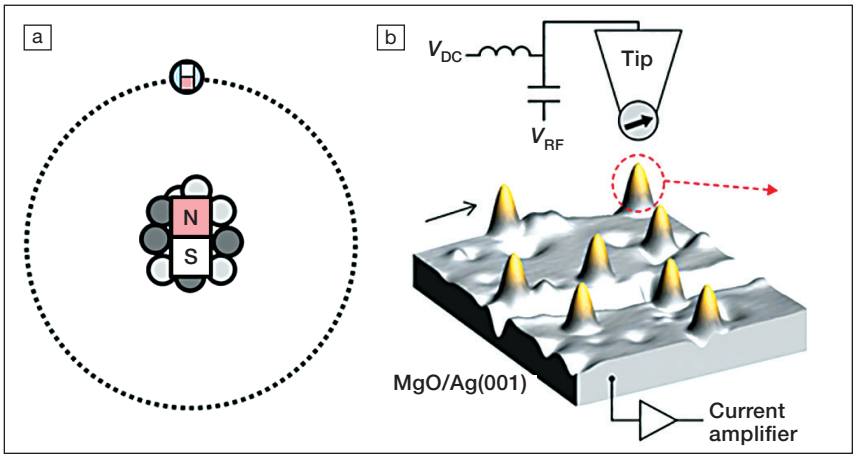
## Researchers magnetize single copper atoms

There is ongoing interest in creating magnets as tiny as possible, to create more efficient hard-drive storage, to perform MRI with injected particles rather than giant rings, and to bring quantum computing closer to reality. As a magnet gets smaller and smaller, it is more likely that interactions with its environment will ruin its internal magnetism. In a recent study in *Nature Nanotechnology* (doi:10.1038/s41565-018-0296-7), a group of researchers from IBM and several universities reported on the small magnets they made by stabilizing the magnetism of a single atomic nucleus.

Both an electron and a nucleus in an atom have intrinsic angular momentum and can act as tiny magnets. The overall energy of an atom differs slightly depending on whether the electron and the nucleus are magnetically pointing in the same or opposite directions. This energy difference is much smaller than the energy difference between different electron orbits, and the different magnetic states are called "hyperfine structure." To allow a single atom to act as a magnet, it is necessary to control its hyperfine structure—to dictate the alignment of the electron and nucleus—without having them de-orient due to thermal fluctuations from the environment.

The researchers wanted to stabilize the magnetism of single atoms, and did so using technology developed by IBM in the 1980s. Individual atoms of copper deposited on a magnesium oxide surface on top of silver substrate were used. The researchers modified a scanning tunneling microscope (STM) to emit electrons with a specific magnetic alignment. An electron jumping from the STM tip exerts a torque on an orbital electron in the copper, putting it in a specific spin state. This then dictates the opposite spin state in the nucleus, to conserve overall angular momentum. As the researchers write, "an electron spin flips and a nuclear spin flops," and this process allows the nuclear spin of atoms to be dictated one at a time.




(a) The nucleus of an atom acting as a magnet, with the magnet of the electron pointing in the opposite direction. (b) A scanning tunneling microscope tip interacts with a Cu atom on a surface. Credit: *Nature Nanotechnology*.

A single-atom magnet is always in a precarious state because the hyperfine energy differences are so small compared to thermal agitation (in this case, electrons scattering from the silver below). The experiment was conducted at a very low temperature (~1 K) and strong magnetic field (~1 Tesla) to allow the atoms to retain their hyperfine state without succumbing to environmental perturbations. Even under these conditions, it is expected that fewer than 2% of the atoms would naturally be found in the desired state. Through their STM polarization technique, the researchers were able to improve this by a factor of 17, resulting in 30% of the atoms having the desired nuclear magnetic state.

The researchers are hopeful that in the future this technology can be used to develop spintronics, in which signals are sent by angular momentum rather than charge, and be used for detecting magnetic fields on extremely small scales.

