Freezing Magnets With Magnets

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A “spin liquid” is a very unique, dynamic material in which each spin – the tiny magnetic field carried by an electron – is not frozen into place, producing clearly defined magnetic regions. Instead, the spins are free to change orientation. Because of this, external magnetic fields applied to spin liquids may produce changes that even extreme temperatures and pressures cannot.

Jason Gardner, a scientist at the U.S. Department of Energy’s Brookhaven National Laboratory and the National Institute of Standards and Technology, has been able to freeze a spin liquid by applying a magnetic field. This liquid-to-solid transition (like water to ice) allowed Gardner and his colleagues to reveal an unusual property of a spin liquid system — a property that may hold the key to understanding this unusual magnetic state and how it could be used to better understand superconductivity.

“Regular liquids are expected to crystallize at low temperatures,” Gardner said. “A spin liquid should too, but the system I’m studying remains a liquid down to temperatures close to absolute zero, the coldest temperature possible.”

Gardner discussed this research at the March meeting of the American Physical Society in Baltimore, Maryland.

Spin liquids are found in several magnetic materials, including high-temperature superconducting materials, however Gardner studies this exotic magnetic state in materials that exhibit geometrical frustration.

This occurs when the geometry of the material's atomic lattice and the magnetic interactions within the material are incompatible. In his most recent study, he examined an insulating material consisting of the elements terbium (Tb), titanium (Ti), and oxygen (O). Abbreviated $Tb_2Ti_2O_7$, this material remains in a spin liquid state at extreme low temperatures, but begins to crystallize under extremely high pressure (100,000 times atmospheric pressure) and now, as Gardner and his group have discovered, under magnetic fields.

"Tb2Ti2O7 is a bit of a mystery in frustrated magnetism," Gardner said. "It remains very dynamic down to 17 milli-Kelvin (absolute zero is 0 Kelvin), but theory states that it should freeze at temperatures 1000 times higher. Fully understanding this magnet will bring new insight into other dynamic systems, not only spin liquids."

The second part of Gardner's talk will center on the "neutron spin echo technique," a new area of research in frustrated magnetism. This technique uses neutrons to measure the slow motions of atoms, molecules, and magnetic spins on very short timescales — as small as nanoseconds (billionths of a second) and even picoseconds (trillionths of a second). It works by measuring the very subtle change in speed of a neutron as it interacts with matter. It has been applied to problems in biology, chemistry and physics including how oil and water interact and how polymer chains vibrate.

"The neutron spin echo facility at the Center for Neutron Research at NIST is unique in the Americas," Gardner said. "In collaboration with Georg Ehlers at the Spallation Neutron Source at Oak Ridge National Laboratory, we have been doing some great work on the slow dynamics in frustrated magnets." Gardner and his colleagues hope that their studies will encourage others to use this facility.

Source: Brookhaven National Laboratory

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