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Press Release

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The world's smallest magnet

As illustrated in the magazine Science on the 4th of January, 2013, physicists at Hamburg University have constructed, atom-by-atom, the world's smallest stable ferromagnet composed of only five iron atoms. These magnets can be utilized in future magnetic storage technology based on atomic spin elements using their special quantum properties.

The peculiar properties of magnets have found their way into a vast number of technologies ranging from information technology to medical imaging. In terms of storage technology, a reoccurring challenge is the continuing demand for smaller "bits" the fundamental storage unit. This involves the question of how small a "stable" magnet can be; namely a magnet which maintains its orientation without flipping over a prolonged period of time. Such stability is necessary in order to store information into magnets. To store more and more information into a smaller and smaller area, extensive research has focused on shrinking such magnets with the ultimate goal of reading and writing magnetic information into single atoms. However, as magnets approach the atomic limit, they de-stabilize causing the orientation of the magnet to flip randomly, thus making it difficult to store information for meaningful periods of time. The nature of how such "nano"-magnets flip and how they react to electrical current is a key question in current research since predicted quantum behavior becomes significant. Since such nano-magnets are thousands of times smaller than typical magnets used in present technology, or more specifically, a million times smaller than a human hair, it is difficult to simultaneously fabricate such magnets and probe the magnetic properties of one such magnet at the atomic length scale. Recently technology has advanced in such a way that it is now possible to controllably fabricate nano-magnets, from the bottom-up, and simultaneously probe their individual magnetic properties. Dr. Alexander Ako Khajetoorians, Dr. Stefan Krause, Dr. Jens Wiebe, Prof. Roland Wiesendanger and collaborators have now constructed the world's smallest stable magnet and demonstrated how to probe the dynamic properties of such a magnet at the single atom level. Such magnets, composed solely of five iron atoms and assembled on the surface of copper serve as the ultimate scaling limit for hard disk drive technology.

In the laboratory of Dr. Alexander Khajetoorians, Dr. Stefan Krause, Dr. Jens Wiebe, and Prof. Roland Wiesendanger, a "spin-polarized" scanning tunneling microscope (SP-STM) is located which operates at temperatures slightly above absolute zero. With such a microscope, one can zoom in far beyond what conventional optical microscopes can "see", approaching the limit of single atoms on a surface. The power of SP-STM relies on an atomically sharp magnetic needle which can be freely positioned above single atoms and sense their magnetic orientation. Additionally, the magnetic probe tip can move single Fe atoms with atomic precision and tailor their properties, as the Hamburg team has recently demonstrated. The spin-polarized tunnel current between tip and sample allows not only for imaging the magnetic properties of a single atom, but also for investigating the response of such an atom to the injection of electronic spins. The Hamburg team has demonstrated in recent years that these methods can be used to perform atomic spin-based logical functions and implement spin fabrication to realize the analogue of LEGO® with atomic spins. Nevertheless, while such experiments present an excellent form to understand fundamental physical problems in magnetism, a lingering fundamental question has been looming for years: what is the connection between a single atom like iron, exhibiting no stable magnetic state and everyday magnets which have a stable magnetic orientation, namely a fixed north and south pole? Moreover, if such a stable magnet can be constructed at these length scales, it is important to understand, for technological developments, how such magnets respond to electrical current. The Hamburg team has now shown that as few as five iron atoms which sit on an atomically flat copper surface can be assembled into a single stable magnet and they have characterized the magnetic nature of such "quantum" magnets.

Clever schemes which utilize electrical current with a degree of spin polarization have been implemented in technology to "write" information into magnets electrically. The so-called "spin-transfer torque" effect replaces the need for bulky magnets in hard drives and allows for efficient information processing. However, as magnets are scaled to the atomic limit, quantum effects can become heavily pronounced which may dramatically modify the behavior of usual magnets, like their stability, and their response to electrical currents. The bridge between an atom, and the conventional refrigerator magnet, is a question of numbers: How many atoms are needed to stabilize the assembled magnet? Such a stable magnet should maintain a stable magnetic state for a lengthy period of time, and ultimately it should be controllable by the injection of an electrical current. People have been able to grow samples with magnets of such size, however the ability to tailor them atom by atom, and probe each one individually has been lacking so far. Moreover, a number of questions concerning how the quantum effects modify the magnetic stability have puzzled theorists for a number of years. Combining collaboration with theorists in Hamburg and Jülich, it was possible to describe the response of such a magnet, by considering quantum mechanical relaxations which are only dominant at such small length scales. As technology approaches towards these limits in the near future, the work from Hamburg clearly demonstrates how such interactions can be controlled to design stable magnets which can be switched electrically. Moreover, this research, with its ultimate combination of spatial, magnetic, and temporal resolution of individual magnetic atoms, opens up the future for the ultimate miniaturization of spin-based technology down to the atomic scale.

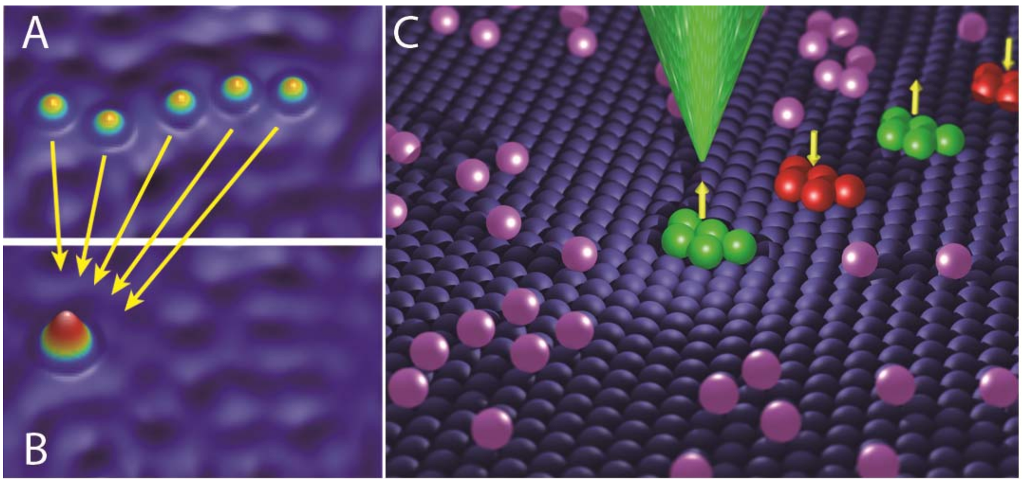

Fig. 1: A-B: Scanning tunneling microscope images of 5 individual Fe atoms on a copper surface, before (A) and after (B), construction of a stable nano-magnet. C: Cartoon illustration of how such magnets can be assembled into a miniature hard drive, where each state is read/written by an atomically sharp metallic tip of the STM which has a magnetic sensing needle at the apex.

Original publication:

Current-Driven Spin Dynamics of Artificially Constructed Quantum Magnets
A. A. Khajetoorians, B. Baxevanis, C. Hübner, T. Schlenk, S. Krause, T. O. Wehling, S. Lounis, A. Lichtenstein, D. Pfannkuche, J. Wiebe, and R. Wiesendanger,
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