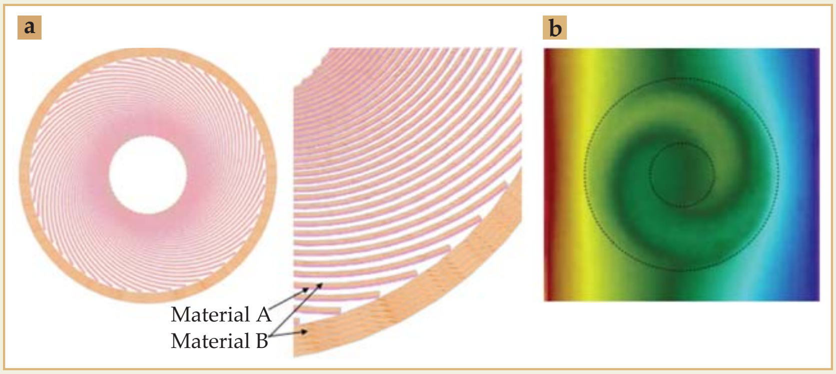
Now Yuki Sato and his postdoc Supradeep Narayana, of the Rowland Institute at Harvard University, have used techniques from the field of metamaterials in order to manipulate heat flux.[1] Inspired by work on devices that "cloak" regions from electromagnetic waves (see PHYSICS TODAY, February 2007, page 19), acoustic waves, static fields, and other signals, they set themselves the challenge of designing a hollow, thick cylinder that, when embedded in a material with a uniform thermal gradient perpendicular to the cylinder axis, could drastically alter the heat flux inside the cylinder without disturbing the flux outside.

They quickly realized that no ordinary substance would do the trick. A hollow cylinder of a material with thermal conductivity much higher *or* much lower than the background material could lessen the thermal gradient inside, but at the expense of severely distorting it outside. "We started out by going back to basics," says Sato, "drawing up thought experiments to challenge our understanding of thermodynamics and to push the envelope a little and then trying to design physical systems to mimic them."

What they needed, the researchers found, was a material with anisotropic thermal conductivity. To make it, they stacked many alternating thin sheets of two ordinary materials, one a good thermal conductor and the other a good thermal insulator. Perpendicular to the planes of the sheets, their thermal resistances add in series; parallel to the planes, they add in parallel. With a suitable choice of the two materials—the product of their thermal conductivities must equal the square of the background material's conductivity—the stacked layers blend into the background material and induce almost no distortion in the surrounding thermal gradient.



A thermal inverter (a) made from layers of copper (material A, pink) and polyurethane (material B, orange) arranged in a spiral pattern. **(b)** When the inverter is embedded in an agar–water block that is subject to a thermal gradient, the gradient outside the cylinder is only slightly distorted. But the gradient inside the cylinder is reversed: The cylinder's inside edge is slightly warmer on the right than on the left. (Adapted from ref. 1.)

By arranging the layers in concentric circles, Narayana and Sato created a thermal shield that isolates the region inside from any measurable thermal gradient at all. Arranging the layers as radial spokes did the opposite: It enhanced the thermal gradient in the region inside the cylinder, a useful task in many energy applications.

But when they arranged the layers in a spiral pattern, as shown in panel a of the figure, they achieved perhaps the most counterintuitive effect of all: local inversion of the flux direction so that heat flows from right to left inside the cylinder in response to a left-to-right flux outside. Panel b shows the temperature map as imaged with an IR camera. Heat still flows from hot to cold (as it must), but the positions of the heat source and sink inside the cylinder are reversed.

Narayana and Sato are working on incorporating other materials engineering techniques into their toolbox for designing their thermal materials. They'd also like to explore the potential of materials with strongly temperature-dependent thermal conductivities.

Johanna Miller

Reference

1. S. Narayana, Y. Sato, *Phys. Rev. Lett.* **108**, 214303 (2012).

physics update

These items, with supplementary material, first appeared at http://www.physicstoday.org.

