cell (*6*). ATP synthase is a biological rotary motor made up of two major structural domains, F0 and F1 (see the figure). The F1 domain is composed of subunits α_3, β_3, γ, δ, and ε; the F0 domain includes one a subunit, two b subunits, and 9 to 12 c subunits arranged in a symmetrical disk. The F0 and F1 domains are linked by central stalks (subunits γ and ε) and peripheral stalks (subunits b and δ). The proton-motive force fuels the rotation of the transmembrane disk and the central stalk, which in turn modulates the nucleotide affinity in the catalytic β subunit, leading to the production of ATP. The c subunit has a hairpin structure with two α helices and a short connecting loop. The two mutations affect the membrane-spanning α helices of the ATP synthase c subunit and may restrict binding of R207910 to the enzyme. Although biochemical confirmation is now required, it is possible that the drug impedes assembly of the mobile disk or interferes with its rotational properties, leading to inadequate synthesis of ATP.

A puzzling feature of R207910 is its exceptional specificity for mycobacteria. ATP synthase is a ubiquitous enzyme found in most living organisms, including humans. There is very limited sequence similarity between the mycobacterial and human AtpE proteins, which bodes well for the safety of the compound, as borne out by the phase I study in human volunteers. The mycobacteria-specific activity of R207910 [(*3*), table S1] may also be the consequence of limited sequence similarity among bacterial AtpE proteins. However, those antitubercular agents that show highly restricted activity (such as isoniazid, ethionamide, and pyrazinamide) are all prodrugs requiring activation by a mycobacterial enzyme (*7*). Although its chemical structure gives no clues to potential activation sites, R207910 may also prove to be a prodrug.

The discovery of R207910 will generate considerable excitement and optimism among all those involved in the treatment and management of tuberculosis. Mouse studies already show that this compound can greatly shorten the duration of therapy, both alone and in association with current antitubercular agents. The DNA gyrase inhibitor moxifloxacin has recently shown similar promise in the same animal models (*8*). For the first time in many years, there is real hope of achieving the quantum therapeutic leap required to make an impact on the global TB epidemic. It is therefore of the utmost importance that R207910 should now enter phase II clinical trials. Furthermore, the equally remarkable activity of R207910 against *M. ulcerans*—the agent of an emerging human disease called Buruli ulcer (*9*), for which surgery is the only cure—also raises expectations for a safer treatment for this disfiguring affliction.

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APPLIED PHYSICS

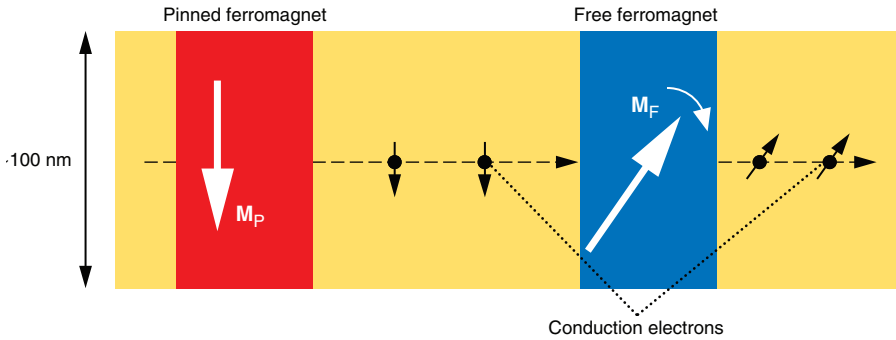
A Ringing Confirmation of Spintronics Theory

Mark Covington

Electrons possess both electric charge and angular momentum (or spin). Traditional electronic devices use only charge, but a growing class of electronic devices exploits spin. One example is the spin-dependent magnetoresistive readback sensors used in hard disk drives and in emerging nonvolatile magnetic memories. However, even more ways to use spin are being proposed for new spin-based electronics, or "spintronics" (*1*).

