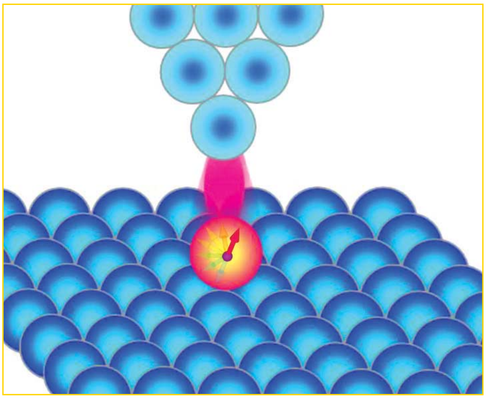
Tunneling electrons leave atom in a spin

CHARACTERIZATION



Conceptual diagram showing electrons tunneling from an STM tip through an Mn atom on a surface. Electrons above a certain energy can flip the spin of the Mn atom. (Courtesy of IBM.)

Andreas J. Heinrich and coworkers at IBM's Almaden Research Center have used a scanning tunneling microscope (STM) to measure the energy needed to flip the spin of a single atom [Heinrich *et al.*, *Sciencexpress* (2004) doi: 10.1126/science.1101077]. The ability to study individual magnetic moments could be very important for future information technologies from spintronics to quantum computing. "We will need fundamental knowledge of the magnetic properties of small numbers of atoms in various environments," says Heinrich. "Our new technique provides this information in much more detail and precision than has been possible before."

The team measured the spin excitation spectra of single Mn atoms adsorbed on Al_2O_3 islands on a NiAl surface using inelastic electron tunneling spectroscopy. Above a certain voltage, tunneling electrons transfer energy to spin-flip excitations of the Mn atoms. This additional tunneling channel results in a step increase in the conductance detected at the STM tip.

The spin excitation spectra, measured under ultrahigh vacuum at 0.6 K, shows shifts in the conductance above a certain voltage. Under a magnetic field of 7 T, the energy required to flip the spin of a single Mn atom is ~0.8 meV. This energy varies with applied field, as expected for Zeeman splitting of Mn spin states. The team was able to determine the magnetic moments of individual Mn atoms and showed that they vary depending on the atom's local environment.

The site specific study of magnetic moments, coupled with STM's ability to fabricate atomically precise structures, could provide a powerful tool for investigating the local properties of engineered magnetic nanostructures, say the researchers.

Jonathan Wood

Quantum optics on a chip

MAGNETIC MATERIALS

Getting a single photon to interact with a single atom has been a focus of atomic physics research for a number of years. Now, researchers from Yale and Indiana Universities have achieved this in a solid-state system that has many desirable features for a future quantum computer [Wallraff *et al.*, *Science* (2004) **431**, 162].

Strong coupling can be achieved between a confined photon and an isolated atom within in a cavity. This setup results in the rapid exchange of energy between the photon and atom, and the state of the system becomes a superposition of two possibilities: the energy is both an excitation of the atom and a photon.

Rather than use an atom and visible light photons from a laser, Andreas Wallraff and coworkers use a superconducting two-level system, which acts as an artificial atom, and microwave photons. A superconducting waveguide resonator confines the microwave photons to the system. A superconducting Josephson tunnel junction placed within this cavity acts as a qubit with two energy states that differ by the transfer of a single electron or Cooper pair. The energy difference can be tuned by varying the gate voltage and applied magnetic field. When the excitation energy matches the resonant frequency of the cavity, strong coupling between the photon and the qubit occurs. In this special case, transmission of microwaves through the cavity no longer occurs at the resonant frequency, but at two different frequencies reflecting the two energy states of the superposed artificial atom-microwave photon system.

The ability to couple qubits to photons could allow qubits to be wired together on a chip via a 'quantum information bus' carrying single photons, which is highly desirable for building a quantum computer.

Jonathan Wood

Ferromagnetic origins of TiO_2

MAGNETIC MATERIALS

Daniel R. Gamelin and colleagues at the University of Washington and Pacific Northwest National Laboratory have observed strong ferromagnetism at room temperature in Co^{2+}-doped TiO_2 nanocrystal films prepared by direct chemical methods [Bryan *et al.*, *J. Am. Chem. Soc.* (2004) **126** (37), 11640].

Ferromagnetic semiconductors are desirable as key components of spin-based semiconductor devices, but developments have been hindered by the cryogenic temperatures required for ferromagnetic ordering in existing materials.

Co-doped TiO_2 (Co^{2+}:TiO_2, anatase) attracted great interest when it was reported that thin films of the material are ferromagnetic above 300 K. However, the ferromagnetism is widely believed to arise from phase-segregated Co metal nanocrystals.

In order to address this issue, colloidal suspensions of Co-doped TiO_2 nanocrystals capped with trioctylphosphine oxide ligands were prepared using an inverse micelle procedure. Thin, nanocrystalline films were then produced by spin coating. These films, prepared under oxidative conditions that preclude the formation of cobalt metal, are strongly ferromagnetic. X-ray absorption studies confirm the majority of the cobalt is in the Co^{2+} oxidation state.

"These results provide strong support for the existence of intrinsic ferromagnetism in this material and bode well for the future of high-temperature ferromagnetic semiconductors in spintronic technologies," says Gamelin. The colloidal nanocrystals could be used as building blocks for the assembly of spintronic devices by soft lithography or self-assembly processes.

Jonathan Wood