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 energy product reported to date, 45 MGOe, with its Crumax material. "We think we can probably tap up to 54 MGOe in two or three years," says Narasimhan. Even at 45 MGOe, the researchers are doing well; this is 1.5 times better than the best cobalt-based magnet and over 11 times greater than levels achieved by conventional ferrites.

Both Crucible and the Sumitomo company in Japan, which has obtained 38 MGOe, make their magnets by grinding an amorphous chunk of the material down to a powder, aligning the micron-size particles in a magnetic field and then bonding the particles together with heat.

GM took another approach called melt-spinning, in which a stream of molten material is directed on to a spinning wheel to produce a thin, brittle ribbon. According to John Croat of GM, the researchers have achieved 14 MGOe with their Magnequench material and believe they can obtain 34 MGOe. However, Croat would not discuss how they plan to do this or, for that matter, how they will make actual magnets.

Electron microscopy reveals that the new magnets are made up of tiny particles. Part of the trick of making high energy products is to align these particles, or orient the crystal axis that is easiest to magnetize, with a magnetic field during the manufacturing process.

What causes high coercivity, however, is still subject to debate. Researchers agree that the anisotropic crystalline structure contributes. But more importantly, perhaps, is how the larger metallurgical arrangement of the particles — as determined by the processing technique — influences the formation of regions, called domains, inside which all the magnetic moments point in the same direction. When an external magnetic field is turned on, the domain walls sweep through the magnet, changing the orientation of the moments along the way in order to minimize the magnetic energy of the system.

In materials made by the powder method, microscopy shows the formation of large grains of the $R_2Fe_{14}B$ phase surrounded by areas of different composition and rich in neodymium and iron. Some scientists argue that the high coercivity in these materials results because the domain walls get stuck, or pinned, at the boundary between the two phases, making it difficult for an external field to change the direction of magnetization within the grain.

Microscopy of GM's rapidly quenched ribbons, on the other hand, reveals much smaller particles and mostly one phase. Herbst says that the coercivity of these samples is due to an optimum size of the particles, about 600 angstroms. (One angstrom equals one ten-billionth of a meter.) Below this size, he says, one would expect particles to have only one magnetic domain. *—S. Weisburd*

Reducing the risks at university reactors

Fears that terrorists could steal highly enriched uranium fuel from university nuclear reactors to make nuclear weapons have prompted the Nuclear Regulatory Commission (NRC) to set new regulations for these reactors. Last week, NRC staff completed work on a draft rule that requires research reactors to switch from using highly enriched uranium to a nuclear fuel with a much lower proportion of the uranium isotope U-235.

The uranium fuel currently in use contains 93 percent U-235. NRC would like to see this level reduced to less than 20 percent. The idea is to make it more difficult to build a bomb from the material. Highly enriched uranium can be fabricated into a bomb simply by chemically separating the uranium from the aluminum alloy that holds a fuel rod or plate together. No additional enrichment is necessary.

A 1982 NRC policy statement outlines the commission's intentions. The statement says, "U.S. research reactor operators have shown little interest in converting to low-enrichment fuels, and as part of a policy to strongly encourage conversion by foreign operators, the commission will take steps to encourage similar action by U.S. research reactor operators." The United States provides the bulk of the highly enriched uranium used in research, training and test reactors and every year exports about 600 kilograms of the material for this purpose. About 500 kilograms are used domestically.

The new rules will affect 25 university reactors, three reactors belonging to government agencies such as the National Bureau of Standards and five private reactors. "We feel that it's technically feasible to replace our existing fuel ... with fuel plates of identical dimensions containing 20 percent enriched uranium," says Thomas J. Parkinson, who heads the reactor program at the Virginia Polytechnic Institute and State University in Blacksburg. "The big problem facing university reactors is who's going to pay." Conversion requires new studies and calculations to ensure that the reactor is still safe and functioning properly. Parkinson points out that it may take a long time for manufacturers to change their products to the new specifications. The reactor conversion may take as long as 10 years, he says, and cost a total of $15 million for all the reactors. Recently, a congressional committee added $1.25 million to the Energy Department budget to start this process.

For the high-performance reactors at the Massachusetts Institute of Technology in Cambridge and at the University of Missouri in Columbia, the situation is more serious because no adequate alternative fuel exists. Missouri's Robert Brugger says, "Our reactor was designed to take advantage of the best technologies that were known at the time to make the best research reactor that could be made." This meant designing it around a compact core of highly enriched uranium. "If we were required to go to low-enriched uranium, it would dim our [neutron] source," says Brugger, "and it would not be an effective research reactor."

NRC's Charles N. Kelber says that the proposed rule allows some leeway by calling for the use of uranium fuel with an enrichment as close to 20 percent "as is available and acceptable to the commission." Kelber says that the Department of Energy has an extensive research program to develop new nuclear fuels that pack a larger amount of uranium into a given volume of fuel. Thus, although the uranium contains a lower percentage of U-235, more uranium is present in the fuel, so that the overall effect should be the same. However, these fuels are far from being commercially available.

Reactor operators are also worried that the fuel changeover will require them to seek an amendment to their reactor operating licenses. This procedure could involve public hearings, extra expense and long delays. The battle over renewing the license for the reactor at the University of California in Los Angeles is often cited as an example. UCLA's Neill C. Ostrander reports that the struggle has taken four years so far and cost about $250,000, and "the end is not yet in sight." At the moment, the UCLA reactor is shut down for maintenance and will remain closed until the end of the Olympic Games this summer.

—I. Peterson

Abundant Ir marks a third boundary

In a finding sure to enhance the debate about impacts of the earth with extraterrestrial bodies and their effect on the earth, Chinese scientists now report high iridium levels at the boundary between the Permian and Triassic periods. This boundary formed about 248 million years ago, at a time when 90 percent of species then living on earth became extinct. At least five other boundaries are marked by the relatively sudden extinction of many kinds of life. The Permo-Triassic boundary is the third where high iridium levels have been found, though one of these was not a time of major mass extinction.

Iridium, like other rare earth metals, is abundant in extraterrestrial bodies such as asteroids and comets, but normally is scarce on the planet's surface. It has been suggested that high levels of iridium indicate that the earth collided with an asteroid or a comet, and that after the impact, the element was carried around the world in a vast cloud of dust (SN: 3/31/84, p. 197). This debris became the clay that marks