**Alex Klotz**

## Dirac material heterostructures lead to next-generation spintronics

Classical materials, such as metals, have electrons that exhibit a parabolic dependence of energy on momentum. This is a consequence of the finite mass of electrons, which limits their speed to well below the speed of light. The physics of such materials can be comprehensively explained using the Schrödinger equation. There also exists a class of materials, however, in which the charge carriers become massless, allowing them to move at relativistic speeds. The Dirac equation is required to capture the physics of such quantum materials. Graphene is a Dirac material that comprises a single sheet of $sp^2$-bonded carbon atoms. Massive charge-carrier mobilities have been reported for graphene. Topological insulators (such as $Bi_2Se_3$), are another exciting Dirac material, and are bulk insulators with electronic surface states that allow high-mobility charge transport on the surface that is "protected" from scattering. As such, Dirac materials are a burgeoning field, due to their exotic physics and the promise of revolutionary applications, such as quantum computing and spintronic-logic devices.

Although graphene offers excellent spin transport, it suffers from low spin–orbit coupling (SOC), a phenomenon that defines the interaction between an electronic spin and its orbital motion. A low SOC results in poor external control over the electronic spin, making the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material incompatible with spintronic applications.Topological insulators (TIs), on the other hand, are endowed with a very strong SOC. A collaboration has now brought these two materials together. In an article published recently in *Science Advances* (doi:10.1126/sciadv.aat9349), a research team led by Saroj P. Dash of Chalmers University of Technology and Stephan Roche of Campus Universitat Autònoma de Barcelona has reported a heterostructure of graphene and bismuth-based TIs. To realize the van der Waals heterostructure, the team transferred mechanically exfoliated flakes of the TI on top of photolithographically patterned graphene. The layered assembly, sitting on a highly doped silicon substrate, was topped with electrodes to complete the stack and enable spin transport measurements.

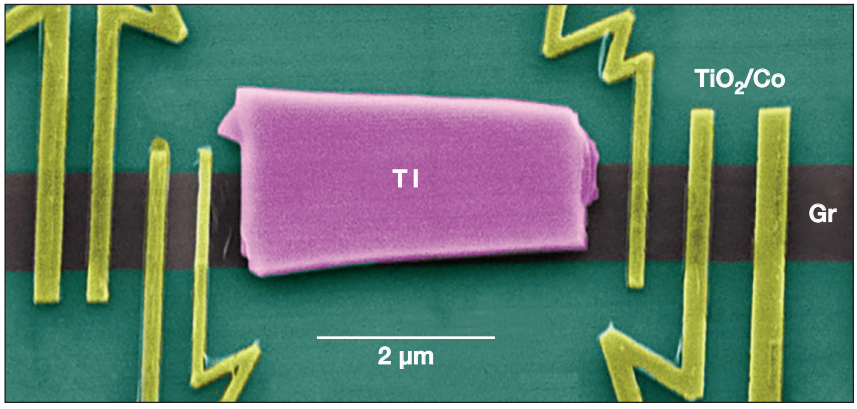
The research group studied the electronic spin lifetime and the magnitude of the spin signal. It was found that the spin lifetimes of the heterostructures were significantly reduced (22 ps for graphene:$Bi_2Se_3$ and 7 ps for graphene:$Bi_{1.5}Sb_{0.5}Te_{1.7}Se_{1.3}$) compared to pristine graphene (400–800 ps). This surprising reduction in spin lifetime was suggested to arise due to the proximity of the TI to the graphene, which induced strong SOC in the graphene layer, and is the first evidence of this phenomenon in graphene–TI structures.

Next, the spin signal was tuned by applying a gate voltage across the heterostructure. These experiments, together with theoretical understanding developed by the researchers, suggest that due to the proximity of the TI, the charge carriers in graphene gain mass, which leads to the opening of a small bandgap (ca. 2–20 meV) and the development of strong SOC. This happens owing to hybridization between the electronic bands of graphene and TI.

"Generation of a large SOC in graphene has been a long-standing goal. We modified the properties of graphene via a proximity effect. Our Dirac material heterostructure still supports spin transport while acquiring a strong SOC," Dash says. "These findings should pave the way toward creation of novel topological quantum effects and help observe new spintronic phenomena."

According to the researchers, it now becomes possible to concomitantly manipulate the electronic spin and maintain spin transport in graphene–TI heterostructures, opening the door to deployment of these structures in next-generation spintronic devices.

**Ahmad R. Kirmani**




Scanning electron microscope image of the Dirac material heterostructure. TI is topological insulator. Credit: *Science Advances*, AAAS.





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