

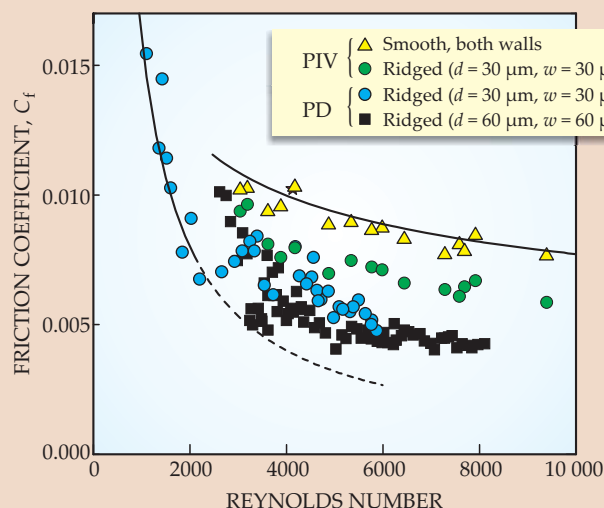


Figure 2. The coefficient of friction C_f refers to the shear stress at a wall divided by the kinetic energy density of the flow and is plotted here for various surfaces as a function of Reynolds number. Solid lines indicate

the predicted C_f along a smooth channel when the flow is laminar (the leftmost curve) and when it becomes turbulent (top-most curve). Data sets are distinguished by whether they are calculated from particle-velocimetry measurements (PIV) or from pressure drops (PD) observed along the channel. The onset of drag reduction occurs in the turbulent regime where the height of the viscous sublayer (about 50 μm) is on the scale of the surface corrugations. Moreover, their effect becomes increasingly pronounced as their width and spacing increase and as both walls (top and bottom) of a rectangular flow channel are made hydrophobic. (Adapted from ref. 1.)

for the jump in the friction coefficient as the flow changes from smooth to turbulent and for the emergence of a veritable zoo of coherent structures such as the ones shown on this month's cover. The tangles and swirling eddies are thought to form in the boundary layer and slowly percolate into the bulk fluid.

Rothstein's UMass colleague Blair Perot and graduate student Michael Martell found those structures in numerical simulations of the fluid's path and velocity in flow channels modeled on the experiments (though with flow-channel depth an order of magnitude smaller).³ Their calculations complement the experimental results. The velocity of water is constrained to be zero at the top of each ridge, but finite slip velocities emerge from the Navier-Stokes equations along the air-water in-

terface. The topology of the surface, the simulations suggest, affects not just the drag reduction—with increased spacing between ridges producing greater slip velocities—but also the location of the turbulent eddies, the mean shear, and the energy dissipation.

Toward practical systems

Should we expect to see superhydrophobic surfaces grace the hulls of ships anytime soon? Research is far from addressing practicalities: The UMass experiments explored flow speeds under 1.5 m/s (3 knots), at pressures under 5 kPa (0.5 m of water), and at Reynolds numbers under 10 000. Supertankers have Reynolds numbers in the tens of millions, but with viscous-sublayer thicknesses comparable to those in the UMass experiments.

Nevertheless, Rothstein is optimistic. "In 1987, 3M coated an America's Cup yacht with a plastic film embedded with riblets," minute, v-shaped grooves that also reduce drag passively, albeit in an extremely narrow band of Reynolds numbers. It won. "And, at least in principle," says Rothstein, "hydrophobic ridges could be produced with even finer features to prevent the air pockets from wetting under several meters of water." The US Navy, which funds the research, remains interested.

Mark Wilson

References

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2. J. Ou, B. Perot, J. Rothstein, *Phys. Fluids* **16**, 4635 (2004).
3. M. B. Martell, J. B. Perot, J. P. Rothstein, *J. Fluid Mech.* **620**, 31 (2009).

