mensions but invariant in the third, then the system could confine an incoming light beam as it flowed downstream, much as an optical fiber confines a propagating wave.

While at a conference this past summer, Schwartz learned that researchers led by Ad Lagendijk from the FOM Institute for Atomic and Molecular Physics in Amsterdam had actually predicted the effect and proposed, but never implemented, the same approach some 17 years earlier.[4] The advantage of the concept, known as traverse localization, lies in its geometry: The spatial evolution of the light in the propagating direction z can be mapped, Lagendijk realized, onto a Schrödinger equation that describes the evolution of a wavepacket, but with z replacing time. Researchers can thus measure localization in space rather than deduce it from a transmission spectrum.

Photonic engineering

As a first step toward measuring localization, Segev and company prepared a 2D photonic crystal—a periodic lattice that diffracts light in much the same way that a semiconductor diffracts electrons. The optical properties of a nonlinear crystal change with light intensity. By shining three intersecting laser beams within such a crystal, they could exploit interference to imprint a 2D periodic pattern onto its refractive index. Then, to introduce disorder, the group added "speckled" light to the lattice by shining yet another laser beam through a diffuser, which randomized the light's phase and amplitude.

As a 2D effect, for which scaling theory predicts no sharp transition between diffusive and localized behavior, transverse localization arises from an exceedingly small amount of disorder—small fluctuations in the 10^{-4} index contrast that defines the photonic lattice. The sensitivity allowed the group to reach the level of disorder required to see the effect by simply increasing the relative intensity of the diffused laser beam.

Crucial to observing transverse localization, however, is ensuring that the index of refraction vary only in the x–y plane, with each index value remaining fixed along z. That is the equivalent of having the potential frozen in time in the Anderson model. To keep the interfering plane waves invariant in that direction, Schwartz had only to arrange the waves symmetrically around the z axis. Eliminating the diffraction of the speckled beam was less intuitive, but passing the light through a conical lens placed some distance before the diffuser did the trick. The optics produced a grainy pattern in the lattice in the form of a random superposition of plane waves, all with a common wave-vector projection in z.

With the disordered lattice set up, the researchers launched a weak probe beam and imaged the intensity distribution in the x–y plane downstream as the light passed through the material (see the figure). In transverse localization, a narrow beam propagating through a disordered medium undergoes diffusive broadening until its width becomes comparable to the localization length. The greater the disorder, the faster the beam evolves into the localized state.

To describe the transport properties of the disordered lattice, Segev's team measured the light-intensity distribution through various scattering regimes. When the 10^{-4} contrast in refractive index fluctuates by 15%, light scatters randomly among lattice sites. Adding progressively greater disorder, the researchers monitored the evolution of the output image, which eventually revealed the signature effect of Anderson localization—an exponential falloff in the light intensity through the beam's cross section.

Central to the concept of localization are large statistical deviations in repeated intensity measurements of the same experiment. Because the intensity can vary wildly—owing to the effects of multiple interference—the researchers averaged 100 different measurements of the effective beam width for each level of disorder. To do that, they rotated the diffusion filter before repeating each measurement; each rotation altered the particular disorder pattern imprinted on the lattice.

Nonlinearity

In Segev's experiment, increasing the laser power offers a path to explore the interplay between disorder and the nonlinear response of photorefractive crystals[5] (see the article by David Campbell, Sergej Flach, and Yuri Kivshar in PHYSICS TODAY, January 2004, page 43). As the probe beam's power rises, so does its influence on the local refractive-index modulation. The beam's intensity has a Gaussian profile that causes the profile's width to slightly narrow while traveling through the lattice. This self-focusing tends to enhance the transverse localization.

Although the addition of nonlinearity to the mix complicates the system, it offers a new tool for studying the emergence of exotica such as solitons, discrete breathers, and other wave instabilities. And as a source of new physics, it whets the appetite for a deeper understanding of the transition between localized and delocalized states in materials.

