Getting to the heart of frustrated magnetism

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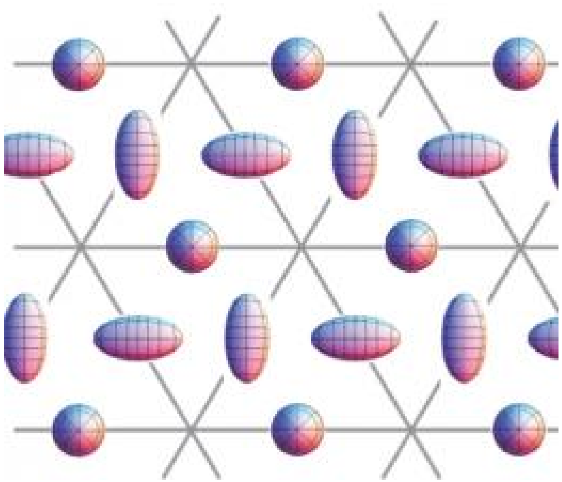

Figure 1: The spin configuration of the quantum ground state of thin films of solid-state helium-3, as revealed by a sophisticated mathematical model. Credit: 2012 American Physical Society

Thin films of helium atoms with nuclei of two protons and one neutron—helium-3—intrigue physicists because they have exhibited unusual and unexpected magnetic behavior in experimental investigations.

To better understand how this behavior arises, a research team from Japan and France has developed a mathematical model that provides some important clues. The model also predicts the appearance of a new quantum state in solid helium-3 films. "The search for a novel quantum state of matter is one of the most exciting aims of condensed-matter physics," says team leader Tsutomu Momoi from the RIKEN Advanced Science Institute in Wako.

Momoi and his colleagues focused on solid-state helium-3 because it enabled them to study a phenomenon known as frustration. Helium-3 thin films are 'frustrated' by interactions between localized areas of magnetism known as spins. The atoms in these films are organized into a triangular lattice, so the interaction between nearest-neighbor-pairs requires that spins act in the same direction—a mechanism known as ferromagnetism. At the same time however, exchange interactions between multiple spins are antiferromagnetic; that is, alternating spins act in opposite directions.

This contradiction leads to the frustration that gives helium-3 its unusual magnetic properties. In general, helium thin films are an ideal system for studying frustration because the ratio of the competing spin interactions can be tuned by varying the density of helium atoms. Momoi and his colleagues provided a more complete understanding of this material by mathematically modeling its lowest energy arrangement, or ground state.

Previous theoretical models included two-spin and four-spin interactions that provided information about the system's ground state when in an external magnetic field. "But these models were too simple to describe the delicate balance of competing interactions," explains Momoi. Indeed, experimental studies have indicated that five-spin and six-spin interactions also play a role, particularly in the absence of an external field. Thus, the researchers extended the multiple-spin exchange model to include five-spin and six-spin interactions.

They found a previously unknown ground state that has a so-called octahedral spin nematic order; that is, the spins are arranged such that they point along a particular direction, and these 'directors' are orthogonal to each other. Momoi and colleagues believe that it is this unusual arrangement that causes the anomalous magnetic behavior of two-dimensional solid helium-3. "Because this is a completely new state, we next need to develop the theory for clarifying characteristics that will be helpful for observing this phase directly in experiments."

More information: Momoi, T., Sindzingre, P. & Kubo, K. Spin nematic order in multiple-spin exchange models on the triangular lattice. *Physical Review Letters* 108, 057206 (2012). DOI: 10.1103/PhysRevLett.108.057206

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