vore reintroductions? The *IUCN Guidelines for Reintroductions* (*16*) emphasizes that prior to a reintroduction "the void created by the loss of the species" must be thoroughly assessed, including the effect that it would have on the ecosystem. We are aware of the problem, but how do we solve it? Should live carnivores be used to precondition prey, and if so, which predator species should be involved? How many predators will be needed for effective teaching of naïve prey? What should be done when prey fail to respond to preconditioning in an appropriate manner? The future of predator and prey populations, which are both threatened by the inevitable processes of extinction, rests with understanding not only current extinction threats but also the historical interactions between predator and prey species.

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PERSPECTIVES: APPLIED PHYSICS

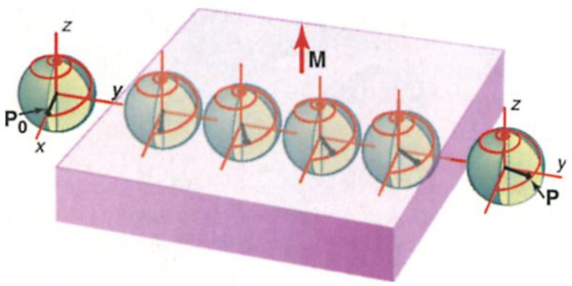
A New Twist for Magnets

Dan Ralph

The manipulation of magnets with electrical currents is an integral part of everyday technology. It is the operating principle behind electric motors and determines how information is written onto magnetic-memory devices such as computer hard drives. The underlying physical mechanism has been understood since the early 1800s: Moving electric charges generate a magnetic field, which exerts a force on a magnet.

A surprising realization has recently emerged in this seemingly mature field. There is a second, fundamentally distinct mechanism by which an electric current can reorient a magnet, and for very small devices, this mechanism can be much more powerful than current-induced magnetic fields. The new mechanism, known as spin transfer, is based on the interaction of a magnet with the intrinsic spin of an electron, rather than with the electron's moving charge. On page 1015 of this issue, Weber *et al.* (*1*) report direct measurements of this spin-dependent interaction between an electron and the elemental ferromagnets iron, cobalt, and nickel.

Berger (*2*) and Slonczewski (*3*) first proposed such a spin-transfer effect. If an electron travels through a thin film of magnetic material, the magnet exerts a torque on the electron, tilting its spin. According to Newton's Third Law, the electron must exert an equal and opposite torque on the magnet, which causes the magnet's moment vector (the direction from its south to north pole) to tilt as well. The effect is called spin transfer because spin angular momentum is delivered from the electron to the magnetic material. The torque produced by a single electron is very small, but if all the electrons in a current are spin-polarized such that their spins all point in the same direction, then the sum of their contributions can produce a substantial torque on the magnet.



Schematic geometry of the experiment of Weber *et al.* When an electron passes through a magnetic thin film, the electron's spin precesses about the direction of the magnetic (**M**) moment of the film. At the same time, the electron spin direction also relaxes toward the spin direction of the majority electrons in the magnet. This means that the magnet and the electron apply spin-dependent torques on each other. $\mathbf{P_0}$ is the original electron spin direction; **P** is the electron spin direction after it has passed through the thin film.

The existence of this effect was demonstrated recently in layered metallic devices (*4–8*). Electrons were first passed through a magnetic layer that acted as a spin filter to produce a partially polarized current. This current then produced a torque on a second magnetic element downstream. Depending on the device geometry and experimental conditions, the spin-transfer effect either can excite a dynamical state, in which a magnet's moment vector precesses continuously at frequencies of tens of gigahertz (*4*, *6–8*), or it can cause simple switching of the magnet from one direction to another (*5–7*, *9*).

Weber *et al.* (*1*) use a different experimental setup that permits quantitative measurements of the torque generated by an electron as it traverses a magnetic thin film. They use photoemission by circularly polarized light to eject fully spin-polarized electrons from a semiconductor cathode into a vacuum. These electrons are collected into a beam with an energy of a few electron volts and are shot through a suspended magnetic film that is a few nanometers thick. The original orientation of the electron spin polarization is selected to be perpendicular to the magnetic moment of the thin film (see the figure). By measuring the spin direction of the electrons that have passed through the film, the torque exerted by the magnet on the electrons can be determined. The (equal-and-opposite) torque of these electrons on the magnet is then also known.

Weber *et al.* can distinguish two separate effects: precession of the electron spin in a circle about the magnet's moment due to the exchange interaction inside the magnet and a simultaneous relaxation of the electron spin toward the magnet's moment due to spin-dependent scattering of electrons in the magnet (see the figure). Experiments as a function of magnetic film thickness allow both processes to be characterized with high accuracy. The torques are sufficiently strong that in a well-designed solid-state device, with current densities on the order of 10^{13} A/m^2, current pulses shorter than 10 ps

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should induce precessional magnetization reversal of a ferromagnetic device element.

