Physicists find evidence of new state of matter in a simple oxide

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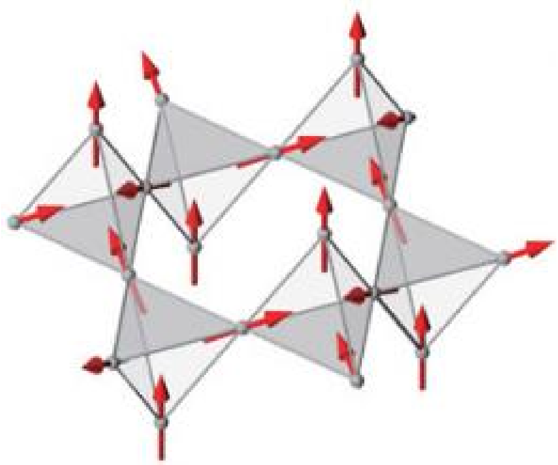

Schematic of the spin-ice structure of the oxide Pr2Ir2O7. Large quantum fluctuations of the spins (red arrows) are predicted to melt the spin-ice structure and form a new state of matter, called a chiral spin liquid. Copyright : Modified, with permission, from Ref. 1 © 2010 Yo Machida et al.

Symmetry is a fundamental concept in physics. Our 'standard model' of particle physics, for example, predicts that matter and anti-matter should have been created in equal amounts at the big bang, yet our existing universe is mostly matter. Such a discrepancy between the symmetry of known physical laws, and what we actually observe, are often the inspiration for realizing that new interactions are important or that new phases of matter can exist.

Shigeki Onoda, a theorist at the RIKEN Advanced Science Institute in Wako, recognized that experimentalists at The University of Tokyo had possibly discovered a new state of matter, called a 'chiral spin liquid' when they reported evidence of time-reversal symmetry breaking[1]—a difference between the trajectory of a particle moving along one path or its inverse—in the oxide called $Pr_2Ir_2O_7$. If a material is magnetic, or in a magnetic field, its electrons will not obey time reversal symmetry; but in $Pr_2Ir_2O_7$, neither contribution was present to explain what the experimentalists had observed.

Now, Onoda and colleague Yoichi Tanaka have explained how a chiral spin liquid could emerge from so-called 'quantum spin fluctuations'—the motion of spins that occurs even at absolute zero[2]. "The possibility of a chiral spin liquid was first proposed twenty years ago and many physicists had lost hope to find it," explains Onoda. "This is a revival of a phase that was found in a totally different system than where it was first expected."

The interesting properties of $Pr_2Ir_2O_7$ are rooted in its crystal structure, called a pyrochlore lattice: four praseodymium (Pr) ions, each of which carries a magnetic 'spin', form a tetrahedral cage around an oxygen (O) ion. At low temperatures, the spins of materials with this structure often 'freeze' into what is called a 'spin ice' (Fig. 1) because of its similarity to the way hydrogen ions form around oxygen in water ice.

Onoda and Tanaka predict, however, that the quantum fluctuations in the spins melt the spin ice structure of Pr2Ir2O7. They proposed a realistic model of Pr spins on a pyrochlore lattice and suggested that both the geometry of the crystal and the small size of the spin on the Pr ion allowed the quantum fluctuations to grow so large that they melted the spin ice into a chiral spin liquid.

If their prediction is correct, $Pr_2Ir_2O_7$ will be the first material in which one can study this new state of matter.

More information: 1. Machida, Y., et al, Time-reversal symmetry breaking and spontaneous Hall effect without magnetic dipole order. *Nature* 463, 210-213 (2010). www.nature.com/nature/journal/ … ull/nature08680.html
2. Onoda, S. & Tanaka, Y. Quantum melting of spin ice: Emergent cooperative quadrupole and chirality. *Physical Review Letters* 105, 047201 (2010).

Provided by RIKEN