Physicists set 'speed limit' for future superconducting magnet

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A research team led by a Northwestern University physicist has identified a high-temperature superconductor -- Bi-2212, a compound containing bismuth -- as a material that might be suitable for the new wires needed to one day build the most powerful superconducting magnet in the world, a 30 Tesla magnet.

The material currently used in magnetic resonance (MR) imaging machines in both hospitals and research laboratories -- a low-temperature superconducting alloy of the metallic element niobium -- has been pushed almost as far as it can go, to around 21 Tesla. (Tesla is used to define the intensity of the magnetic field.) There are no superconducting magnet wires currently available that can generate 30 Tesla.

"A new materials technology -- such as a technology based on high-temperature superconductivity -- is required to make the huge leap from 21 Tesla to 30 Tesla," said William P. Halperin, John Evans Professor of Physics and Astronomy in the Weinberg College of Arts and Sciences at Northwestern, who led the team. "We have shown that Bi-2212 could be operated at the same temperature as is presently the case for magnets made with niobium -- 4 degrees Kelvin -- and also achieve the stable state necessary for a 30 Tesla magnet."

The findings will be published online Feb. 11 by the journal *Nature Physics*.

"We are exploring nature's limitations, and our discovery has basic implications for the study of superconductors and for applications to magnetic resonance imaging," said Halperin. "The dream would be to have powerful magnets that don't require helium for cooling. Some day new materials might be discovered where this restriction is lifted, but it isn't possible at the present time."

A superconductor, when cooled to its appropriate temperature, conducts electricity without any resistance. Superconductivity first appears in Bi-2212 at a high temperature of 90 degrees Kelvin, but Halperin and his colleagues found that the stable state required in high-magnetic fields can be established only when the temperature falls below 12 degrees Kelvin. The team is the first to establish this limit for Bi-2212.

"Sometimes what seems to be bad can be good," said Bo Chen, lead author of the paper and a graduate student of Halperin's. "Our findings set a speed limit. If you go beyond this speed you may have trouble. Knowing the upper temperature limit is a kind of security."

"To create a 30 Tesla magnet, we need a superconducting material that can carry the required amount of electricity without blowing up," said Halperin. "We have found that the operating temperature for Bi-2212 must be below 12 degrees Kelvin. The good news is that this temperature can be reached by cooling the magnet with liquid helium. If we had found the upper limit to be 2 degrees Kelvin then the cryogenic requirements would be intractable."

MR imaging is widely used by hospitals for medical diagnosis, and scientists at universities, national laboratories and pharmaceutical companies use even more powerful MR technology to study DNA, proteins and other complex molecules. About a dozen labs around the country take advantage of the highest magnetic field now in use -- 21.1 Tesla, which produces a magnetic field 10 times larger than your average hospital machine. Increasing the field of the magnet even a small amount, from 21.1 to 22.2 Tesla, would increase the cost of the machine by two million dollars.

"A holy grail of the scientific community, as set out recently by the National Research Council, is to build a superconducting magnet of 30 Tesla," said Halperin. "In MR imaging, the higher the magnetic field, the higher the resolution, which provides scientists with more detail for analysis. A 30 Tesla magnet could drive significant advances in chemistry, biology and medicine."

Using MR techniques at the National High Magnetic Field Laboratory in Tallahassee, Fla., Halperin and his team studied Bi-2212, one of the "darlings" of superconductivity. To measure its properties, they put the rare isotope oxygen-17 into a crystal of Bi-2212, with the isotope acting as a probe, much like a fluorescent dye. They then determined the phase diagram of the material where superconductivity is stable, which showed high temperature and high magnetic field could not be achieved together.

"Now that we have this information about Bi-2212, the next question is, 'Can such a magnet actually be made?'" said Halperin. "I really don't know -- it depends on engineering and processing the materials to make them into wires. My fellow scientists and engineers will have to solve the materials problems, and they don't like to accept no as an answer."

Source: Northwestern University