It has been shown that a current of spin-polarized electrons can change the magnetic orientation of a nanometer-scale ferromagnet via an exchange of spin angular momentum (*2*, *3*). This effect originates from the way in which ferromagnets align the spin of conduction electrons along the direction of magnetization. In other words, ferromagnets exert a torque that changes the electron angular momentum. Conversely, conservation of angular momentum requires a back-action torque on the magnet. Theory predicts that this torque differs fundamentally from the usual torque exerted by magnetic fields. The most direct way to test this prediction experimentally is to study the dynamical motion of a nanomagnet in response to a spin-polarized current. On page 228 of this issue, Krivorotov *et al.* (*4*) present an extensive set of dynamical measurements that elucidate this effect (see the first figure).

How does a nanomagnet respond to spin transfer? The relative orientation of the electron spins and the magnet determines whether the spin torque augments or opposes the damping torque that forces the magnet to settle into static equilibrium. Within this scenario, two competing models predict very distinct behavior when spin transfer reverses, or switches, a nanomagnet. The spin-torque model predicts that nanomagnets respond coherently to spin-polarized electrons (*3*). Depending on the strength of the spin torque relative to the damping, three different types of dynamical states can



Schematic of the "nanopillar" structure used by Krivorotov *et al.* (*4*). Electrons polarized by the pinned ferromagnet exert a torque on the free ferromagnet. At these nanoscale dimensions, spin transfer dominates over the magnetic field produced by the moving electrons, and the large current densities that are necessary to induce a response are easily achieved. Motion of the free layer magnetization, $\mathbf{M}_F$, is monitored through the resistance, which depends on the relative orientation of $\mathbf{M}_F$ and the pinned-layer magnetization, $\mathbf{M}_P$. The resistance continuously varies from low to high resistance as $\mathbf{M}_F$ and $\mathbf{M}_P$ go from parallel to antiparallel, respectively.

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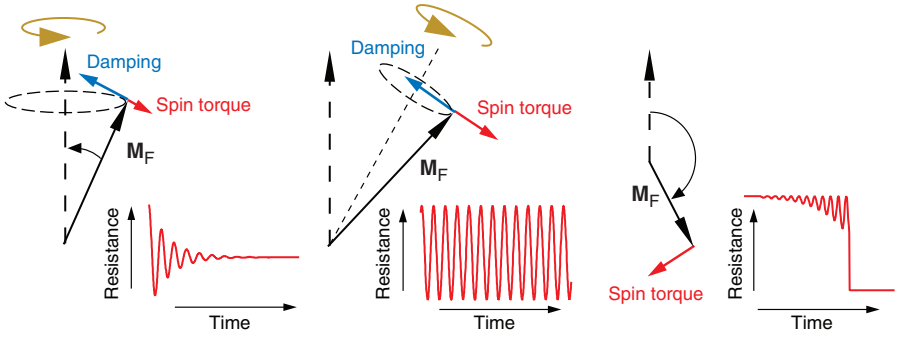
occur (see the second figure). Reversal occurs through spatially and temporally coherent precession of the magnetization. Another model proposes that spin transfer induces incoherent, short-wavelength magnetic oscillations that mimic what would happen if the magnet got hot (*5*, *6*). The magnetization then switches in a stochastic manner akin to a thermally activated process.

The experiments of Krivorotov *et al.* provide direct evidence for the coherent switching process predicted by the spin-torque model. When a sufficiently large current pulse is sent through a nanomagnet, such that the spin torque opposes the damping, the forces that keep the magnet settled along a particular direction are overcome, and the magnet starts to rotate in response to the driving torque from the electrons. The electrons continually impart angular momentum to the magnetization before the precession has a chance to die down. The amplitude of this oscillation, or "ringing," increases until the magnet reverses its direction (see the second figure, right panel). Larger currents drive this switching process even faster. This is what Krivorotov *et al.* observe experimentally.

