## Biological applications

The researchers hope that their study will offer insights into the dynamical nature of synchronization and quorum-sensing transitions in biological systems. In one recent study, researchers in France and Denmark found that in a stirred system of yeast cells, oscillations in the rate of a metabolic process synchronized via a dynamical quorum-sensing transition.[5] The BZ study suggests that biological systems such as stirred yeast cells might also undergo Kuramoto-type transitions, depending on the efficacy of the molecular signaling.

Showalter and colleagues have extended their study to look at catalytic particles in an unstirred solution, in which the coupling between particles is not global but local. They've found that spiral and bull's-eye patterns propagate over the surface of a layer of particles, but only when the group contains more than a critical number of particles—adding or removing just a few particles is enough to turn the behavior on or off. Says Showalter, "We are excited about this because there is a striking resemblance of the grouped particles to groups of bacteria."

**Johanna Miller**

## References


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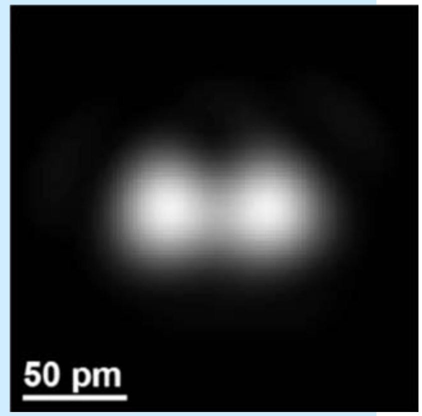
## physics update

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

**Plasma waves and cosmic rays.** With energies exceeding $10^{20}$ eV, the highest-energy cosmic-ray protons are as energetic as well-hit tennis balls. How does a proton become so energetic? Recent cosmic-ray data disfavor the notion that these ultra-energetic protons have exotic origins such as the decay of very massive particles as yet unidentified. So one must seek the proton acceleration mechanism in familiar astrophysical environments. The conventional suggestions—acceleration by relativistic shocks, spinning black holes, or flares on hypermagnetized neutron stars—each have problems accounting for the highest observed energies. Shock acceleration, for example, becomes increasingly inefficient at high energy because the inevitable trajectory bending causes severe synchrotron energy loss. Now theorist Pisin Chen (SLAC and National Taiwan University) and coworkers have demonstrated analytically and by computer simulation that so-called magnetowaves—electromagnetic waves with unusually strong magnetic components in magnetized plasmas—can drive plasma waves in their wake much as laser pulses in the laboratory drive plasma wakefields in experimental plasma-based accelerators (see PHYSICS TODAY, March 2009, page 44). The mechanism avoids synchrotron loss, and it provides strong accelerating gradients even at very high energy. Chen and company show that a proton surfing a stochastic succession of such plasma wakes can, with luck, be accelerated to $10^{21}$ eV. Magnetowaves are believed to be produced in the relativistic jets emanating from active galactic nuclei. And the "luck" required for the proton to catch just the right sequence of plasma waves in an AGN jet accords with the observation that ultra-energetic cosmic rays are extremely rare. That's why the detector arrays that study them cover thousands of square kilometers. (F.-Y. Chang et al., *Phys. Rev. Lett.*, in press.) —BMS

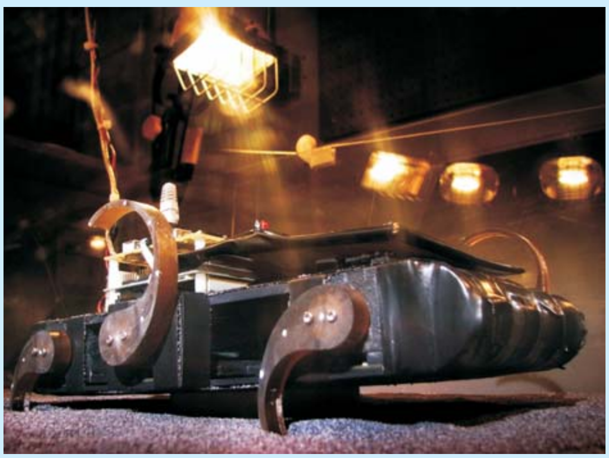
**Electron microscope attains 50-picometer resolution.** Ultimately, the resolution of an electron microscope is limited by the electron's de Broglie wavelength. For the 300-keV electrons typical in scanning transmission electron microscopy, that limit is about 2 pm, or 1/25th of the radius of hydrogen's 1*s* orbital. But STEM images are formed by focusing a billion or so electrons per second onto a sample. The spherical aberration of the electromagnetic lenses and the finite size of the electron source cause the electrons to lose phase coherence, lowering the resolution to about 100 pm, or about twice the distance between atoms in many crystals. Now, a team from Lawrence Berkeley National Laboratory in California has halved the STEM resolution limit to 50 pm. The boost in performance comes from two novel components: an electron source that emits copious electrons from a region just 25 pm across and a hexapole corrector that can compensate for phase aberrations up to fifth order. Using their new microscope, the LBNL researchers looked at a piece of germanium foil. According to x-ray crystallography, Ge atoms are arranged in rows of dumbbell pairs aligned end-to-end. Ordinarily, the dumbbells are too small to be resolved with STEM. But, as the accompanying figure shows, the LBNL microscope could resolve the 47-pm separation between two paired atoms. The resolution is so fine that the thermal jiggling of the atoms during the room-temperature measurement acts as an additional source of blur. (R. Erni, M. D. Rossell, C. Kisielowski, U. Dahmen, *Phys. Rev. Lett.* **102**, 096101, 2009.) —CD




