Hidden order found in a quantum spin liquid

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An international team, including scientists from the London Centre for Nanotechnology, has detected a hidden magnetic “quantum order” that extends over chains of 100 atoms in a ceramic without classical magnetism. The findings, which are published today by *Science*, have implications for the design of devices and materials for quantum information processing.

In quantum information processing, data is recorded and manipulated as quantum bits or ‘qubits’, generalizations of the classical ‘0’ and ‘1’ bits which are traditionally represented by the ‘on’ and ‘off’ states of conventional switches. It is widely believed that if large-scale quantum computers can be built, they will be able to solve certain problems, such as code breaking, exponentially faster than classical computers.

Theoretically, the spin of an individual electron is an excellent qubit, but in a real material it interacts with other electrons and its useable quantum properties are rapidly lost. The new research is important because it explicitly demonstrates, using a practical material, that a large number of electron spins can be coupled together to yield a quantum mechanical state with no classical analog. In addition, the team has also established the factors that affect the distance over which the hidden ‘quantum order’ can be maintained.

“We had two objectives,” explains Professor Gabriel Aeppli, Director of the London Centre for Nanotechnology and the paper’s senior author. “The first was to show that we could actually image the quantum order, which is sometimes referred to as phase coherence. The second aim was to manipulate the distance over which it can be maintained." This distance - and how sensitive it is to changes in temperature or chemical impurities in the material - can be essential in determining whether a material will have real-life applications, where it would be crucial to control and maintain quantum order over predetermined extents in space and time.

The team studied a ceramic material consisting of chains of nickel-centered oxygen octahedra laid end-to-end. The chains are not ordinary magnets such as those used to fix reminders onto refrigerator doors, but an exotic quantum spin liquid in which the electron spins (analogous to tiny bar magnets) point in random directions with no particular order, even at very low temperatures.

To measure the quantum order throughout this classically disordered liquid, the scientists used neutrons to image the magnetic excitations - "flips" or fluctuations of the spins - and the distances over which they could propagate. The experiments were performed at the National Institute of Standards and Technology (NIST) Center for Neutron Research in the US and at the ISIS particle accelerator of the Rutherford Appleton Laboratory in the UK.

The scientists found that despite the apparent classical disorder, magnetic excitations could propagate over long chains of atoms at low temperature - in the otherwise magnetically disordered material.

Other examples of large-scale quantum phase coherence include superconductors and superfluids where quantum physics leads to fascinating properties.

The team also discovered that they could limit the coherence or make it disappear altogether by introducing defects into the material either by adding chemical impurities (doping) or heating. These defects break the chains into independent sub-chains, each with its own, hidden order. This part of the reported research is the first step towards engineered spin-based quantum states in ceramics.

Aeppli and other members of the team note that their work was initially not intended to have direct applications, but that they later realized that what they are learning could be applied in a range of fields from nanotechnology to quantum computing.

Source: University College London

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