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species after millions of years of divergent evolution (7) testifies to its importance in parasite survival. Perhaps the HCT signal is also conserved in other intraerythrocytic protozoan parasites. From an evolutionary standpoint, it is intriguing that the vast majority of proteins targeted to the host cell are encoded in the subtelomeric domains of chromosomes. Because these domains are dynamic (8), they are ideally suited to harboring genes involved in host-parasite interactions, allowing adaptation to a particular host.

The next step is to isolate factors interacting with the HCT signal and to investigate their contribution to the transport

process. A simple model would be a translocon, which selectively recognizes proteins and transports them across the PVM (see the figure). Such a model is easy to imagine for the transport of soluble proteins, but is difficult to reconcile with the transport of transmembrane proteins. However, it seems that PfEMP1, at least, travels in a soluble form through the parasite's secretory system and only enters a membrane-bound state after translocation across the PVM (9). Much remains to be done to elucidate protein-sorting mechanisms in *Plasmodium*, but it is increasingly clear that lessons can be learned from this fascinating parasite, distinct from its star-

ring role as an agent of human disease and misery.

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Fig. S1

10.1126/science.1107072

APPLIED PHYSICS

Mesmerizing Semiconductors

Gerrit E. W. Bauer

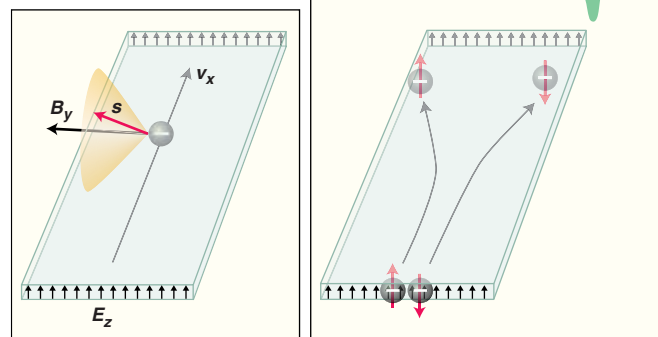
Since the Renaissance, physicians have used ferromagnets as a therapeutic tool, believing in the beneficial effects of their mysterious stray magnetic fields. Franz Anton Mesmer (1) discovered that he could magnetize (“mesmerize”) his patients even without using magnets. Recently, Kato *et al.* have performed a similar feat: They have magnetized nonmagnetic semiconductors without ferromagnets (2, 3). On page 1910 of this issue (4), they report that this magnetization can flow. The observations confirm earlier predictions (5–9). They do not require a completely new type of magnetism, but many details remain mysterious.

The electron has a charge and a magnetic moment, the spin. In a few materials (such as iron, cobalt, and nickel), the spins align below a certain temperature to create a macroscopic magnetic moment. Such ferromagnets are used, for example, in information storage devices. The young field of spintronics aims to also employ the electron spin in semiconductor-based microelectronic devices. Unfortunately, semiconductors resist direct injection of spins through ferromagnetic contacts.

Theoreticians proposed possible alternative routes. It was predicted, for example, that in some nonmagnetic conductors, an electric current would excite a magnetization (10). The magic ingredient is the relativistic interaction between the spin and the motion of the electron (spin-orbit coupling). Electrons moving in a magnetic field experience an electric field. Similarly, electrons

moving in an electric field experience a magnetic field. This internal magnetic field tends to align the spins, but they precess like a top, maintaining a constant projection along the direction of the magnetic field (see the figure, left panel). As electrons scatter at defects and impurities, the magnetic field fluctuates. On average, only those spins accumulate that are aligned normal to the electric current. In piezoelectric materials such as III-V semiconductors, the electric field can be generated by a built-in strain (2–4). The theory is complicated, but sometimes reduces to the simple picture sketched above (11, 12).

In their recent studies, Kato *et al.* (2, 3) realized these theoretical ideas. The authors monitored the spin



Spins at the edge. (Left) Electrons moving with velocity v_x in an electric field E_z experience a spin-orbit coupling that causes a top-spin precession (yellow cone), with constant projection on the internal magnetic field $B_y = v_x \times E_z$ (black). (Right) The spin Hall current is caused by the separation of up and down spins due to the spin-orbit interaction. Kato *et al.* (4) report that the z -component of the spin accumulation (s_z , green) peaks at the edges as a result of the spin Hall current. They previously showed that the y -component of the spin accumulation (s_y , blue) is constant across the sample (3).

accumulation with a noninvasive optical spectroscopy technique that can resolve, both spatially and temporally, the spins that are aligned with the probing light beam. They investigated thin GaAs and InGaAs films that are lightly doped to maximize the lifetime of the spins. In (2), the authors confirmed the existence of the internal magnetic field in strained GaAs by observing the precession of an optically injected spin accumulation. In (3), they detected the current-induced spin accumulation in strained InGaAs.

The observed magnetization is believed to differ fundamentally from the one that is injected into metals by ferromagnetic contacts. It is, for example, not accompanied by a spin current (13)—that is, a net flow of spin angular momentum—in the field direction.

The flow of information encoded by spins is, however, an essential ingredient of spin-

tronics applications. The prediction of the spin Hall effect—that is, a net flow of spin momentum normal to the driving current (see the figure, right panel)—has therefore attracted a lot of attention. An “extrinsic” spin Hall effect can occur when impurities with strong spin-orbit interaction deflect the up and down spin electrons to opposite edges of the sample (5–7). More recently, two groups predicted “intrinsic” spin Hall effects for semiconductors that do not require impurities. Sinova *et al.* (8) examined finely layered structures, in which carriers are lo-

The author is at the Kavli Institute of NanoScience, Delft University of Technology, Delft, Netherlands. E-mail: g.e.w.bauer@tnw.tudelft.nl

calized at the interfaces between semiconductors but are free to move in lateral directions (the two-dimensional electron gas). Murakami *et al.* (9) considered empty states (holes) in the valence band. The latter system is more complicated, but its phenomenology fits the simple picture sketched above.

