nature of the decay mechanism remains a matter of debate in the literature (*6*). This represents the sum total of our current knowledge of ground state two-proton decay processes.

In 2000, experiments at the GANIL laboratory in France directly detected the existence of the highly exotic isotope ^{48}Ni (*7*). This isotope is thought to be a prime candidate for two-proton radioactivity because its ground state is predicted to be energetically unbound to the simultaneous emission of two protons, but bound to the emission of a single proton. Calculations generally assume a binary model of ^{48}Ni consisting of an inert nuclear core and two outer protons that form a pointlike ^{2}He cluster. According to this model, the ^{2}He cluster quantum tunnels through a potential energy barrier and then decays into two protons outside the barrier. However, theoretical objections have recently been raised to this simple approach (*8*). A more sophisticated theoretical approach based on an explicit three-body democratic decay model of the simultaneous two-proton emission process suggests that the probability of two-proton emission is reduced substantially compared with the pure ^{2}He emission calculations (*8*), in which case ^{48}Ni may decay by β-emission instead. It should be noted that this more sophisticated theoretical approach allows for a ^{2}He component in the decay process because it is one possible scenario for nonsequential two-proton emission.

Given the paucity of information on the ground state two-proton decay mechanism, nuclear physicists have sought to study excited states of nuclei that are two-proton unbound. Unfortunately, in all cases studied to date, these states have preferred to decay by the sequential emission of protons. For example, in work at the Louvain-la-Neuve Laboratory in Belgium, a radioactive ^{13}N beam was used to bombard H atoms and thereby populate an excited state of ^{14}O. A two-proton emission decay branch was identified, but a path for decay by sequential emission was also available and this is what the nuclei overwhelmingly decided to do (*9*).

Physicists at the Oak Ridge National Laboratory have been developing a ^{17}F radioactive beam. They recently used this beam to bombard H atoms to produce two-proton unbound excited states in the fused compound nucleus ^{18}Ne (*10*). These excited states cannot decay sequentially because there are no allowed paths in the appropriate energy region for this process to occur. The observation of a two-proton decay branch in this system would therefore have to be attributed to simultaneous two-proton emission.

This year, the Oak Ridge Group reported the observation of such a simultaneous two-proton decay branch (*3*) from one of the excited states in ^{18}Ne. Monte Carlo simulations of the energy and angular distributions of the two protons are consistent with either the binary model described above or a three-body democratic decay process.

Is this state democratic or tyrannical (that is, dominated by ^{2}He emission)? The researchers at Oak Ridge plan to resolve this mystery by using a larger detection system. A pure ^{2}He decay component would be a major surprise and would be indicative of a larger than expected ^{2}He cluster component in the nuclear wave function. If this is the case, then one needs to ask whether this could be observed in many other two-proton unbound nuclear states, and if not, what is so special about ^{18}Ne?

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10. When two nuclei collide, they initially fuse to form a single composite system known as the compound nucleus, which subsequently de-excites, in this case by the emission of two protons.

PERSPECTIVES: ECOLOGY AND EVOLUTION

The Risk of Extinction—What You Don't Know Will Hurt You

John L. Gittleman and Matthew E. Gompper

Ecological circumstances, such as living on an island or in a pristine habitat, often lead to an unusually high level of predation among prey populations when predators are reintroduced. For example, Darwin was able to collect a specimen of the now extinct Falkland Island wolf simply by walking up to one and killing it. Indeed, 81% of known mammalian extinctions during the last 500 years have been among mammals endemic to island habitats (*1*). The most powerful illustration of how naïveté to danger may lead to elimination comes from the extinctions of the late Quaternary, during which more than half of the 167 genera of large land mammals (>44 kg) became extinct, primarily because of the rapid and catastrophic effects of "first contact" with colonizing human hunters (*2*). Currently, many of the world's large terrestrial carnivores are threatened with extinction. But conservation efforts to reintroduce carnivores to their original habitats have met with concern because of the possible drastic reduction in naïve prey populations. An elegant study by Berger and colleagues (*3*) on page 1036 of this issue investigates whether ignorance of danger (naïveté) should be added to the "Evil Quartet" of extinction causes—habitat destruction, overexploitation, introduced species, and secondary extinctions (*4*).