**Breathing Earth, venting cracks.** The couplings between Earth's solid surface and atmosphere are a rich area for study. For example, it is known that soil "respiration" plays a large role in the global water cycle. Researchers have long assumed that diffusion is the dominant mechanism for transferring gases across the interface between air and soil or rock, enhanced somewhat by wind- and pressure-fluctuation-driven transport. But scientists working in Israel's Negev Desert have uncovered a surprisingly important new mechanism: In regions where Earth's porous surface has cracks, fractures, or other discontinuities, thermal convection can expel, on a daily basis, up to 200 times more gas than diffusion, depending on the surrounding conditions. The team from Ben Gurion and Oregon State universities

installed arrays of sensors in the large—2-cm-wide, 1-m-deep—crack in the foreground of the photograph: Temperature and relative-humidity data were acquired every 10 minutes for more than two years. Every day, the Sun's warmth propagates slowly down through the rock until, as the evening cools, the air in the crack becomes less dense than the overlying atmosphere, and convection sets in. Venting of warm, moist air from the rock surrounding the crack, along with the entrainment of cool dry atmospheric air, then continues until dawn. Convection takes place for up to 19 hours a day in the winter, 12 during the summer. The process, say the researchers, is natural and pervasive and could have a large impact on Earth-atmosphere gas exchange. Also, because water vapor, carbon dioxide, and other gases are involved, there may be implications for climate change studies. (N. Weisbrod et al., *Geophys. Res. Lett.* **36**, L02401, 2009, doi:10.1029/2008GLO36096.) —SGB

**A robot walks, sinks, and swims in granular media.** Inspired by crabs, cockroaches, and other nimble creatures, engineers at the University of Pennsylvania have designed robotic vehicles to traverse complex terrain such as deserts and presumably the Martian landscape. Equipped with six spring-loaded and synchronously rotating C-shaped limbs, the robots outmaneuver



current military and rescue vehicles over coarse but rigid terrain. On granular media, however, that agility comes at a cost: The latest robot model, the 30-cm-long SandBot, shown in the image and designed by Georgia Institute of Technology physicists in collaboration with the UPenn engineers, drops from a speed of 60 cm/s on a rigid surface to a crawl of 2 cm/s in a bed of poppy seeds. (See videos with this item at http://www.physicstoday.org.) Only when the researchers empirically tweak the limb-control parameters does the speed approach a respectable 30 cm/s. A team led by Daniel Goldman at Georgia Tech set out to determine how the robot's speed is influenced by the angular frequency of its limbs and the granular medium's packing fraction. The experiments revealed that the robot's legs sink into the fluid-like medium, then slip, before walking forward. Below a critical packing fraction, and at high limb frequencies, a sharp transition from rotary walking to a slower swimming motion was observed. The researchers say that understanding the physics associated with crater formation and collapse in granular media will lead to advances in limb geometry and robot locomotion. (C. Li et al., *Proc. Nat. Acad. Sci. USA* **106**, 3029, 2009.) —JNAM

**Carbon nanotubes for fuel cells.** The several approaches being pursued for fuel cells vary in their chemical reactions, materials, and optimal operating conditions, but they share a basic configuration (see Physics Today, November 1994, page 54, and October 2006, page 38). A fuel, often hydrogen, is oxidized at the anode, where it liberates electrons. The electrons travel through and power an external circuit and eventually reach the cathode, where oxygen is reduced. Meanwhile, to complete the redox reaction, ions travel through an electrolyte that separates the electrodes. In alkaline fuel cells, first developed for the Apollo space missions in the 1960s, oxygen combines with water and electrons at the cathode to form hydroxyl ions ($OH^-$) that travel through an aqueous alkaline electrolyte to produce water by combining with protons from the anode. Commercialization of those fuel cells, however, has been limited by the high cost of the platinum used for the cathode. New work by Liming Dai of the University of Dayton and colleagues at the Air Force Research Laboratory and the University of Akron has shown that vertically aligned carbon nanotubes doped with nitrogen provide an efficient, lower-cost alternative for the cathode. Nitrogen-doped nanotubes have better long-term stability and, unlike Pt, are not harmed by the presence of carbon monoxide or any fuel molecules that cross the electrolyte from the anode to the cathode. The researchers attribute the catalytic performance to the relatively high positive charge density on the carbon atoms adjacent to the nitrogen atoms. (K. Gong et al., *Science* **323**, 760, 2009.) —RJF

**Martian methane.** A group of astronomers headed by Michael Mumma of NASA's Goddard Space Flight Center in Greenbelt, Maryland, has reported in substantial spatial and temporal detail the first definitive detection of methane ($CH_4$) in the atmosphere of Mars. The Martian atmosphere consists overwhelmingly of oxidized gases such as carbon dioxide; reduced gases such as methane were known to be rare. In 2003 and 2006, using two telescopes on Mauna Kea in Hawaii, the group observed much of the planet's surface spectroscopically at IR wavelengths to confirm the presence of methane and determine its seasonal and "ariegraphic" distribution. (A Martian season is about six months long.) Mumma and company found extended plumes of methane that appear to emanate at substantial rates from three localized sources in the northern summer (see the figure). They suggest that the summer emergence results from the unfreezing of pores and fissures connecting with underground accumulations of the gas, and that oxidation in winter dust storms accounts for the very meager methane signal remaining at the start of spring. Is the methane biogenic? On Earth 90% of it is, the rest coming from inorganic geochemistry. If it is biogenic on Mars, it could be a vestige of life long extinct or a sign of ongoing life in warm precincts deep underground, perhaps energized by molecular hydrogen from the hydrolysis of water by radioactivity. Isotopic ratios measured by future IR missions to Mars should help determine the methane's origin. (M. J. Mumma et al., *Science Express* **323**, 1041, 2009, doi:10.1126/science .1165243.) —BMS