

PHYSICS UPDATE

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

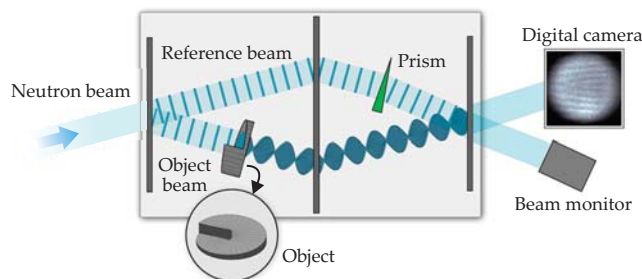
THE PERSISTENCE OF ASH IN THE STRATOSPHERE

On 13 February 2014, the Kelud volcano, considered one of the most dangerous in Java because of its frequent eruptions and deadly mudslides, spewed billions of tons of sulfur dioxide and ash high into Earth's stratosphere. Such large eruptions are known to cool the planet's surface because sulfate aerosols, created by oxidation of the SO_2 , can linger

for months to years in the atmosphere, where they efficiently reflect solar radiation. The heavier ash particles, by contrast, are assumed to fall from the sky within days because of rain and gravity, and climate models almost universally neglect them. NASA atmospheric scientist Jean-Paul Vernier and his colleagues have now refuted that assumption. Following the Kelud eruption, they monitored the diffusive evolution of its plume using the CALIPSO (Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation) satellite. Polarization measurements can distinguish between the backscatter signals of volcanic ash, sulfate aerosols, and ice clouds. The researchers found that within 11 days of the eruption, sedimentation had caused much of the ash to settle to the bottom of the plume in the lower stratosphere. Surprisingly, though, the contribution of the fine ash to the plume's optical depth—the logarithm of the ratio of incident to transmitted radiant power—three weeks later amounted to almost 40%. A subsequent balloon campaign conducted in late May confirmed the presence of ash even then and found that it accounted for up to 25% of the optical depth. Vernier and colleagues argue that upward-moving air currents in the tropics, where Kelud's plume was largely confined, reduce the ash particles' settling speed and account for the longevity. (J.-P. Vernier et al., *J. Geophys. Res. Atmos.* **121**, 11104, 2016.) —RMW

NEUTRON HOLOGRAPHY MAKES ITS DEBUT

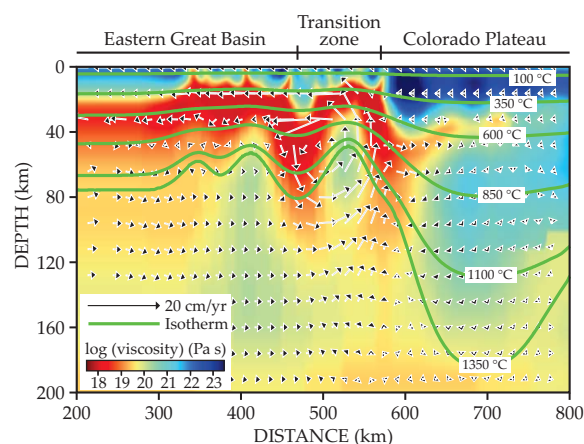
The invention of the laser turned optical holography into a practical imaging tool. But the utility of recording both the amplitude and phase of a scattered wave as an interference pattern is not exclusive to light. Holographic techniques find use in electron microscopy, acoustics, and now neutron interferometry. Dmitry Pushin and his colleagues at the University of Waterloo, together with collaborators from NIST, the Joint Quantum Institute at the University of Maryland, and North Carolina State University, have made the first neutron holograms of a macroscopic object. The interferometer's first blade splits each incident neutron wavepacket into a reference beam and an object beam, as illustrated in the schematic; then a second blade directs the beams to the third blade where they interfere. The wavepacket is again split and sent to a digital neutron camera and a beam monitor. For the experiment, the researchers placed a 224- μm -thick aluminum disk with a spiral staircase structure carved into it in the object beam's path. That structure imparted a helical wavefront, or orbital angular momentum, to the beam. By slightly tilting the reference beam's wavefronts with a prism, the researchers obtained the pitchfork interference pattern seen in the figure. Neutrons, unlike electrons and photons, easily penetrate most materials, so neu-



tron holography should lend itself to imaging structures in the interiors of material. And because appropriately illuminating a hologram reproduces the object beam that created it, the demonstration by Pushin and his colleagues suggests that holograms could be employed to custom-shape neutron beams. (D. Sarenac et al., *Opt. Express* **24**, 22528, 2016.) —SC

A MAP OF EARTH'S VISCOUS CRUST

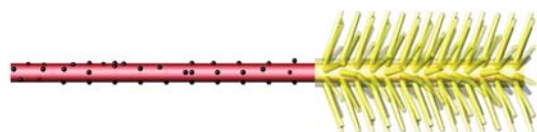
On long scales of length and time, Earth's crust and upper mantle flow like a stiff liquid. To understand how the rocks deform under geologic stresses, you need to know their viscosity—a property that depends on the rocks' temperature, strain rate, and composition. Among those features, variations in composition, specifically trace amounts of water and magma, are the most difficult to determine but exert a strong influence on the rocks' behavior (see the article by Marc Hirschmann and David Kohlstedt, *PHYSICS TODAY*, March 2012, page 40). The hotter, wetter, or more molten a rock, the weaker it is. Fortuitously, the same factors that weaken a rock and lower its viscosity also make it more electrically conductive. Since the 1950s, researchers have been able to infer resistivity profiles as a function of depth in crustal and mantle rocks from variations in magnetic and electric fields they measure at Earth's surface. The method, widely used for oil and gas exploration, is known as magnetotelluric (MT) imaging. Geologists Lijun Liu (University of Illinois at Urbana-Champaign) and Derrick Hasterok (University of Adelaide in Australia) have now derived an empirical conversion factor to determine viscosity variations from two-dimensional variations in electrical resistivity obtained from an MT survey across the western US—more specifically, the eastern Great Basin and the Colorado Plateau. The researchers calibrated the magnitudes of the viscosity variations with geodynamic flow models to produce a viscosity map, shown here. Spanning six orders of magnitude, the map predicts the region's



rough surface topography, crustal deformation, and mantle upwelling (upward arrows) more accurately than do standard geological models. The upwelling identifies spots of potential earthquakes or volcanism. (L. Liu, D. Hasterok, *Science* **353**, 1515, 2016.) —RMW

