

physics update

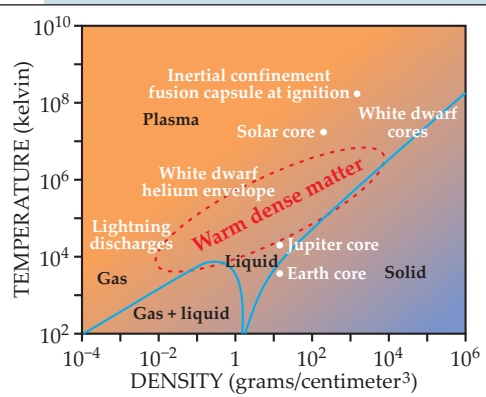
These items, with supplementary material, first appeared at <http://www.physicstoday.org>.

Ultrafast 4D core-loss spectroscopy meets graphite.

Electron energy-loss spectroscopy (EELS) uses an electron beam shot through a sample to knock a resident atom's electron into an unoccupied outer shell or out of the atom entirely. In the process, the probing electrons lose energy. When the target is a tightly bound core electron, the beam's energy losses can easily exceed 100 eV; by analyzing the resultant "core-loss" spectra, researchers can glean information about a sample's chemical and structural properties much as they could using soft x rays. Unlike x rays, however, electrons interact strongly with the light elements that are prevalent in organic materials. A group at Caltech led by Ahmed Zewail has now incorporated nano- and femtosecond time resolution into EELS to study the chemical and structural dynamics of a 50-nm-thick film of graphite. The researchers first use a laser to excite electronic and lattice motions in a small spot of the sample; after the desired time delay, they probe the spot with ultrashort focused electron pulses from a transmission electron microscope (for more on TEMs, see *PHYSICS TODAY*, April 2015, page 32). Combining the electron energy-loss spectra with molecular dynamics simulations—to account for vibrations and other thermal disorder in the film—the Caltech group deduced that the transient laser heating caused the in-plane bonds of the carbon lattice to contract even as the carbon-carbon bonds between the planes elongated. Additionally, they found that laser-induced phonons caused the overall energy gap between filled and empty electronic bands to shrink significantly on a subpicosecond time scale. (R. M. van der Veen et al., *Struct. Dyn.*, in press.) —SGB

Extreme heating with an x-ray free-electron laser. The border between condensed-matter physics and plasma physics, illustrated by the phase diagram below, is home to a little-understood state called warm dense matter (WDM), in

which thermal and Coulomb energies become comparable. (See the article by Paul Drake, *PHYSICS TODAY*, June 2010, page 28.) Such matter is thought to inhabit the inner cores of giant planets and is formed during the compression

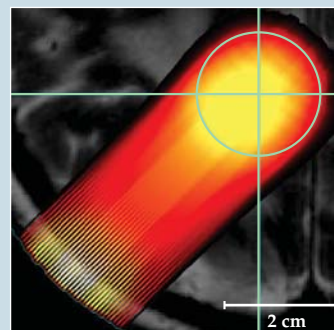


stage of inertial confinement fusion experiments. To study WDM, researchers want to controllably create the stuff with uniform temperature and density in the lab. But of the usual heating techniques, optical lasers lack sufficient penetration depth, ion beam pulses last too long, and laser-induced shocks are limited to a narrow slice through temperature-density space. Now, Anna Lévy of Marie and Pierre Curie University, Patrick Audebert of École Polytechnique, and their collaborators have shown that x-ray free-electron lasers (XFELs) are just the tool for the job. At SLAC's Linac Coherent Light

Source, the group used a focused XFEL pulse to heat a 0.5- μm -thick silver foil to temperatures greater than 100 000 K. Then they simultaneously probed the foil's front and back surfaces with IR pulses. The results showed that temperature and density profiles were nearly uniform throughout the foil. Next on the agenda is to investigate other WDM properties such as ionic structure and electrical and thermal conductivities. (A. Lévy et al., *Phys. Plasmas* **22**, 030703, 2015; figure adapted from *Basic Research Needs for High Energy Density Laboratory Physics*, US Department of Energy, Office of Science and National Nuclear Security Administration, 2010.) —SC

Minibeams may minimize damage in cancer treatment.

The goal of radiation therapy is to deliver a fatal dose to a tumor while sparing the surrounding tissue. One advantage of using high-energy x rays is that they spare the first couple of centimeters of tissue they pass through, a region that is often clinically significant but radiosensitive. But then the dose—the energy deposited per unit mass—rapidly builds, and it can damage healthy regions both upstream and downstream of the target. Proton beams, in contrast, deliver most of their dose in a confined region, at a depth that depends on the beam energy (see the article by Michael Goitein,



Tony Lomax, and Eros Pedroni, *PHYSICS TODAY*, September 2002, page 45). Attaining full coverage of the tumor, though, can cause excess exposure of shallow tissues. That damage is of particular concern for pediatric brain tumors, since it can affect neurological and cognitive development. Now Avraham Dilmanian (Stony Brook University), John Eley (now at the University of Maryland), and Sunil Krishnan (MD Anderson Cancer Center) show that using a collimator to break up a particle beam into multiple parallel planar or pencil-shaped "minibeams," only 0.3 mm in size, can significantly spare shallow tissue: Because of the small irradiated volume, the tissue can both tolerate high doses and begin repairs promptly. As the minibeams penetrate, they gradually broaden and reunite, as seen in this simulated dose map. Through simulation and experiments on tissue surrogates, the researchers find that proton minibeams can stay safely small to depths of about 25 mm; helium and lithium minibeams, even further. Those depths suffice to spare much of the cerebral cortex. Moreover, say the researchers, the collimation is straightforward to implement in current treatment facilities. (F. A. Dilmanian, J. G. Eley, S. Krishnan, *Int. J. Radiation Oncol. Biol. Phys.*, in press.) —RJF

