

PHYSICS UPDATE

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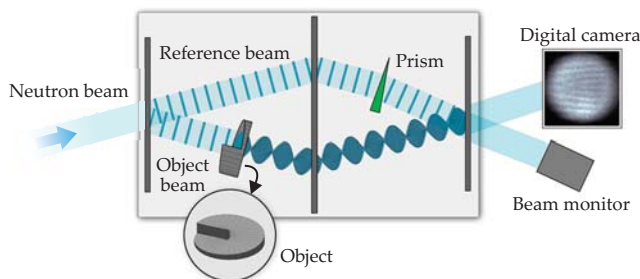
THE PERSISTENCE OF ASH IN THE STRATOSPHERE

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