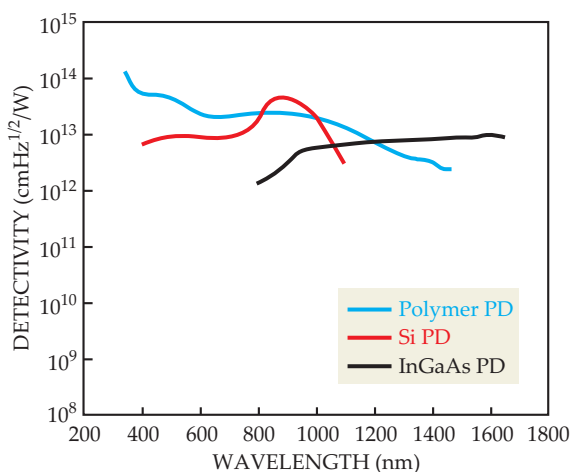
physics update

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

A new exoplanet to test tide theories. Almost 400 extrasolar planets have been found to date (see *PHYSICS TODAY*, May 2009, page 46), but a new planet reported by Coel Hellier (Keele University) and colleagues stands out. Like many exoplanets, theirs, dubbed WASP-18b, is massive (10 times the mass of Jupiter) and has a small orbital radius (only 1/50th of Earth's). But its orbital period of only 0.94 day is the shortest for any "hot Jupiter" yet observed. Moreover, its large mass and small orbit are predicted to cause the strongest tidal interactions of any known star-planet system. According to current theory, the tidal bulge that the planet raises on its host star exerts a torque that will drain angular momentum from the planet and cause it to spiral inward. (For more on tidal interactions, see *PHYSICS TODAY*, August 2009, page 11.) If the star's tidal dissipation rate is comparable to what's been measured for binary stars and for the gas giants in our own solar system, the infall will be quick: WASP-18b has less than a million

years left in a lifetime, estimated from the age of its host star, of about a billion years. Over the next decade, WASP-18b's death spiral should produce a measurable shift in the planet's observed transit time. The absence of tidal decay—a notable possibility, given the rarity of finding a planet so close to the end of its life—would constitute direct evidence for a different class of tidal interactions in the host star and provide new constraints on models of stellar interiors. (C. Hellier et al., *Nature* **460**, 1098, 2009.) —RJF

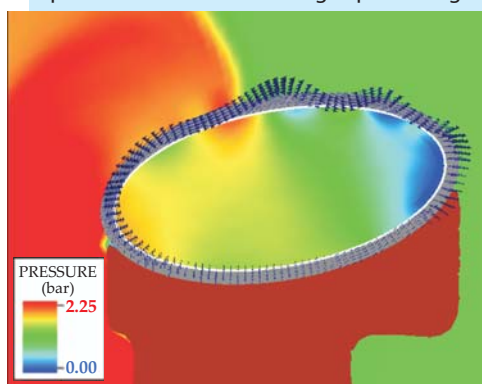
Bright-eyed polymer. Light sensors—photodetectors—have myriad uses in scientific, industrial, and consumer settings: Digital cameras, environmental monitors, remote controls, surveillance equipment, and biosensors are just a few applications. Most photodetectors are made from inorganic semiconductors and are sensitive in some limited waveband in the range between IR and UV. A new photodetector, however, that uses a semiconducting polymer shows good responsiveness from UV (300 nm) to near-IR (1450 nm), as shown in the figure. The polymer is a small-bandgap semiconductor that exhibits photoinduced, ultrafast electron transfer to fullerenes—blended with the polymer in the form of PC₆₀BM. Sandwiched between two



electrodes, the two materials form a phase-separated blend with interpenetrating donor and acceptor networks. Because the new light sensor covers nearly the entire solar spectrum at Earth's surface, the researchers—led by Alan Heeger of the University of California, Santa Barbara, and CBrite Inc—note that it holds promise for photovoltaic cells. The next step is to make addressable arrays of these broadband, high-detectivity photodetectors. (X. Gong et al., *Science*, in press, doi:10.1126/science.1176706.) —SGB

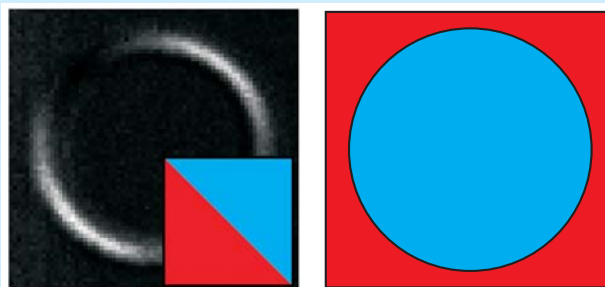
Skulls flex, damage brain, under battlefield explosions.

