Weisburd report from the American Physical Society meeting in Detroit.

Mediocosmic quantum effects

Quantum mechanics developed as a theory of behavior in the microcosm — molecules, atoms and smaller things. Sometimes, however, quantum mechanical effects appear in the macrocosm, in things like electronic circuit elements. Josephson junctions are an example. The stepwise (quantized) relations between magnetic fields and electric current characteristics, such as voltage and alternating current frequency, displayed by Josephson junctions makes them useful in many technological applications. They are used particularly to sense and measure weak magnetic fields and to sense or generate electromagnetic radiation. They are also beginning to play a role in computer circuitry.

The Josephson effect requires superconducting materials, metals in which all electrical resistance has been suppressed by chilling. Physicists had not expected that such quantized relationships would appear in normal, resistive conductors. But Yoseph Imry of Tel Aviv University told the meeting that recent experiments show that such quantized relations between magnetic field and electrical current can appear for rings made of normal conductors, provided they are small enough.

These effects depend on interference between different electron waves. One of the important and paradoxical features of the quantum mechanical world is that everything is both a particle and a wave. The effects associated with Josephson junctions arise from interference between different electron waves, whether they reinforce or cancel each other when they come together.

Interference effects are meaningful only in situations where the waves can maintain their phases as they move through space. In a very good vacuum or in a superconductor they can do this. In a normal conductor, the electrons are continually bounced and scattered — this is what electrical resistance amounts to — and the phases of their waves change every time, rendering the situation hopeless as far as interference effects are concerned.

Closer inspection, however, reveals a difference between the two types of scattering that occur. Electrons may be scattered elastically from imperfections and impurities in the crystal lattice or inelastically from vibrations of the lattice. If the bit of conducting material can be made small enough that the inelastic scattering is weak — that is, that the electrons can travel through a large part of it without being scattered that way — interference effects are possible.

At a temperature of one kelvin the characteristic length for a metal can become several thousand atomic lengths, Imry says, so a system of 1,000 to 2,000 atomic lengths should show these effects at "reasonable" temperatures. Semiconductors and semimetals should require less stringent conditions. Microfabrication techniques are advancing so well, he says, that in the not too distant future a wide variety of useful devices should be possible. They would not require the costly and bulky refrigeration techniques (usually with liquid helium) that superconductors need.

Channeling gives protons the bends

Channeling is a technique, indigenous to nuclear and solid state physics, in which a stream of ions is projected down the open pathways lying between the planes of atoms neatly arranged in a crystal. If an ion is aimed correctly into the crystalline landscape, its path will be shaped by the electrostatic forces of the atoms residing in the solid.

One application of this process in high energy physics is to use a bent crystal to deflect particles in an accelerator beam (SN: 1/5/80, p. 5). Richard A. Carrigan and colleagues suceeded in doing just that in January with the M-Bottom beam at the Fermi National Accelerator Laboratory in Batavia, Ill. The researchers replaced a 20 foot, 10 kiloGauss magnet in a secondary beam line with a 1 inch long, 1 millimeter thick silicon crystal that was mechanically bent with a set of screws.

Carrigan reports that the crystal deflected particles, mostly protons, at energies of 400 billion electron volts — twice what had been possible with the magnet. This is the highest energy ever reported for channeling. Other tests, notes Carrigan, indicated that the crystal is very resistant to radiation damage from the impinging particles.

A disadvantage of the crystal is that because of its small size it can only accept about 1 percent of the particles in the beam, and of that, 90 percent is thought to "spin out" like a car going too fast around a curve. Nonetheless, while they can't replace many existing magnets, Carrigan thinks that bent crystals will be useful for a number of specific applications in accelerators.

One future experiment, he says, is to put a series of bent crystals in tandem, leaving spaces between to harvest short lived sub-atomic particles that normally decay before they reach the end of conventional, longer magnets. Another idea, he adds, is to measure a particle's magnetic moment by causing it to precess around the magnetic field, which from the particle's perspective, is created when the crystal zips by. Carrigan also says that other workers have permanently bent a crystal by implanting ions in one side, but these crystals have not yet been used in channeling experiments.

Much noise about electron traps

Noise in electrical systems, like stereo static, is an annoyance to researchers making measurements of very small signals. But noise is also a scientific curiosity, especially "1/f noise," so called because its intensity increases as the frequency (f) drops (SN: 3/22/80; p. 187). 1/f noise weasels its way into virtually every type of material that conducts electricity, as well as some nonelectrical systems such as quasars, music and the weather. Scientists have been searching for the cause of 1/f noise for over half a century.

Theories about 1/f noise in semiconductors have suggested that the responsible parties are defects in a crystal that trap and expel electrons. While 1/f noise has been observed in semiconductor devices in the past, these were too large — and hence contained too many traps — for observers to see the descrete effects of electrons jumping in and out of one trap.

Now Kristin S. Ralls and co-workers at Bell Laboratories in Holmdel, N.J., have fabricated a device small enough to enable the viewing of these individual events. The device is a MOSFET, a Metal-Oxide-Semiconductor Field-Effect Transistor, that has a channel for conducting electricity 1 micron long by 0.1 micron wide. Ralls, who is now a doctoral candidate at Cornell University in Ithaca, N.Y., says that when measuring the electrical resistance of this channel, the researchers obtained a "random telegraph signal," or an irregular series of rectangular pulses varying in width, but not height. This switching, the scientists believe, is due to individual electron traps "turning on and off."

In larger devices, says Ralls, presumably many of these switching sequences overlap to build up a 1/f spectrum. "We don't have the statistics to prove that this is responsible for *all* the low frequency or 1/f noise in larger devices," she says. But the experiment does fit in with theories involving traps and certainly bears further study, she notes.

In addition to its relevance to 1/f noise, the experiment also provided a unique opportunity to study individual traps. The researchers were able to estimate how far each trap was located from the interface between the oxide and the channel and what energies the trapped electrons had. They also discovered that these energies were above that required for conduction. Traps in this regime, say the researchers, have never been studied before.