Hidden magnetism appears under hidden symmetry

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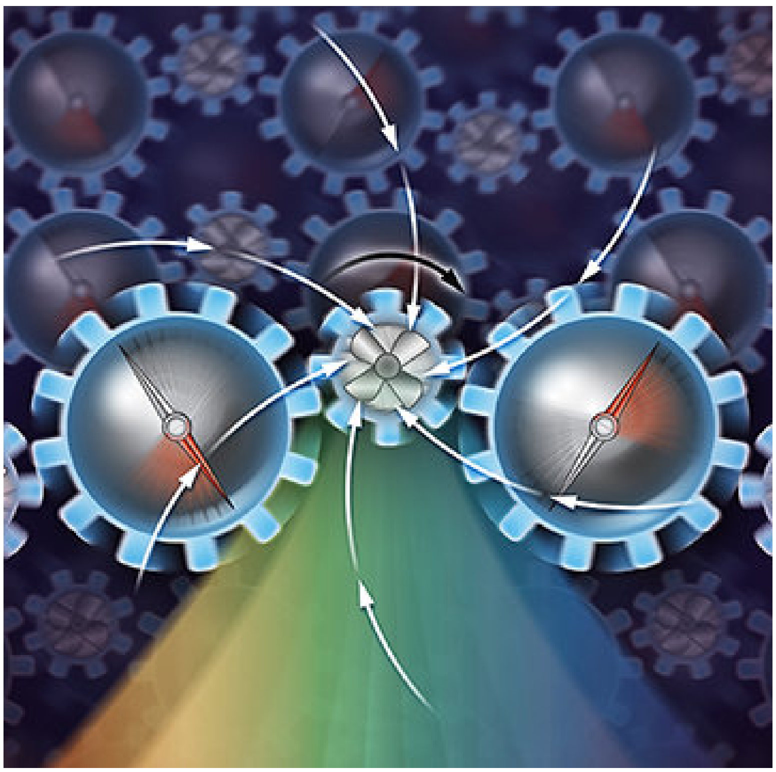

Brookhaven National Laboratory. Artistic rendering of a pair of antiferromagnetically coupled spins driven by magnetic field through the hidden symmetry. Credit: University of Tennessee at Knoxville

Sometimes a good theory just needs to right materials to make it work. That's the case with recent findings by UT's physicists and their colleagues, who designed a two-dimensional magnetic system that points to the possibility of devices with increased security and efficiency, using only a small amount of energy. By exploiting a hidden symmetry in the material, their results support a theory first proposed 20 years ago.

Keeping Control without Losing Flexibility

People have known about magnetism since ancient times but are still learning how it works, especially at the quantum scale. In ferromagnets, atoms and their neighbors have magnetic moments (caused by spin) that all align along the same direction. We can easily control that direction by an external magnetic field. In antiferromagnets, however, the magnetic moments anti-align with their neighbors and alternate one-by-one. This microscopic spin alignment perfectly shields any external magnetic field and is hidden from the outside world. Antiferromagnets were discovered by Louis Néel in 1948, but were described in his 1970 Nobel lecture as being theoretically interesting but technologically useless.

Jian Liu, assistant professor of physics, explained that generally spins in an antiferromagnet can rotate anyway they want as long as the anti-alignment is maintained. But, if the interaction between the atoms is anistropic, "it will give the spin a certain preferential direction." This is the DM (Dzyaloshinskii-Moriya) interaction originating from relativistic effect, and Liu explained that it does two things. First, it tilts (or cants) the spins slightly away from the perfect anti-alignment, which is good because this means that an external magnetic field won't be completely shielded and can couple to the canted spins, even if they're staggered. There's a tradeoff, however, in that while this interaction allows for canting, it pins the direction.

"So you are gaining some control," Liu said, "but you're also losing some flexibility. And that evens out."

To get around this problem, he and a team of fellow researchers exploited a hidden spin symmetry: SU(2).

"SU(2) is actually a terminology that theorists and mathematicians use in group theory," Liu said. "What it means is that spin is isotropic—it can point in any direction that you want."

Yet how, exactly, is this symmetry hidden?

Liu said it's hiding if you only look at things from a local scale.