When a person's head strikes, or is struck by, another object, it accelerates. As it begins to decelerate, the brain slams into the skull, then bounces off and oscillates until the impact energy dissipates. The resulting shear and compressive strains can lead to brain damage. But in battlefield explosions, the acoustic waves alone can cause soldiers traumatic brain injuries. To better understand that process, Lawrence Livermore National Laboratory's William Moss and Michael King and the University of Rochester's Eric Blackman compared numerical simulations of a head colliding with a wall to one being struck by an explosion's blast waves. Despite accelerating the head at less than half the rate of the wall collision, the simulated blast produced on the brain surprisingly comparable pressure spikes—ranging up to 3 bars—and even larger pressure gradients. Apparently,



those mechanical loads are delivered by the skull, which ripples under the pressure of blast waves—the rippling motion is indicated in the image by velocity vectors. The researchers confirmed the role of the skull's elasticity by making it 1000 times stiffer in their simulations and observing a fivefold drop in the pressure spikes. The simulations also revealed that helmets in contact with the head can impart an additional mechanical load to the skull and helmets that allow for an air cushion geometrically focus and increase the magnitude of blast waves. (W. C. Moss et al., *Phys. Rev. Lett.*, in press.) —JNAM

A ghost image violates a Bell inequality. In conventional photography, photons bounce off an object and imprint its shape onto film. In ghost imaging, an object's shape is revealed after interrogating two light beams, only one of which interacts with the object. Ghost imagers have been practicing their craft for more than 10 years. Some of their schemes are based on photon entanglement, but others use classical light sources. Now Barry Jack of the University of Glasgow and colleagues have reported experiments in which quantum entanglement is manifest; their ghost images violate a generalized Bell inequality—a condition



on correlations that can arise classically. The accompanying figure presents one of their runs. The object to be imaged introduces a π phase difference between a disk (blue) and the surroundings (red). A smaller reference object (inset) introduces the phase difference on either side of a diagonal. After bouncing entangled photons, separated in space, off the object and reference, Jack and company measured photon coincidence counts. The black-and-white ghost image shown here maps those counts, with brighter regions corresponding to a greater coincidence rate. The brightest sections appear along those portions of the disk's bounding circle parallel to the reference bisector. The variation in the coincidence rate along the bounding circle violates the Bell inequality, thus demonstrating the quantum nature of Jack's system. Evidently, the ghost imaging relies on spooky action at a distance, accepted nowadays but so troubling to Albert Einstein decades ago. (B. Jack et al., *Phys. Rev. Lett.* **103**, 083602, 2009.) —SKB

Aerosols from trees. Atmospheric aerosols affect climate: The particles scatter, absorb, and emit radiation, and they also induce cloud formation. (See *PHYSICS TODAY*, May 2004, page 24.) Much of the aerosol mass is produced by oxidation of organic compounds emitted into the atmosphere through human activity and from the biosphere. But many aspects of aerosol formation are poorly understood. It's thought that biogenic aerosols might be formed from isoprene, a light hydrocarbon given off in large quantities by certain trees. Isoprene itself is volatile—at sea level it boils at 34 °C—so it must undergo a series of chemical reactions before it can form long-lived aerosol particles. Now Caltech's Paul Wennberg, graduate student Fabien Paulot, and their colleagues offer some insight into what those reactions are. In laboratory experiments designed to replicate atmospheric conditions far from any human pollution, they found that isoprene reacts several times with OH radicals to ultimately form large amounts of dihydroxyepoxide, a newly identified airborne molecule and a likely aerosol precursor. Its hydroxyl groups make it hydrophilic, so it should be readily taken up by existing aqueous aerosol particles. And epoxides under acidic conditions can form low-volatility polymers; a similar reaction is used in epoxy adhesive. Knowing the reactants and their mechanisms will help researchers improve atmospheric models to better predict the consequences of human activity such as deforestation and pollution. (F. Paulot et al., *Science* **325**, 730, 2009.) —JLM ■