Spin-transfer torques may allow magnets to be manipulated in ways that are impossible with traditional magnetic fields. Potential applications in high-density magnetic-memory devices, for instance, computer random access memory, are particularly exciting. As memory elements are scaled to sizes well below 1 μm, it is proving very difficult to control the orientation of the magnetic bits with the use of magnetic fields. On such small scales, very large current densities (approaching destructive levels) are needed to generate magnetic fields strong enough to produce magnetic switching. Furthermore, these fields decay slowly with distance, making it difficult to switch one magnetic element without disturbing its neighbors. Spin transfer has neither of these drawbacks. The spin-transfer effect can produce stronger torques per unit current than current-induced magnetic fields in devices much smaller than a micrometer, and spin-transfer torques extend only over atomic length scales. The additional ability of the spin-transfer effect to generate and control oscillations in magnetic materials in the tens of gigahertz range also opens possibilities for applications in high-speed logic and communications.

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RETROSPECTIVE IN SCIENCE

Louis Néel (1904–2000)

Bernard Barbara and Claudine Lacroix

Louis Néel, perhaps the last pioneer of classical magnetism, died on 17 November 2000 in Brive in southwestern France, where he had rejoined his daughter Marguerite a year before.

Louis Néel was born in Lyon on 22 November 1904. He studied at the Ecole Normale Supérieure in Paris before moving to Pierre Weiss' laboratory at Strasbourg University, where he began his studies of magnetism. Enlisted in 1939 to help improve the French naval defense, he invented an effective method for protecting ships against magnetic mines. Thousands of soldiers were saved from dying in magnetic mine explosions in the Channel. After the Armistice of 1940, Néel joined the University of Grenoble. In 1946, he received funds from the Centre National de la Recherche Scientifique (CNRS) to establish the Laboratoire d'Electrostatique et de Physique du Métal, the first CNRS laboratory outside Paris. Néel became its director. The laboratory expanded rapidly and in 1970 was divided into separate laboratories for the study of electrostatics, very low temperatures, thin films, crystallography, and magnetism. After Néel's retirement in 1976, the Magnetism Laboratory was renamed "Laboratoire Louis Néel." Ph. Nozières moved from Paris to replace him at the university. Having feared brain drain to the capital at the beginning of his career, Néel had succeeded in reversing the tendency.

Néel created and led numerous laboratories in Grenoble and contributed to the decision to install the Nuclear Research Center of Grenoble (CENG), the Institut Laue-Langevin (the European neutron scattering facility), and the European Radiation Synchrotron Facilities (ESRF) in Grenoble. Néel was also a member of the Board of Directors of the CNRS from 1949 to 1969, a scientific adviser to the French Navy since 1952, and the French representative at the Scientific Committee of NATO from 1956 to 1957 and 1960 to 1980. He received an impressive collection of French and foreign distinctions and honors.

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After his arrival in Grenoble in 1940, Néel started to work with a few students on new research directions such as the magnetism of thin films and the random aspects of magnetic hysteresis. In 1947, he generalized his theory of antiferromagnetism, building on earlier work in Strasbourg. His theory of ferrimagnetism allowed the properties of ferrites and garnets to be understood. The applications of these systems, for example, in lasers, filters, and power attenuators, still have a large impact on our society. In 1970, Néel was awarded the Nobel Prize in physics for these discoveries. The research directions initiated by Néel and his collaborators are still active. For example, the magnetism of thin films and fine particles is now intensely studied under the name of nanomagnetism, and the random aspects of hysteresis have led to the physics of disordered systems.

An important aspect of Néel's style was his broadmindedness. Besides physics, Néel contributed to the development of other disciplines such as applied mathematics and computer science. He also fostered strong relationships with industry that continue today. With his communicative passion for research, he inspired his former students, and their students, with an eagerness that is not ready to fade.

At the height of his career, Néel greatly impressed young researchers, so great was his prestige and so elegant his manner. But beyond the severe appearance and through occasional remarks, one could catch a glimpse of the enthusiastic, nonconformist, progressive man. During one of the weekly seminars for young physicists that he organized at the Laboratory of Magnetism, he blurted out "If I were you, I could not go to sleep before managing to explain this phenomenon." To a boisterous colleague, he said "you remind me of myself when I was young." But Néel did not easily commiserate with his researchers when it came to working conditions. In the "heroic" 1950s, he refused to buy a stove for one of the labs although the room temperature was only 14°C, arguing that it was good for the health. He readily agreed to buy the stove when he realized that the measurements were not accurate at this temperature.

In his memoirs (*1*), Louis Néel said that research and human or family relationships cannot be put on an equal footing and that he would have been as satisfied with his lot living as a country lawyer with his wife (*2*). Nevertheless, physics and magnetism played an essential role in his life until the last moment. The day before his death, Néel was preparing a TV programme for the Academy of Science; at 95, he still had lucid views on most important questions.

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2. In 1931, Louis Néel married Hélène Hourticq. They had three children, Marie-Françoise, Marguerite, and Pierre.

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