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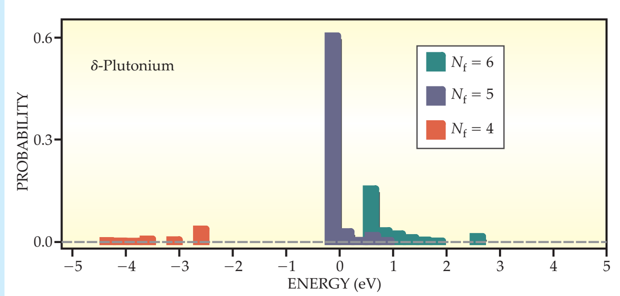
physics update

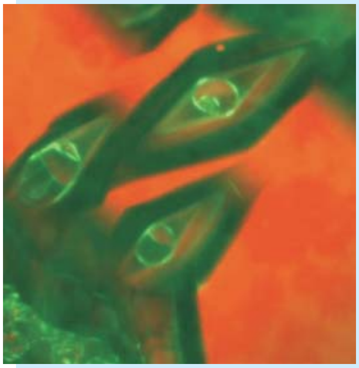
Supplementary material related to these items can be found at www.physicstoday.org.

Plutonium's bizarre behavior explained. Plutonium, a radioactive metal best known for its proclivity to undergo nuclear fission chain reactions, is not magnetic and does not conduct electricity well. In addition, plutonium's so-called δ phase at 600 K shows a 25% greater volume per atom than its more dense room-temperature α phase. What makes plutonium so bizarre? For starters, it is a strongly correlated material, in which the valence electrons cannot be treated as independent agents. To accurately model the system, condensed-matter theorists at Rutgers University in New Jersey combined two computational approaches to solid materials—the local density approximation and dynamical mean-field theory. (For more on DMFT, see PHYSICS TODAY, March 2004, page 53.) In the new model, plutonium's eight outermost or valence electrons can circulate among different orbitals rather than being confined to specific ones. The physicists found that the number N_f of valence electrons in plutonium's $5f$ orbital—the



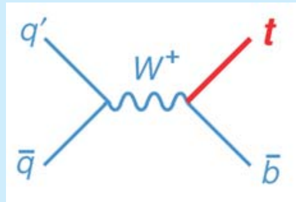
one with the greatest influence on its chemical properties—fluctuates. As the figure shows, five electrons are found there about 80% of the time, six about 20% of the time, and four less than 1% of the time. The new model accurately accounts for plutonium's key properties and makes several experimentally verifiable predictions. The theorists hope to use their method to understand the chemistry of uranium oxide and plutonium oxide, two important byproducts in nuclear reactors. (J. H. Shim, K. Haule, G. Kotliar, *Nature* **446**, 513, 2007.) —BPS

Hyperactive antifreeze proteins. AFPs occur naturally in many fish, insects, plants, and other organisms, allowing them to survive sub-freezing temperatures. The proteins come in various forms, but all seem to act similarly—they bind to nascent ice crystals and inhibit the crystals' subsequent growth, which effectively reduces the freezing point of ice in the organism. The AFP that is found in the spruce budworm (sbw) seems to be hyperactive and especially effective at protecting its host in the frigid winters of the northern US and Canada. A US–Canada team led by physicist Ido Braslavsky (Ohio University) and biochemist Peter Davies (Queen's University) marked sbwAFP with green fluorescent protein and with the help of fluorescence microscopy observed how the hyperactive protein coated the basal planes of ice crystals, halting their growth out of that plane. Previously the researchers had studied fluorescently tagged fish AFP types I and III. In this confocal microscopy image, it is apparent that the marked hyperactive sbwAFP (appears green) has accumulated on several surfaces of the ice crystals, including the basal planes, while the fish AFP type I (appears red) is mainly still in solution. Natural, nontoxic AFPs have many current and potential applications in the medical, agricultural, and food industries. Braslavsky reported the work at the March 2007 APS meeting in Denver. (N. Pertaya et al., paper J35.8. For the fish AFP type III work, see N. Pertaya et al., *Biophys. J.* **92**, 3663, 2007.) —BPS



