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Polish physicists co-discover “lonely” spinons - a new step towards quantum technologies

Researchers from the Faculty of Physics at the University of Warsaw and the University of British Columbia have described how a so-called lone spinon - an exotic quantum excitation that is a single unpaired spin - can arise in magnetic models. The discovery deepens our understanding of the nature of magnetism and could have implications for the development of future technologies such as quantum computers and new magnetic materials. The findings were published in the renowned journal “Physical Review Letters.”

Magnetism has been known to humanity since ancient times, when naturally magnetized magnetite was discovered. This finding soon found highly practical applications. The first compasses were created which in the 11th century in China, began to be used for navigation. Today, magnets play an important role in many technologies that surround us, from computer memory and speakers to electric motors and medical diagnostics. Interestingly, alongside photography, magnets have also become a common souvenir of travel, occupying a prominent place in our homes.

Magnets and quantum mechanics

Despite its widespread use, the nature of magnetism remained incompletely understood for a long time. The situation became further complicated when Niels Bohr and Hendrika Johanna van Leeuwen showed that magnetism could not be explained within the framework of classical physics. It was not until the development of quantum mechanics in the 1920s that it was understood that the magnetic properties of matter are primarily due to interactions between the spins of electrons. Spin, along with mass and electric charge, is one of the fundamental properties of elementary particles.

In 1931, Hans Bethe proposed a mathematically elegant solution to one of the fundamental quantum models of magnetism — the so-called one-dimensional Heisenberg model. Less than half a century later, in 1981, Ludwig Faddeev and Leon Takhtajan realized that the solutions to this model exhibited a surprising phenomenon: as if an indivisible electron “splits” into two more fundamental particles. The spin of the electron is $1/2$ (in units of Planck's constant $\hbar$) and can be oriented in any direction in space. In the standard situation, an excitation involves the reversal of the spin of one electron, resulting in a change in the spin of the whole system by 1. However, from Faddeev and Takhtajan's theory, it follows that the fundamental excitations in a magnet change the total spin of the system by $1/2$. These exotically behaving excitations were named spinons. Since then, many experiments have confirmed their existence. However, it was long believed that spinons could only form in pairs — and indeed, they had always been observed in this form — which made the phenomenon seem somewhat less “exotic.”

A lone spinon

In a paper just published in “Physical Review Letters”, a team of scientists from the Faculty of Physics at the University of Warsaw and the University of British Columbia has shown how such a singular excitation can be created as a single spinon. Such a spinon can be created in a very simple way: it is enough to add one extra spin to the ground state of the one-dimensional Heisenberg model (a theoretical description of a number of interacting spins). The researchers also discovered that the same effect can be obtained if, instead of the ground state, a very simplified model of the so-called valence-bond solid (VBS) is used, in which the spins are paired in a very ordered way. A spinon in this model can be understood as a single unpaired spin that “travels” through a network of such paired spins.

Importantly, this theoretical prediction was recently successfully confirmed experimentally in the paper by C.Zhao et al. “Spin excitations in nanographene-based antiferromagnetic spin-1/2 Heisenberg chains”, published in Nature Materials.

Spinons and their significance for future technologies

This is an important step towards a better understanding of the quantum properties of magnetism and could open the way to discovering new features of them. Of particular importance, spinons are the result of strong interactions between electrons and quantum phenomena such as quantum entanglement. Similar mechanisms play a key role in phenomena as fundamental as high-temperature superconductivity or the fractional Hall effect in two-dimensional quantum liquids. Quantum entanglement is also the foundation of quantum computers and quantum computing as a whole. “Our research not only deepens our knowledge of magnets, but can also have far-reaching consequences in other areas of physics and technology”, concludes Prof Krzysztof Wohlfeld of the Faculty of Physics at the University of Warsaw.

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Faculty of Physics of the University of Warsaw

Physics and astronomy at the University of Warsaw appeared in 1816 as part of the then Faculty of Philosophy. In 1825, the Astronomical Observatory was established. Currently, the Faculty of Physics at the University of Warsaw consists of the following institutes: Experimental Physics, Theoretical Physics, Geophysics, the Department of Mathematical Methods in Physics, and the Astronomical Observatory. The research covers almost all areas of modern physics on scales from quantum to cosmological. The Faculty's research and teaching staff consists of over 250 academic teachers. About 1,100 students and over 170 doctoral students study at the Faculty of Physics UW. The University of Warsaw is among the 300 best universities in the world, educating in the field of physics according to Shanghai's Global Ranking of Academic Subjects.

SCIENTIFIC PUBLICATION:

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https://www.fuw.edu.pl/tl_files/press/images/2025/FUW250707b_01.jpg Today, magnets play a key role in many technologies - from computer memory and speakers to electric motors and medical diagnostics. They have also become a common travel souvenir. Photo by Marek Wohlfeld Copy © University of Warsaw.