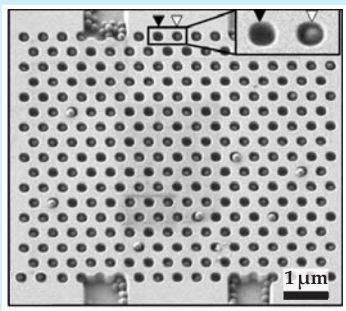
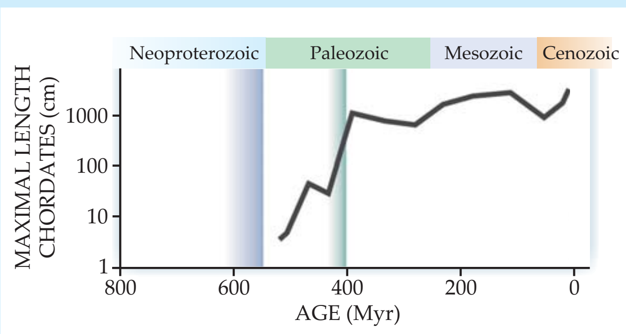
physics update

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

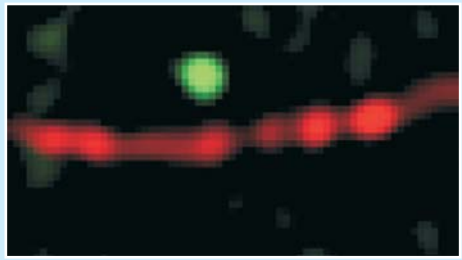
Photonic-crystal slab for biodetection. The public-health and biosecurity communities need biosensors that are sensitive, operate in real time, and can be easily deployed. Many approaches are being pursued, including one by a group from Lawrence Livermore National Laboratory that uses a photonic crystal (PC) slab connected to two waveguides. The idea is for viruses or other tiny pathogens to randomly infiltrate the pores of a silicon PC, whose optical properties—specifically, the in-plane transmission spectrum's band edge—change accordingly. First, the researchers used simulations to determine a PC geometry suitable for a specific virus, vaccinia, and for their laser's wavelength. They then fabricated an appropriate 17 × 17 array of 280-nm pores and exposed it to a flux of polystyrene beads with two different sizes; those with 260-nm diameter entered the pores (see the figure, with empty and filled pores enlarged) while 320-nm ones did not. The measured band-edge redshifts were then used to calibrate the simulations and predict detection limits. Theoretically, as few as 10 vaccinia viruses could be detected with the PC, comparable to other biodetection methods. Advantages accrue, however, from the small sensor size, the ability to tune the geometry for different particles, and the ease of integration into lab-on-a-chip setups. The authors say that their random-binding scheme is more practical than methods that rely on binding organisms to single PC defects. (S. E. Baker et al., *Appl. Phys. Lett.* **97**, 113701, 2010.) —SGB



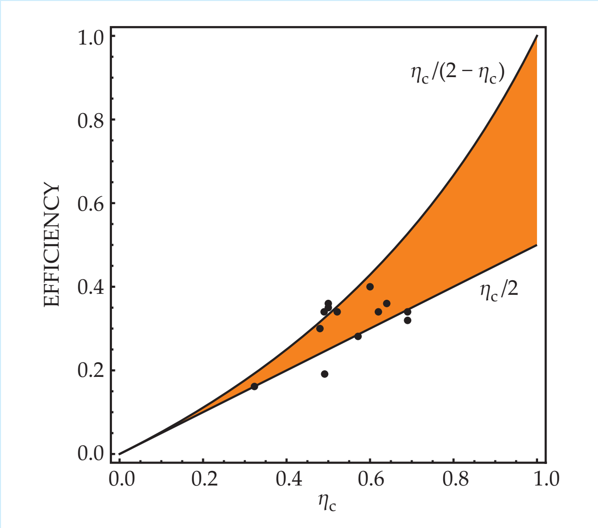
Oxygen in ancient oceans. Oxygen in the air and dissolved oxygen in the ocean are crucial for sustaining animal life on Earth. But that oxygen wasn't always there. Researchers can gain some information about the history of ocean oxygenation from the compositions of sedimentary rocks, because dissolved O_2 affects the solubility and precipitation of certain elements. Now, an international team of researchers led by Tais W. Dahl (University of Southern Denmark) has studied the problem using a new technique based on molybdenum isotopes. In oxygenated water, Mo forms the soluble molybdate ion, MoO_4^{2-}, and precipitates in small quantities by a mechanism that favors lighter isotopes. But when hydrogen sulfide is present instead of O_2, all Mo isotopes precipitate quickly. By analyzing the Mo in 180 rock samples with ages spanning almost 2 billion years, the researchers concluded that O_2 levels increased twice: 550 million years ago and 400 million years ago, as shown by the blue and green bands in the figure. The first increase coincides with the emergence of the first motile animals, and the second coincides with the evolution of much larger animals in the phylum Chordata, including large predatory fish. The method does not provide a quantitative measure of O_2 levels over time. Still, based on the physiological requirements of fish, the researchers suggest that prior to 400 million years ago the ocean and atmosphere contained O_2 at just 15–50% of their present levels, which means that the earliest animals survived with much less oxygen than we breathe today. (T. W. Dahl et al., *Proc. Natl. Acad. Sci. USA*, in press, doi:10.1073/pnas.1011287107.) —JM



