NANOCOMPOSITE EXTRAORDINAIRE

Magnetic nanoparticles freely rotate inside nanocavities in a solid matrix

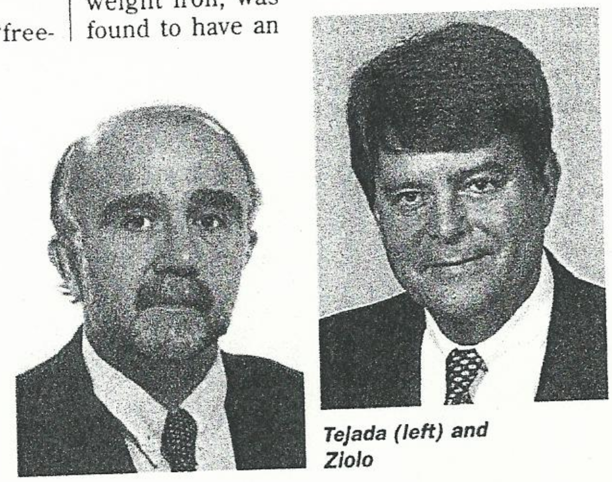
A new type of nanocomposite in which magnetic nanoparticles, dispersed in a solid matrix, are free to rotate inside nanocavities could lead to nanoscale compasses, gyros, sensors, and switches, as well as more efficient electrical transformers.

The first example of such a "free-rotor" nanocomposite is described in the *Journal of Applied Physics* [**87**, 8008 (2000)] by chemist Ronald F. Ziolo, physicist Javier Tejada, and their coworkers at the University of Barcelona Xerox Laboratory for Magnetics Research, which Ziolo and Tejada cofounded in 1997. In that material, the matrix consists in large part of frozen methanol, so it functions as a solid nanocomposite only up to 200 K.

However, the Barcelona researchers have prepared a room-temperature polymer-based version of the material—not described in their journal article—that Ziolo says is being investigated for transformer core applications. Transformers, which convert power from one voltage to another, form eddy currents in the iron core that sap power and generate heat. Ziolo claims that replacing the iron core with a nanocomposite containing freely rotating nanomagnets could result in a transformer that operates more efficiently because of the elimination of these eddy currents. The nanocomposite's lower density and insulating nature also could provide advantages over conventional cores, he believes.

The new family of nanocomposites was discovered accidentally when Ziolo and coworkers were attempting to make a methanol-based ferrofluid (a stable colloidal dispersion of magnetic particles) using a magnetic nanocomposite they had prepared previously. That earlier nanocomposite—consisting of nanocrystals of a magnetic form of iron oxide known as maghemite (γ-Fe_2O_3) dispersed in a sulfonated polystyrene ion-exchange resin—was finely ground and mixed with methanol.

The resulting ferrofluid, about 2% by weight iron, was found to have an unusual property: It could be made to interconvert between a liquid and a gel, with a noticeable change in its magnetic properties. On further study, Ziolo, Tejada, and coworkers discovered that by cooling the ferrofluid to 4.2 K and then subjecting it to a gradually increasing alternating magnetic field, they could produce a solid material that had magnetic properties like no other known material. Their data suggest that the magnetic nanocrystals are free to rotate in the matrix and can line up with an applied magnetic field.



Tejada (left) and Ziolo

Exactly how this free-rotor material forms is unclear. Before the magnetic treatment, the frozen ferrofluid is a conventional-type nanocomposite consisting of particles rigidly fixed in the solid matrix. Ziolo believes the alternating magnetic-field treatment causes the γ-Fe_2O_3 particles to break free and wiggle back and forth "just enough to carve out some elbow room in their immediate vicinity," as the American Institute of Physics noted in a press release about the work. The resulting nanocavities allow the particles to rotate, but not to wander, Ziolo says.

The magnetic and other properties of such nanocomposites suggest a range of applications, including "smart" materials that could sense and signal orientation, motors and generators, microwave shielding, and magnetic refrigerants.

The Tejada-Ziolo paper is "a nice piece of work" that "opens up a new avenue for making nanocomposites," says Richard W. Siegel, head of the materials science & engineering department at Rensselaer Polytechnic Institute in Troy, N.Y.

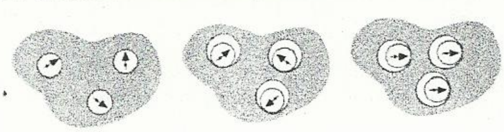
And Sara A. Majetich, a physics professor at Carnegie Mellon University in Pittsburgh, says the work is "important" and "scientifically very interesting." But she hasn't yet seen enough data to be convinced that such nanocomposites will find practical applications.

Nevertheless, she is intrigued by the authors' suggestion that a rotating-magnet system might explain how birds and other animals navigate in Earth's magnetic field.

Ziolo hopes that the paper will "change the way researchers think about composite materials in general. If one were to design a composite containing nonmagnetic particles that were free to rotate or translate, one could realize composites with new and unexpected acoustical, thermal, optical, mechanical, electrical, and electromagnetic properties as well. What can be done remains to be seen."

Ron Dagani

A nanoscale magnetic compass?



An ordinary composite containing magnetic particles locked into a matrix is shown at left. In the new composite reported by Tejada, Ziolo, and coworkers, the magnetic nanoparticles are free to rotate inside tiny cavities in the matrix (center). The free nanoparticles line up in the presence of an applied magnetic field (right). Whether the particles would respond to Earth's magnetic field and function as a nanoscale compass remains an open question.