Spin correlation in top-quark pairs. Almost 200 times heavier than the proton, the top quark is by far the most massive of the six quark species that, together with their antiquarks, are the building blocks of the hadrons. But because it's so massive, a top quark (or its antiparticle) decays within 10^{-24} seconds of its creation—too fast to be affected by the processes that ordinarily clothe a quark in hadronic garb. So top–antitop pairs produced in CERN's Large Hadron Collider (LHC) provide a unique opportunity for studying the production and decay of quarks without the obscuring hadronic complications. Now the team that runs the LHC's gargantuan ATLAS detector has reported an analysis of correlation between the spin orientations of the top and antitop quarks in some 4000 identifiable top–antitop pairs produced in 10^{14} collisions between 3.5-TeV protons. The spin correlation is deduced from the directional correlations of high-energy decay leptons. The standard model (SM) of particle theory predicts that the top and antitop spins prefer to emerge with the same rather than opposite helicities (spin projections along the momentum direction). The team measured the correlation parameter A (same minus opposite fraction of all pairs) to be $(40 \pm 8)\%$, in reasonable agreement with the SM prediction. If, as some theories suggest, nonstandard Higgs bosons are involved in the production or decay processes, A could differ from the SM prediction. (G. Aad et al., ATLAS collaboration, *Phys. Rev. Lett.* **108**, 212001, 2012.) —BMS

Theory meets experiment in the blink of an eye. A healthy human eye has a thin, moist tear film that protects it, removes waste, and provides a smooth optical surface. The film—containing layers of lipids, water, and mucin—evaporates as the eye stays open and is replenished with a blink. Mathematical models typically show that the film warms between blinks. But precise noncontact laboratory measurements show that it actually cools by a degree or two Celsius as the film evaporates, especially in the thinnest region near the center of the cornea. Mathematicians Richard Braun and Longfei Li at the University of Delaware have now resolved the discrepancy. Along with the usual physical parameters of the problem—surface tension, viscosity, lipid concentration gradients, corneal wettability, and so on—they included heat diffusion in both the tear film and the eye beneath it. Allowing for heat transport in a realistically thick substrate that includes the cornea proved to be crucial. In addition to simulating the observed cooling, the new model also reproduces the experimental thinning rate of the film, a rate that is higher for people with so-called dry eye. In the next stage, to better capture blinking dynamics, Braun and coworkers are letting one boundary of their model eye move. (L. Li, R. J. Braun, *Phys. Fluids*, in press.) —SGB

Reevaluating NMR coupling. Magnetic resonance imaging, spectroscopy, and other applications of nuclear magnetic resonance rely on the sensitivity of nuclear spins to their magnetic environment. The spins couple not only to externally applied magnetic fields but also to the dipolar fields produced by other spins. The continuous motion of atoms and molecules in liquids and gases provides a constantly varying environment that averages out the dipolar fields of neighboring spins (top) and greatly simplifies experimental and theoretical analysis. The long-range couplings don't average out so neatly (bottom), so the distant dipolar field is usually approximated as an additional applied field whose strength is proportional to the local magnetization. Though that approximation has been remarkably successful for decades, some straightforward experiments can produce results dramatically different from expectations. For example, a uniformly magnetized spherical sample has no dipole field, but tipping a trivially small fraction of the spins will produce a large effective dipolar field. Yuming Chen, Rosa Branca, and Warren Warren of Duke University have now reexamined the assumptions underlying the mean-field approximation and show both theoretically and experimentally that the mathematical framework needs to be modified for general imaging and other modern applications. At the core of those modifications is acknowledging the possibility, increasingly exploited in modern experiments, that the applied pulses don't always uniformly modulate all components of the magnetization in the same direction. The new understanding, though, can allow researchers to craft new pulse sequences that may, among other uses, enhance imaging contrast. (Y. M. Chen, R. T. Branca, W. S. Warren, *J. Chem. Phys.* **136**, 204509, 2012.) —RJF

Ancient Maya astronomical tables. As part of an urban renewal project circa 800 CE, Maya inhabiting what is now the Petén region of Guatemala filled residential dwellings with rubble and dirt before building over them. A structure's walls in the now-excavated Xultún complex have recently provided a multidisciplinary team led by archaeologist William Saturno of Boston University with an intellectual treasure: two tables, apparently of ancient astronomical reckonings. One table of hieroglyphs includes dozens of columns each with three digits. Most columns are illegible, but the final three—all of which have Moon glyphs above the digits—evidently represent a sequence of numbers separated by 177 or 178, corresponding to the number of days in the Maya "semester" of six lunar months. The second table has four columns; each of those presents a glyph above five digits that express a base-20 number. Digital enhancement of the section of wall shown in the figure revealed the hieroglyphs. The large numbers in each column are related to important Maya time periods, including the 365-day year. But each number is also an integer or half-integer multiple of the synodic periods (apparent orbital periods as perceived from Earth) of Venus and Mars. Codices dating from 1300 to 1521 CE, write Saturno and colleagues, show that the Maya sought harmony between astronomical events and sacred rituals. The Xultún tables, they continue, may have been inspired centuries earlier by the same desire. (W. A. Saturno et al., *Science* **336**, 714, 2012.) —SKB