Synchronized cameras catch messenger RNA on the run. Messenger RNA (mRNA) is the shuttle that carries genetic information across a cell's nuclear membrane and into the cytoplasm, where the information is translated into a protein sequence. However, the movement of mRNA, which is about 25 nm in diameter, through the nuclear pore complex, roughly 120 nm in diameter, has been difficult to resolve visually since both mRNA and the NPC are well below the 200-nm diffraction limit for optical microscopes. Now, Robert Singer at Yeshiva University's Albert Einstein College of Medicine in New York and David Grünwald at the Delft University of Technology in the Netherlands have developed a new nanometer-resolution imaging technique that they used to track mRNA's passage. Emission signals from mRNA and the NPC—labeled with spectrally different fluorescent probes and shown in the image as green and red, respectively—were chromatically separated and tracked by two synchronized high-speed CCD cameras. The researchers achieved 26-nm spatial resolution by resolving the misalignment between the mRNA and the NPC in the images collected before and during tracking by both cameras—a technique they've dubbed super-registration microscopy. In their experiments, they also observed that mRNA spent about 5–20 ms crossing the NPC, a fraction of the time it spends at the pore's entrance and exit—as if, say the researchers, the mRNA was being double screened for quality. That information may support research into understanding how defective mRNA is prevented from escaping the nucleus. (D. Grünwald, R. H. Singer, *Nature* **467**, 604, 2010.) —JNAM

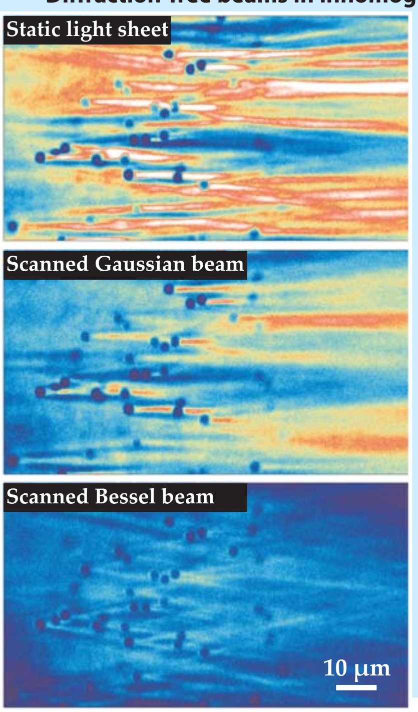


Efficiency bounds for powerful engines. Thermodynamics teaches that the efficiency of a heat engine operating between a hot reservoir at temperature T_h and a cold one at T_c can be no greater than the Carnot value $\eta_C = 1 - T_c/T_h$. To achieve its theoretical maximum, the engine must run infinitely slowly and generate zero power—surely an unsatisfactory state of affairs in the real world. Now Massimiliano Esposito (Free University of Brussels) and colleagues have derived efficiency bounds for engines operating at maximum power. They assume that the engine

