where the level spacing $\hbar\omega_c$ is too small, as the disorder broadens the levels and smears the hyperbolic features between levels. In graphite, owing to the small size of the Fermi pockets, the quantum limit is only about 8 T. Thus, the field creates enough spacing to resolve the feature between Landau levels. The similarity between this simple model of DOS and the observed Nernst signals suggests that the Nernst-effect measurements can be a powerful probe of the dimensionality of the electronic state of unusual materials.

The asymmetric features in the Nernst signals of graphite provide a unique way of understanding the dimensionality of the electronic state — a 2D electronic state with weak interlayer coupling. Remarkably, the Nernst-effect signals in bismuth show a similar pattern[3]. In bulk bismuth, the quantum limit is about 8–13 T, depending on the sign of the carrier and the alignment angle between the z-axis and the field direction[5]. Amazingly, the Nernst signal still establishes a series of peaks in higher fields up to 40 T, which some argue to be fractional levels[10]. Would the Nernst signal of graphite follow the trend of bismuth and oscillate in higher fields? Further exploration of the high-field properties of graphite and bismuth will definitely help in our understanding of the electronic state in these semimetals, especially the role of the surface state in bismuth and related compounds BiSb, BiTe and BiSe, potential hosts for topological quantum computation. ❐

Lu Li is in the Department of Physics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139-4307, USA.
e-mail: luli@mit.edu

References

1. Zhu, Z. *et al. Nature Phys.* **6,** 26–29 (2010).
2. Wang, Y., Li, L. & Ong, N. P. *Phys. Rev. B* **73,** 024510 (2006).
3. Behnia, K., Méasson, M-A. & Kopelevich, Y. *Phys. Rev. Lett.* **98,** 166602 (2007).
4. Li, L. *et al. Science* **321,** 547–550 (2008).
5. Obloh, H., von Klitzing, K. & Ploog, K. *Surf. Sci.* **142,** 236–240 (1984).
6. Zuev, Y. M., Chang, W. & Kim, P. *Phys. Rev. Lett.* **102,** 096807 (2009).
7. Wei, P. *et al. Phys. Rev. Lett.* **102,** 166808 (2009).
8. Checkelsky, J. G. & Ong, N. P. *Phys. Rev. B* **80,** 081413 (2009).
9. Jonson, M. & Grivin, S. M. *Phys. Rev. B* **29,** 1939–1946 (1984).
10. Behnia, K., Balicas, L. & Kopelevich, Y. *Science* **317,** 1729–1731 (2008).

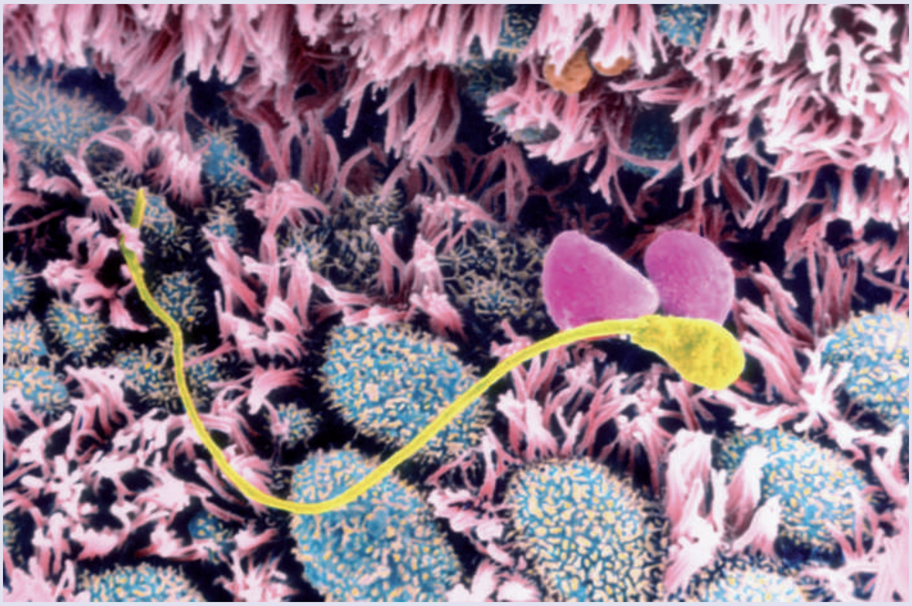
BIOMIMETICS

Guided in the right direction

Cilia are eyelash-like protrusions that extend from some cells, notably those that line tracts in the body. Their purpose is to mediate the flow of fluid across a surface: cilia on the inside of fallopian tubes, for example (pictured), aid the progress of an egg to the womb; although this is not exactly helpful to sperm trying to go the other way (which themselves are propelled by an extended cilium-like structure known as a flagellum). Artificial cilia have now been created using strings of superparamagnetic spheres, with some intriguing implications for microfluidics (M. Vilfan *et al. Proc. Natl Acad. Sci. USA* 10.1073/pnas.0906819106; 2009).

A cilium sways in an asymmetric way: bending first in one direction, pushing against the surrounding fluid, before sweeping along the surface to which it is attached on the return stroke, which produces very little backflow. Cilia are often found in dense carpets in which this movement is synchronized — a two-phase collective motion that behaves very much like the oars on a rowing boat — acting as a means of propulsion. The efficiency of this procedure has inspired the idea of using artificial cilia for pumping microfluidic channels. Mojca Vilfan and colleagues have now shown directed fluid flow using man-made cilia.

These artificial cilia are composed of chains of superparamagnetic spheres — they only become magnetized in an external magnetic field. The beads cling to one another because of the attractive forces that arise between the magnetic dipoles, and the chain is attached to the surface by a nickel anchor. Each chain is made of seven 4.4-μm-diameter beads that are positioned together using either optical tweezers or can be self assembled by creating a trench in the photoresist substrate. The ability to create the artificial cilia by self assembly means that large arrays can be produced relatively easily.



© DR YORGOS NIKAS / SCIENCE PHOTO LIBRARY

The cilia align to an applied magnetic field, the orientation of which is varied to induce a conical motion. To make this movement asymmetric, it is tilted by an angle equal to the cone half-angle. Fluid flow is measured by monitoring the position of non-magnetic 1-μm-diameter spheres. At a tilt angle of 30° and a rotation rate of 1 Hz, the fluid flows at a rate of 3.3 μm s^{-1}. The flow is dependent on the height of the trace particle above the surface and reaches a maximum at a height equal to the length of the cilia, but flow is still observed 100 μm above the surface. Any higher than this and the tracer movement is dominated by Brownian motion.

DAVID GEVAUX