Artificial chameleon. The colors we see usually arise from the chemistry of materials, dyes, or pigments: A surface might reflect only some wavelengths of light; a filter might transmit only a narrow range of colors. Less common than chemistry, structural materials sometimes come along to split white light into some of its constituent colors (see *PHYSICS TODAY*, October 2006, page 82). But that is a very low-efficiency process. Now Connie Chang-Hasnain and a team of researchers at the University of California, Berkeley, have made a carefully tailored metastructured surface that can harness almost all of



The Berkeley group's calculations show that such a high-contrast metastructure (HCM) is capable of enhancing any one of the many diffraction orders at the expense of the rest. What's more, the resulting anomalous reflection (or refraction) of the HCM is highly efficient, collecting more than 80% of the desired color's power from the incident white light. The team's final twist, as shown here, is that small bends and stretches of the HCM can change the colors in a predictable way by altering the spacing of the high-index nanostructures. Chang-Hasnain and company envision applications that include display technologies, active camouflage, and sensors. (L. Zhu et al., *Optica* **2**, 255, 2015.) —SGB

Glaciers melt noisily into the sea. When a glacier meets the sea, vast chunks of ice can split from its terminus and crash into the water below. Those spectacular events are not the only source of glacial sound. Even when glacial ice merely melts on contact with seawater, millimeter-sized pores of pressurized air that are trapped in the ice wriggle noisily free to form bubbles that float to the surface. Erin Pettit of the Uni-



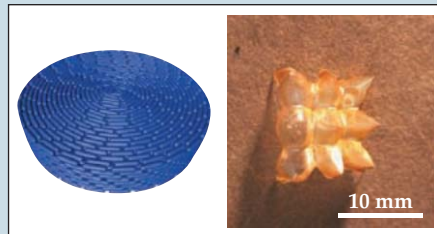
versity of Alaska Fairbanks and her collaborators have measured, both in the field and in the lab, the noise made by the escaping air. Their finding: Melting ice is the predominant source of ambient noise in glacial fjords. To reach that conclusion, Pettit's team first set

up hydrophones in three glacial fjords: Icy Bay and Yakutat Bay in Alaska and Andvord Bay in Antarctica. They found that the time-averaged acoustic spectrum in all three locations featured a broad peak between 1 kHz and 3 kHz. To confirm that the pores are responsible for the peak, the researchers retrieved blocks of ice from the terminus of Alaska's Gulkana Glacier and shipped them to the lab of their collaborator Preston Wilson at the University of Texas at Austin. There, they floated cubes of the ice in cold water and monitored the sound as the cubes melted. As in the field study, the acoustic spectrum peaked at 1–3 kHz. Having measured the pores' acoustic spectrum and correlated it with the properties of melting ice, Pettit and her collaborators have identified a cheap, safe, and convenient means to monitor glacial melt. (E. C. Pettit et al., *Geophys. Res. Lett.*, in press.) —CD

A pop-up rubbery material that can unpop. A substance that stores flat, transforms into a three-dimensional shape on demand, and reverts to flatness once the job is done could improve the portability of myriad devices and might even find applications as biomedical implants. Now Timothy J.

White (Air Force Research Laboratory) and colleagues have created such a material by carefully patterning thin liquid-crystal domains into a rubber called a liquid-crystal elastomer (LCE). Although liquid crystals flow like a liquid, their molecules are aligned. And when heated, illuminated, or exposed to electromagnetic fields, the crystals' molecular order can be disrupted, which causes the crystals to contract along that alignment direction. The left figure is a schematic representation of a 3-mm-diameter pattern induced by White and colleagues in one of their experiments. As illustrated, liquid-crystal monomers line up end to end in concentric circles.

Once patterned, the monomers are polymerized. When heated, the circular polymer chains contract along their alignment axes; to conserve volume, the LCE expands radially. With their circumferences decreasing and radii increasing, the liquid-crystal circles can't remain in a plane: The LCE pops into the third dimension and assumes a conical shape. The right figure shows an example of an LCE created with nine circular patterns. When cooled, the process reverses and the LCE once again becomes flat.



(T. H. Ware et al., *Science* **347**, 982, 2015.) —SKB

Nanobubbles distinguish themselves from impostors. A close-up look at a surface under water might reveal squat bubbles hundreds of nanometers in diameter and a few tens of nanometers tall. The surface nanobubbles could be useful for reducing drag in microfluidic devices. But they have puzzled researchers because their longevity defies conventional wisdom: They can survive for days even though they should only last for microseconds, given the high internal gas pressure implied by their small size. The usual way to image them is with atomic force microscopy, which can easily mistake common contaminants, such as polymer droplets, for nanobubbles. That ambiguity and conflicting results from spectroscopic studies have led some researchers to question the existence of the diminutive bubbles.

Now researchers at Nanyang Technological University in Singapore, led by Claus-Dieter Ohl, have conclusively identified nanobubbles. Using a total-internal-reflection fluorescence microscope and a high-speed camera operating at 2000 frames per second, they watched suspected nanobubbles in a microchannel as air was pushed through the channel to displace the water. The snapshots here show a water-air-substrate boundary moving right to left through nanobubbles. Unlike polymer droplets or solid particles, the nanobubbles collapsed just as expected when the moving boundary touched them. The researchers found that molecular kinetic theory does a far better job of describing the collapse than bulk hydrodynamics. With that observation in mind, the group is working on a new microscopic model they hope will help answer why nanobubbles live so long. (C. U. Chan et al., *Phys. Rev. Lett.* **114**, 114505, 2015.) —SC