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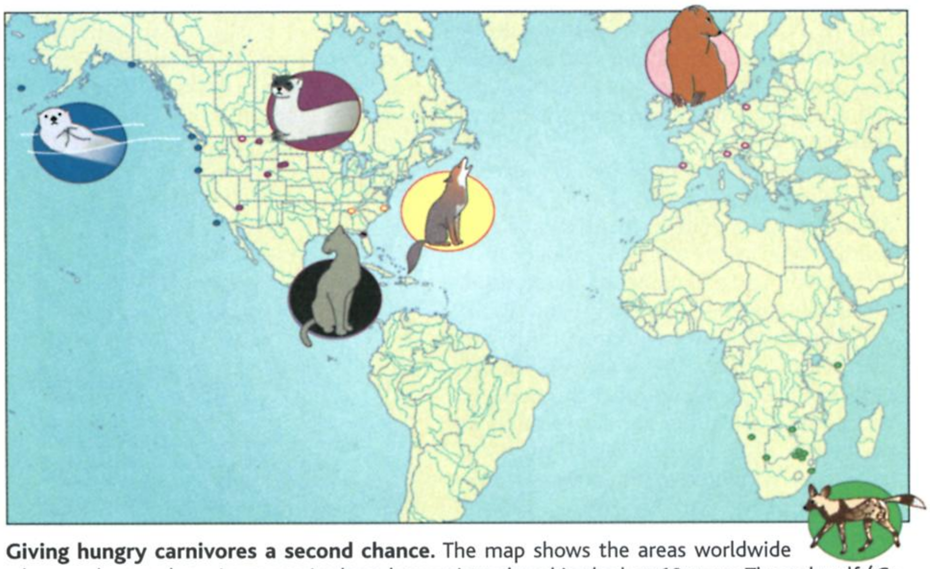
J. L. Gittleman is in the Department of Biology, University of Virginia, Charlottesville, VA 22904, USA. E-mail: JLGittleman@virginia.edu M. E. Gompper is at the Center for Environmental Research and Conservation, Columbia University, New York, NY 10027, USA. E-mail: meg75@columbia.edu

With the local extirpation of increasing numbers of carnivore species, recolonization and reintroduction efforts are commonplace. Many species are even being introduced into areas where they did not previously roam. For predatory carnivores, such as grizzly bear and wolf, a very conservative estimate is that there have been 173 independent introductions worldwide, about 19% recorded on continents, 18% on continental shelf islands, and 63% on islands (*5*). Given the fragility of island populations, this does not bode well for long-term ecological success. More appropriate to the goals of conservation are reintroduction programs in which species are reestablished in their historical range. But even these projects have their problems. First, of the 165 carnivore reintroduction programs carried out so far (*6*), only 28 involve threatened species (see the figure). Second, according to the published opinions of those working on these projects, 70 of the 165 (42%) have been successful, 44 (27%) have failed, 12 (7%) still have uncertain outcomes, 15 (9%) are in the release phase, and 24 (15%) have not been evaluated. Last, and most relevant here, none of the carnivore reintroduction projects have assessed how prey populations respond to the reintroduction of predator species. The effects of worldwide carnivore expansion on prey populations that have lost, or never had, the capacity for predator vigilance could be quite devastating. Thankfully, Berger and co-workers (*3*), in their study of the response of endemic moose populations in North America and Scandinavia to the reintroduction of wolf and grizzly bear, demonstrate that previously naïve moose are remarkably quick learners.

Predation is the primary cause of mortality in many species (*7*). The percent mortality among large herbivores—such as buffalo, springbok, and wildebeest—by predators in natural ecosystems in Africa ranges from 59 to 96% (*8*). Given the various biological and anthropogenic forces that act on prey—particularly ungulates (hoofed mammals)—these taxa should be highly threatened. According to data in the *1996 IUCN Red List of Threatened Animals* (*9*), of the 26 mammalian orders, five contain a greater number of threatened species than expected (*10*). Two of these five orders—the Artiodactyla (pigs, hippos, deer, and antelope) and the Perissodactyla (horses, rhinos, and tapirs)—constitute the ungulate prey of large carnivores. Furthermore, a markedly higher proportion of ungulate species compared with other mammalian taxa have become extinct in the past 500 years (*11*). All of these numbers add up to a greater sensitivity of ungulate prey to extinction risk. Could prey naïveté, coupled with increasing colonization by carnivores around the globe, lead to an extinction Blitzkrieg of ungulates?

In their field observations of moose populations in multiple independent locales, Berger *et al.* (*3*) demonstrate how rapidly and resolutely antipredator responses can be gained and lost. In central Alaska, where grizzly bears, wolves, and moose have continuously lived together for millennia, moose were extremely sensitive to olfactory signals or vocal signs of predators. Even the calls of ravens, sometimes associated with the presence of large carnivores, resulted in markedly increased vigilance among the moose (*12*). In contrast, further south in Wyoming's Grand Teton National Park, moose that had been isolated from wolves and grizzly bears for no more than 75 years, or about 10 moose generations, were devoid of any ability to detect predators. These moose ignored playbacks of wolf howls and the odor of wolf and grizzly bear urine and feces.