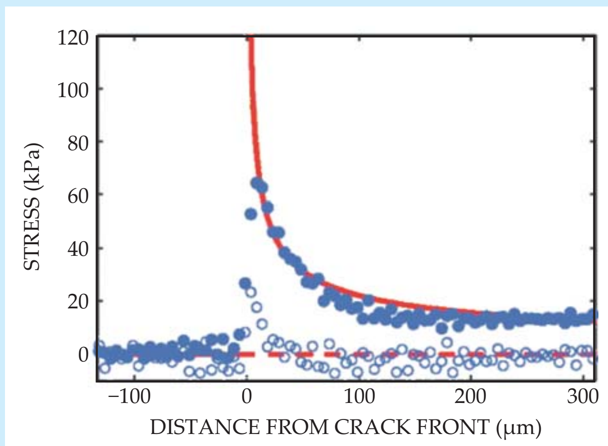


operates in a Carnot cycle and interacts with the hot reservoir for a finite time τ_h, presumed much greater than the duration of the adiabatic steps. They then express entropy as a sum of the standard term of heat over temperature and a term of the form a_h/τ_h for some constant a_h (the cold reservoir is treated analogously); placing the interaction time in the denominator ensures that the reversible-process result is obtained in the infinite-interaction-time limit. After deriving the maximum power as a function of the interaction times, Esposito and company can readily calculate the efficiency, which depends in particular on a_c/a_h. The figure shows the allowed range of efficiencies at maximum power. The upper bound corresponds to $a_c/a_h = 0$; the lower bound to an infinite ratio. The points in the figure give observed efficiencies for several heat engines worldwide. Those engines may not satisfy the assumptions of the Esposito model or even run in Carnot cycles; still, their efficiencies lie within or near the idealized bounds. (M. Esposito et al., *Phys. Rev. Lett.* **105**, 150603, 2010.) —SKB

Diffraction-free beams in inhomogeneous media. An axicon lens is flat on one side, conical on the other. After passing through the flat surface, a beam of light with a Gaussian profile emerges from the conical surface with a profile that looks approximately like a zeroth-order Bessel function. Bessel beams interest physicists because of a remarkable property: Thanks to the way the beams' energy and phase components are spread in space, the beams barely diffract—even around certain obstacles. Now, Florian Fahrbach, Philipp Simon, and Alexander Rohrbach of the University of Freiburg in Germany have demonstrated that Bessel beams can propagate without significant diffraction through inhomogeneous media. The accompanying figure shows the intensity of fluorescence emitted by a transparent fluorescent gel when three kinds of beam passed through from left to right: a sheet-shaped beam from a cylindrical lens, a Gaussian beam scanned from top to bottom, and a Bessel beam scanned from top to bottom. The different patterns arose from the beams' interactions with hundreds of 2-μm-diameter glass beads that the Freiburg researchers had dispersed throughout the gel. As the light sheet and Gaussian beam encountered the beads, their scattered components interfered constructively, leading to bright streaks and therefore to what would amount to image artifacts. The Bessel beam had far less streaking. The researchers obtained similar results with a sample of fresh human skin, whose densely packed cells, like those of other biological tissues, are micron sized. Bessel beams could therefore form the basis of a new kind of biological microscopy. (F. O. Fahrbach, P. Simon, A. Rohrbach, *Nat. Photon.*, in press, doi:10.1038/nphoton.2010.204.) —CD



The physics of peeling paint. The complex mechanical properties of colloidal coatings are hard to measure because they vary spatially and temporally. Paint, for instance, starts as a fluid that, as the solvent evaporates, dries into a brittle solid that can crack and peel away from a substrate. To better understand the stresses that drive the fracture process, researchers led by Yale University's Eric Dufresne have now adapted a technique from cell biology known as traction force microscopy. In the technique's biological application, researchers observe a cell crawling across a rubber substrate and monitor the deformations within the rubber. Knowing the rubber's mechanical properties, the researchers convert the displacement field into a stress field and deduce which parts of the cell exert force on the substrate. Dufresne and colleagues replaced the cell with a drying film of a silica-particle suspension, which they applied to a soft layer of silicone rubber that would deform as the film dried and cracked. To map those deformations and convert them to a three-dimensional stress field, the team monitored the motion of tiny, fluorescent tracers mixed into the rubber. In the plot of stress as a function of distance from the crack front, the normal stress



(solid dots) shoots up rapidly just ahead of the crack front—with much greater magnitude than does the in-plane stress (open dots) and, reassuringly, with a scaling that roughly agrees with that predicted by classic fracture theory (red). (Y. Xu et al., *Proc. Natl. Acad. Sci. USA* **107**, 14964, 2010.) —RMW