Spin transfer also affects the magnetization dynamics below the switching threshold. Situations can occur where the spin torque effectively counterbalances damping. In this case, the magnet neither switches nor settles back into equilibrium but instead rings indefinitely (see the second figure, middle panel). Hence, a dc current can drive microwave oscillations, which can potentially be used as microwave source.

Krivorotov *et al.* observe this steady-state precession, confirming previous measurements (*7*–*9*). Moreover, they show that the magnetic precession is synchronous with the current pulse and can quickly wind up to its full amplitude in only a few periods (less than 1×10^{-9} s). Finally, they demonstrate that a dc current can affect the time it takes for the magnetization to settle into static equilibrium (see the second figure, left panel). These data provide clear proof of the spin-torque model by demonstrating that spin transfer can continuously tune the magnetic damping and induce coherent magnetic motion.

The precise, deterministic magnetic motion induced by spin transfer is already being explored for use as tunable magnetic-based microwave oscillators in logic and communications applications (*8*). Magnetic memory is another application for which spin transfer seems well suited. In addition to its ability to switch a magnet between bistable states (that is, either a "0" and a "1"), switching with spin transfer is more efficient than with magnetic fields at nanoscale dimensions. Because miniaturization is required to achieve higher performance and lower cost in solid-state electronics, spin transfer has the potential to replace field-driven switching in magnetic memory and enable ever higher storage capacity.



Dynamical regimes where spin transfer opposes damping. (**Left**) When the spin torque is smaller than the damping torque, precession is quickly damped and the magnet settles into static equilibrium (dashed arrow). The time scale of the damping can be tuned continuously by the current. (**Middle**) When the spin torque and the damping torque are effectively equal and opposite over a precessional orbit, persistent precession occurs. (**Right**) When the spin torque is larger than the damping torque, the precession increases in amplitude until the magnetization completely reverses direction.

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CHEMISTRY

Odd Electron on Nitrogen: A Metal-Stabilized Aminyl Radical

Wolfgang Kaim

Carbon- and oxygen-centered organic radicals were once considered chemical curiosities or, at best, reactive intermediates. However, in recent years some of these molecules have received widespread attention beyond chemistry—for example, as spin carriers in materials science (*1*) or as reaction sites in biology (*2*–*7*). Stable organic radicals with the unpaired ("odd") electron centered on nitrogen have received less attention, although some examples have been known since the late 19th century. On page 235 of this issue, Büttner *et al.* (*8*) report the first isolation and unambiguous characterization of an aminyl ($NR_2^{\bullet}$) radical stabilized by metal coordination.

Radical cations of nitrogen-containing amino acids such as tryptophan or histidine have recently been discussed in connection with electron transfer in cytochrome c peroxidase (*6*) and photosystem II of photosynthesis (*7*). Aminyl radicals ($NR_2^{\bullet}$, where R is an aryl or alkyl) are the most elementary class of nitrogen-centered organic radicals. An earlier report of their stabilization through metal coordination was proven erroneous because of intramolecular reduction to an amide (NR_2^-) ligand (*9*, *10*). After that false start, Büttner *et al*. now demonstrate (*8*) that an aminyl radical can indeed be stabilized by metal coordination.

The chemical properties of aminyl radicals are intermediate between those of alkyl radicals ($CR_3^{\bullet}$) and aryloxy species ($OR^{\bullet}$ with R = aryl). Alkyl radicals have essential biochemical roles, for example as $CH_2R^{\bullet}$ in coenzyme B_{12}–dependent processes (see the figure, top left panel) (*3*). Aryloxy species also have established functions in oxidation reactions (see the figure, bottom right panel) (*4*, *5*), photosynthesis (*7*), and DNA synthesis (*6*). In almost all cases, the radicals are accompanied by transition metal ions, which can activate and control these reactive species through electron transfer. Aminyl radicals

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