The rapid loss of the capacity to perceive signs of dangerous predators by the Grand Teton moose is intriguing. This loss occurred despite a long evolutionary history of coexistence between prey (moose) and predators (wolves and grizzly bears) in this area. The Berger *et al.* data also indicate how such psychological and behavioral naïveté can be devastating once predators return. They report that in Jackson Hole (part of the Grand Tetons), which was recolonized by grizzly bears in 1996, at least 10 moose kills have been recorded in the 5 years since reintroduction (*3*). By contrast, in nearby Yellowstone National Park, where grizzly bears and moose have coexisted for the last 100 years, no predation on moose was observed between 1959 and 1992 (*13*). This clearly indicates the susceptibility of naïve prey to new predators. The return of large carnivores is not uniformly deleterious, however. Berger and co-workers clearly show that prey seem to quickly relearn an appropriate response to a predator: For moose mothers in the Grand Tetons, the loss of an offspring during the first wave of predation by reintroduced wolves resulted in a sudden and marked hypersensitivity to wolf howls. It is this ability to withstand the initial wave of recolonizing predators that has allowed moose populations in North America and Scandinavia to survive a Blitzkrieg.



Giving hungry carnivores a second chance. The map shows the areas worldwide where endangered carnivore species have been reintroduced in the last 10 years. The red wolf (*Canis rufus*) has been reintroduced into North Carolina and the Southern Appalachians (yellow dots); the African hunting dog (*Lycaon pictus*) to South Africa, Namibia, Zimbabwe, and Kenya (green dots); the mountain lion (*Felis concolor*) to Northern Florida (black dot); the sea otter (*Enhydra lutris*) to Alaska, British Columbia, Washington, Oregon, and California (blue dots); the black-footed ferret (*Mustela nigripes*) to Wyoming, Montana, the Dakotas, and Arizona (maroon dots); and the grizzly bear (*Ursus arctos*) to Poland, Austria, France, Italy, and Montana (pink dots).

Given that recolonization is a fundamental goal of conservation biology, what is the psychological component that should be considered for programs that involve prey populations, either directly when potential prey are reintroduced to an area, or indirectly when predators are returned to a habitat already containing prey? Should prey be preconditioned to avoid predation? Prior to prey reintroductions, predator avoidance conditioning has been shown to increase prey survival (*14*). But for predator reintroductions, it may not be necessary to condition potential prey populations, given the speed with which they learn to detect predators. Are immediate prey extinctions likely? Probably not, as long as the population is able to sustain the first wave of predation while it learns predator-avoidance behaviors. The real effects of predator reintroductions are a matter of numbers. Small prey populations may not be able to sustain the impact of the first wave of predation in addition to the possible additive effects of a new predator in the system. So, if a prey population is already reduced for some other reason, quick learning skills will not help. The initial dramatic impact that returning predators might have on a robust prey population is unlikely to be sustained. Hence, as long as the prey population is large enough, predator reintroductions should not result in extinction of prey.

Like most ecological and evolutionary problems, extinctions rarely have a single cause. Extinction results from a series of factors, interactions among factors, and the multiplicative effects of these interactions (*15*). As humans increasingly transform prey populations through the reintroduction of carnivores, the capacity of prey to quickly learn antipredator behaviors will become even more critical. How should we intervene? Should conservation planners precondition prey prior to carni-

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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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17. We thank U. Breitenmoser, K. Holt, and K. Jones for suggestions.

PERSPECTIVES: APPLIED PHYSICS

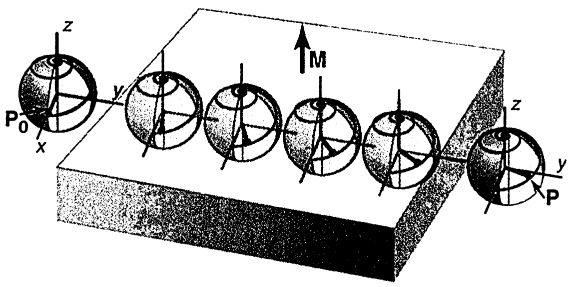
A New Twist for Magnets

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

The author is in the Physics Department, Cornell University, Ithaca, NY 14853, USA. E-mail: ralph@ccmr.cornell.edu