MICROMOTORS SWIM TOWARD AND AWAY FROM THE LIGHT

Since the first molecular motors were synthesized in the late 1990s, the catalog has expanded to include self-propelling micromotors that roll, walk, or swim. Building such devices is challeng-



ing enough, but controlling their direction of motion has also proved difficult. Now chemist Baohu Dai and his colleagues at the University of Hong Kong have created a tree-shaped micromotor that exploits the motion of charges inside and outside the device to swim toward or away from a light source. Each device is about 10 μm long and consists of titanium dioxide nanowires (yellow in the illustration) sprouting from one end of a silicon wire (pink). Ordinarily the microswimmers succumb to Brownian motion (see the article by Dean Astumian and Peter Hänggi, *PHYSICS TODAY*, November 2002, page 33). But the randomness is overcome when the miniature trees are immersed in an aqueous solution of hydrogen peroxide and illuminated with 365 nm UV light. That combination spurs a redox reaction in which the rod end serves as the cathode and consumes electrons and protons that are supplied by the dissociation of H_2O_2 on the branched (anode) end. While the electrons travel through the silicon wire, the protons migrate in the surrounding solution, dragging fluid in one direction so that the motor is propelled in the opposite direction. Dai and colleagues demonstrated that they could alter the swimmers' direction of motion either by tailoring the surface charge of the silicon wire beforehand or by illuminating one side of the

TiO_2 tree to produce a torque. The motors may find use as micro-sized pumps. A potential future experiment would be to monitor the collective behavior of many of the devices. Bathing a swarm of microswimmers in light would cause their ion gradients to overlap and result in complex interactions between individuals that may resemble the chemical-fueled communication and motion of slime molds. (B. Dai et al., *Nat. Nanotechnol.*, in press, doi:10.1038/nnano.2016.187.) —AG

A PULSAR'S CHANGING MAGNETIC FIELD

The Vela X-1 binary consists of a massive blue star and a spinning neutron star. The pair are close enough that the neutron star's gravity draws in material from its companion's powerful wind. Because of the neutron star's intense magnetic field, the material is funneled onto the star's poles. In the process, the material gets so hot that it emits x rays, which are pulsed because the magnetic and rotation axes are misaligned. NASA's *Swift* has been monitoring Vela X-1 since the orbiter's launch in 2004. That long train of data has given Valentina La Parola of Italy's National Institute for Astrophysics and her colleagues the opportunity to investigate changes in the neutron star's magnetic field. Specifically, they tracked a cyclotron absorption line at around 54 keV; the line arises, as in the quantum Hall effect, from the quantization of energy levels in a strong magnetic field. The researchers found that shifts in the line's energy were positively correlated with fluctuations in x-ray luminosity. Two mechanisms could account for the correlation. When the wind is strong and more material falls onto the poles, the luminosity rises and the x-ray-emitting region is pushed down into a region of higher magnetic field. Alternatively, the higher the luminosity, the more radiation pressure slows the infalling material and the smaller the line's Doppler redshift. La Parola also found that since 2004 the line's energy and, therefore, the magnetic field at the poles have been steadily dropping, independently of changes in luminosity. Distortion or displacement of the field lines by piled up material is a possible cause. (V. La Parola et al., *Mon. Not. R. Astron. Soc.* **463**, 185, 2016.) —CD

HOW TO DETECT OIL SPILLS UNDER SEA ICE

As petrochemical companies prospect for oil in the crust beneath the Arctic Ocean, the threat of oil spills looms. Compounding the threat is the possibility of a spill happening underneath sea ice, where it could spread unseen. To meet the challenge of detecting such spills, Christopher Bassett of Woods Hole Oceanographic Institution and his collaborators are investigating the feasibility of using autonomous underwater vehicles equipped with sonar.

Given that seawater, crude oil, and ice have different acoustical properties, the approach might seem straightforward. It isn't. The resulting ice contains a network of brine channels and a water-ice interface with small dendritic structures. If an oil spill occurs underneath growing ice, the oil gets trapped under the ice and be-

tween the finger-like structures to form a complex multilayer system. Bassett and his colleagues re-created that process in a tennis-court-sized tank of seawater (shown here) at the Cold Regions Research and Environmental Laboratory in Hanover, New Hampshire. Specifically, they grew six patches of ice and pumped in adjustable amounts of Alaskan crude oil from below. A cart equipped with six transducers ran on rails beneath each patch in turn to record the echoes of acoustic pulses of various frequencies and bandwidths.

The researchers found that the channel with the highest nominal frequency (500 kHz) and the largest bandwidth (370–590 kHz) was best able to resolve oil layers thinner than 1 cm, but at the cost of



lower penetration and less sensitivity to ice's complex structure. By contrast, the channel with the lowest nominal frequency (100 kHz) and the smallest bandwidth (75–130 kHz) could resolve only thick layers of oil, but it could detect oil that had been newly encapsulated by an underlayer of ice. (C. Bassett et al., *J. Acoust. Soc. Am.* **140**, 2274, 2016.) —CD PT