Making slow salt. With their various internal vibrational and rotational motions, molecules are difficult to cool. Even so, millikelvin temperatures have been reached by using liquid helium for molecular vapors, and by decelerating polar molecules; microkelvin temperatures are obtained by welding together pairs of cooled atoms. A mechanical technique, using a spinning beam source whose speed cancels the velocity of the emerging molecules, has obtained speeds down to around 60 m/s. With a new kinematic technique, two physicists at the University of Bielefeld in Germany have now produced a beam of potassium–bromine salt molecules with an average molecular speed of 42 m/s; an estimated 7% of the beam travels slower than 14 m/s, corresponding to a temperature below 1.4 K. At that speed, some of the molecules could be loaded into a trap. The cold KBr molecules are made by sending a beam of K atoms into a counterpropagating beam of HBr molecules. With the beam velocities carefully tuned, chemical reactions produce the KBr molecules with a very small center-of-mass velocity. Other heavy salt molecules and radicals can also be produced this way, according to researcher Hansjürgen Loesch. Slow molecules are a prerequisite for performing cold chemistry, which could simulate conditions in cold planetary atmospheres or interstellar clouds. If the chemistry is cold enough, new quantum effects might emerge. (N.-N. Liu, H. Loesch, *Phys. Rev. Lett.* **98**, 103002, 2007.) —PFS

Unpaired top quarks. Weighing 200 times as much as a proton, the top quark is by far the heaviest elementary particle known. Because the strong nuclear force can't change a quark's flavor, it can produce quarks only in pairs with their antiquarks. The weak force can change flavors. But weak-interaction cross sections are so small that it's almost impossible to produce any quark, let alone the heaviest and rarest, without its antiquark in collisions between hadrons. But the DZero detector collaboration at Fermilab's Tevatron collider seems to have managed it. From among 10^{14} high-energy proton–antiproton collisions, the collaboration has found evidence for about 60 collisions that produced an unpaired top quark. One can't actually point to the individual events within the sample of 1400 selected candidates. The experimenters' case is indirect and sophisticated, involving complex decision trees and Bayesian neural networks to deduce the fraction of true single-top events buried within an overwhelming background of impostors. Impostors are less of a problem when one looks for top–antitop pairs. DZero's tour de force is important because the same technique will be required to ferret out evidence of the much-sought-after Higgs boson at CERN's Large Hadron Collider and possibly even at the Tevatron. Furthermore, the observation confirms the somewhat surprising standard-model prediction that at the Tevatron's 2-TeV collision energy, the cross section for producing single top quarks by the weak interaction is not much smaller than the strong-interaction cross section for making top pairs. The result also provides the first direct measurement of the top quark's coupling to the W boson that mediates the change of quark flavors. (V. M. Abazov et al., *Phys. Rev. Lett.*, in press.) —BMS



Free-space transmission of quantum code over a distance of 144 kilometers (89 miles) between two of the Canary islands has been demonstrated by a team of researchers in Europe. At the APS March Meeting in Denver, Anton Zeilinger of the University of Vienna described how he and his colleagues transmitted single photons from an astronomical observatory on La Palma to another one on Tenerife. The transmitted photons' entangled polarization states formed the basis of a "quantum key," a stream of information that could be used to decipher a longer encrypted message. To allow detection of potential eavesdroppers, the researchers further entangled the outgoing particles of light with photons kept at the transmitting station. The data transmission rate was low, only 178 photons in 75 seconds, but the experimenters overcame the difficulties imposed by long-distance propagation through a turbulent atmosphere. In a proposed experiment to be coordinated by the European Space Agency, which operates the Tenerife telescope, astronauts aboard the International Space Station would transmit an entangled key to two earthbound stations separated by distances 10 or more times greater than the two islands. (For a preprint, see R. Ursin et al., http://arxiv.org/abs/quant-ph/0607182.) —BPS ■