APS MEETING

SCIENCE NEWS of the week

Superconductivity: Betwixt and Between

Superconductivity and magnetism are usually incompatible. Superconductivity—the loss of all resistance to electric currents—and ferromagnetism—spontaneous magnetization — appear in certain metals as an effect of cooling. Generally if a metal becomes superconducting, it does not become ferromagnetic, and vice versa. Now, however, a new variety of superconductivity that seems compatible with magnetism has appeared. It is a strangely paradoxical phenomenon, and although theorists expected it, or something like it, to appear, they did not expect it to be as strong as it is.

The new variety is known as heavy electron superconductivity. It appears in materials that are on the border line between those that can become ordinary superconductors and those that become ferromagnets. "These don't know which way to go," says James L. Smith of the Los Alamos National Laboratory in Los Alamos, N.M.

According to Hans R. Ott of the Eidgenössische Technische Hochschule (Federal Polytechnic Institute) in Zurich, Switzerland, this exotic form of superconductivity tends to appear in rare earth actinides, the most studied substances being a uranium-beryllium compound, UBe_{13}, and a uranium-platinum compound, UPt_3. Ott and Smith discussed recent work on them at last week's meeting in Detroit of the American Physical Society.

These materials that are unsure which way to go produce a superconducting state that seems a bit of a hybrid. In normal superconductivity, the superconductor will not permit a magnetic field to penetrate it until the field reaches a certain critical strength (different for each material). At the critical field strength, the superconductor's resistance to the magnetic field fails. The field penetrates, quenches the superconductivity, and the metal returns to its normal state regardless of the temperature. Superconducting magnets use little current and produce no waste heat, but their maximum field strength is limited by this condition. The exotic superconducting state coexists quite well with quite high magnetic fields. If it can be found at temperatures of a few kelvin (rather than fractions of a kelvin), it could produce, in Ott's words, "tremendous magnets."

The exotic state seems to be produced by "heavy" electrons rather than the ordinary conduction electrons. In ordinary superconductivity the conduction electrons, which tend not to be bound to specific atoms, bind together in pairs with their spins directed oppositely. In this state they can move without resistance. The exotic superconductivity seems to involve electrons much heavier than the conduction electrons. Electrons in a metal generally experience a certain drag from their surroundings and so act as if they were heavier than free electrons. The electrons in question act 100 to 1,000 times as heavy as free ones. It seems that they belong to the inner shells of the atoms rather than the outer fringes. How such strongly localized electrons could provide a long-range correlated effect like superconductivity is a paradox the investigators are still working on.

This also seems to be superconductivity with a magnetic moment. The spin of an electrically charged particle makes it a little magnet. If the electrons pair with spins opposite, the pair has no net magnetism. The exotic pairs seem to have net magnetism. They could even have their spins lined parallel. (This parallelism, although it produces a superconducting state, is analogous to what happens when a metal becomes ferromagnetic.) In ordinary superconductivity vibrations of the crystal lattice called phonons bring the pairs together. In the exotic variety some magnetic interaction between the spins seems to do it. If they are parallel, this would be "P wave superconductivity." The ordinary variety is S wave. Ott says, "We do not claim [the work done so far] is a proof of P wave superconductivity." But Smith calls it "a very compelling argument for P wave superconductivity." —*D.E. Thomsen*

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Rare earth magnets attract attention

The makers and users of magnets have found their moment, in the form of a new rare earth magnetic compound. Several research groups in the United States and Japan are locked in a race to claim patents and find processing methods that will generate the best and strongest magnets. Many of the key scientists involved in this race met last week at the American Physical Society (APS) meeting in Detroit to discuss the structure of the new compound and theories explaining its unique magnetic properties. Data from measurements of a single crystal of the material were presented that set for the first time a theoretical limit on how good the competing researchers could hope to make their magnets.

The search for the new material began in 1978 when the price of cobalt—the most widely used ingredient in permanent magnets—soared because of political instabilities in the south African countries where it is produced. Last year a few research groups independently came upon the rare earth compound as an alternative to cobalt-based magnets. With some of the technical aspects still to be ironed out, companies—ebullient about the potential for producing inexpensive, lightweight, small magnets—are now planning to market the magnets for uses ranging from stereo speakers, computer disk drives and printers to telecommunications. General Motors, the largest consumer of permanent magnets in the world, plans to use its own brand of the rare earth compound to replace, in 1986, the ferrite magnets or the battery-driven electromagnets currently used in starter motors.

When cooking up magnets, scientists try to invent recipes that maximize two properties: coercivity and energy product. The coercivity is a measurement of how difficult it is to demagnetize a material with an external magnetic field, and is often highest in materials that exhibit some anisotropy, or preferred direction for magnetism. Jan Herbst of General Motors Research Laboratories in Warren, Mich., recently showed, using neutron diffraction of a sample containing the rare earth element neodymium, that the structure of individual crystals of the new material is tetragonal. This contributes to the coercivity because, as Herbst found, the magnetic moments of the neodymium and iron atoms point along the longest axis of the tetragon, defining a preferred magnetic direction.

The coercivity multiplied by the maximum intrinsic magnetic field of the material gives the energy product—a property that is used most often as the yardstick for comparing materials in the magnet race. The higher the energy product, the smaller the magnet required for a given application.

Most of the researchers at the meeting agree with Herbst's analysis that the compound with the highest energy product contains a rare earth (R), iron (Fe) and boron (B) in the phase $R_2Fe_{14}B$. While many rare earths can be used to form this phase, says Herbst, only neodymium and praseodymium have been shown to result in high energy products.

According to Norman Koon of the Naval Research Laboratory in Washington, D.C., who recently measured the maximum manetization of a single crystal of a rare earth compound, the highest possible energy product is 64 million Gauss Oerstead (MGOe—a unit of energy density). However, says Kalatur Narasimhan of Colt Industries, Crucible in Pittsburgh, that's more like a dream, because processing introduces structural defects and impurities that reduce the energy product.

Crucible has achieved the highest en-