"For example, if you sit at one spin, and you look around, you see a very anisotropic environment," he explained. "Basically, the other spins—your neighbors—are telling you that you have to cant (a certain way) to be compatible with them. If you look at a very global scale—if you consider all the spins—it turns out the entire system is perfectly isotropic and preserves this rotational symmetry.

"You can think of it this way," he continued, "hundreds years ago, people thought the earth was flat. That's because we were sitting at a very local scale. We thought that if we continue to walk along one direction we would never come back to the same point. But it turns out the earth is a sphere, so if you continue walking north at some point you pass the pole and then you come back. So if you look at the earth on a global scale, you see that it has rotational symmetry, which you would not notice if you're bound to the surface."

Adding Just Enough Space

The role of this global symmetry in antiferromagnetic systems was actually predicted two decades ago. Liu said while the theory was fascinating, the material used to test it wasn't suitable for the task.

For their studies, he and his colleagues grew samples made from strontium, iridium, and oxygen (SrIrO3), as well as strontium, titanium, and oxygen (SrTiO3) and, using pulsed laser deposition, grew them on a base layer of SrTiO3 only a single crystal thick. They focused on three points: the material's chemistry, preservation of the symmetry, and a crucial additional layer. Iridium proved to be an important choice because it provided strong DM interaction. The structure enables the hidden symmetry, largely because the team separated the layers with a "spacer" of SrTiO3 so that each layer would have its own two-dimensional properties.

The inspiration for this research came last year after Liu and fellow scientists published results on controlling ultrafine materials in *Physical Review Letters*. He explained that once they found a way to separate the layers to explore intrinsic two-dimensional properties, they realized they had a material that could test the symmetry theory.

Safer Systems; Faster Switching

Aside from scientific discovery, these latest research findings also present the potential to control antiferromagnetism for more secure and efficient devices.

As Liu explained, most current magnetic devices are based on ferromagnetic materials.

"However, we are getting to the limit of the performance of ferromagnets," he said. "We need to find another way to overcome the technical barrier. Antiferromagnetism provides another option. For example, antiferromagnetic materials have this anti-aligned spin. So if you look at an antiferromagnet, there's no magnetic field around it. It actually appears to you as no different from a material that's not magnetic, because they fully compensate each other."

What that means, he continued, is that we don't want the bits in our computer hard drive to get too close to each other because each bit is one ferromagnet. This limits the density of the information storage.

"Now if the bits are antiferromagnetic, they will be magnetically invisible to each other, and you can pack them right next to each other," he said. "Essentially the storage capacity will dramatically increase."

Another possible benefit is more efficient switching in devices.

Liu said that switching the spins up and down in ferromagnetics is a slow and energy-costly process because we have to turn around its magnetic field on a macroscopic scale. With the anti-aligned spins in antiferromagnets under the hidden symmetry, he said, "it displays no magnetic field, and we just need to apply a little bit of energy to turn it on and off or rotate it. The amount of energy that we put into the system is very tiny compared to the self-anti-alignment energy, but the spins still respond instantaneously, and that makes the switching process much faster."

The Importance of Collaboration and Investment

The initial results were very encouraging, yet the experimental team wanted some additional verification.

"At the very beginning we couldn't believe what we saw because the effects were really strong and the amount of energy you put into the system is one-thousandth of (its) internal energy," he explained. "It almost sounds too good to be true."

For validation, they took their questions to UT Physics Professor (and Lincoln Chair) Cristian Batista, a theorist in condensed matter physics.

"He guided us through all the detail of the theory and he came up with the explanation: not just qualitatively but actually quantitatively," Liu said. "He did the simulation and found that everything perfectly fell into the requirements for that theory of hidden symmetry."

The results were published in *Nature Physics*.

More information: Lin Hao et al. Giant magnetic response of a two-dimensional antiferromagnet, *Nature Physics* (2018). DOI: 10.1038/s41567-018-0152-6

Lin Hao et al. Two-Dimensional Jeff=1/2 Antiferromagnetic Insulator Unraveled from Interlayer Exchange Coupling in Artificial Perovskite Iridate Superlattices, *Physical Review Letters* (2017). DOI: 10.1103/PhysRevLett.119.027204

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