In the present work (4), Kato *et al.* focus on the spin accumulation in thin films of doped GaAs and strained and doped InGaAs layers in the presence of an electric current. They observe a component of the spin accumulation that is normal to the film and strongly localized at the edges (see the figure, right panel). The data provide strong evidence for the existence of the spin Hall effect. The spin Hall current is blocked at the edges, where the spins accumulate. The same impurities that create the spin Hall current dissipate the spin accumulation that diffuses back into the film (7), on a length scale that can be estimated by inspecting the image of the spin accumulation (4).

The results for the two semiconductors are very different, highlighting the importance of differences in band structure and strain field. The direct proof for an internal field in the

strained InGaAs film makes this material a candidate for the intrinsic spin Hall effect. Nevertheless, Kato *et al.* suggest that it is extrinsic, because the effect is small and no dependence on crystal direction is observed. Hence, in the present samples, the intrinsic Hall effect appears to be suppressed by the scattering from impurities and defects.

The experiments reported by Kato *et al.* (2–4) provide an unprecedented glimpse into a new magnetic effect, but many open questions remain. For instance, there is no consensus among theoreticians about the resilience of the intrinsic spin Hall effect to defect scattering (14), and some voice doubts about the concept of a spin current in the presence of spin-orbit interactions.

It should be very interesting to repeat the present experiments on hole-doped samples with a larger internal magnetic field. Such experiments may confirm the observation of the intrinsic spin Hall effect in the two-dimensional hole gas (15) or test theories that predict a more robust effect in the valence band (16). Another big challenge also remains: To fulfill the promises of spintronics, scientists must transform the novel spin

accumulation and spin currents into voltage differences and charge currents in micro- or nanoelectronic circuits.

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PHYSIOLOGY

Turning on a Dime

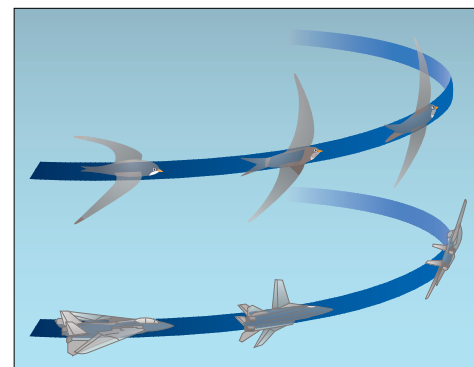
Ulrike K. Müller and David Lentink

Scientists may think that insects are the masters of unconventional lift (1–4), but it seems that birds have caught on to the same trick, using it to outsmart their insect prey. On page 1960 of this issue, Videler *et al.* (5) report how swifts—agile aerial hunters that catch insects on the wing—produce unconventional lift: They use their wings to generate a so-called leading-edge vortex. Biologists first caught on to this vortex in 1996 when trying to explain how insects fly (1). Since then, this vortex has been observed again and again in flying insects (2–4). The new study reveals that a bird's wing also can generate this type of vortex (5).

A leading-edge vortex forms on the top of a wing when the angle between the wing and the oncoming air flow is large. The flow then separates from the wing at the leading edge and rolls up into a vortex. To form a leading-edge vortex at lower angles of attack, some wings have a sharp rather than blunt leading edge. To exploit this vortex, the

flying animal needs to keep the vortex close to its wing. Insects and swifts have found different solutions to this problem. To stabilize the vortex, flying insects beat their wings rapidly (1), whereas gliding swifts sweep their wings backward (5). The leading-edge vortex spirals out toward the tip of the wing, adopting the shape of a tornado. Like a tornado, the air pressure in the core of the vortex is low, sucking the wing upward and sometimes forward (during flapping).

Swifts have scythe-shaped wings that consist of a long curved hand-wing, which is attached to the body by a short arm-wing. The hand-wing is composed of primary feathers, which form a sharp and swept-back leading edge. Both features help to generate and stabilize a leading-edge vortex. Videler *et al.* cast a model of a single swift wing in fast gliding posture and recorded the flow fields around the wing in a water tunnel using digital particle image velocimetry. (Flow patterns in water are the same as in air as long as the same Reynolds number is used.) They observed that a vortex forms on top of the wing close behind the wing's leading edge. This leading-edge vortex is robust against changes in flow speed and angle of attack—observations that agree well with those of other biologists studying the leading-edge



On the wing. Swifts are aerial hunters, catching flying insects on the wing. To outmaneuver their agile prey, swifts are able to fly fast and to make very tight turns. To maximize flight speed as well as maneuverability, evolution and aeronautic engineering converged on the same solution—variable wing sweep. Swifts (**top**) and the Tomcat jet fighter (**bottom**) keep their wings swept back to reach high flight speeds. To execute tight turns, both flyers reduce their wing sweep.

vortices of insects. However, surprisingly, the swift wing produces such a vortex at angles of attack as small as 5°, compared with 25° to 45° typical for insects (6, 7).

The achievements of aerospace engineers have inspired biologists to study the aerodynamics of flying animals. Engineers first discovered the extraordinary amount of lift that leading-edge vortices produce when they solved the problem of how to land supersonic fighter jets and passenger aircraft like the Concorde. Swept-back wings not

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The authors are in the Department of Experimental Zoology, Wageningen University, the Netherlands. E-mail: ulrike.muller@wur.nl