repeatedly preparing the state and measuring the states of both atoms. Usually (but not always, because the experiments were imperfect), when the first atom was in $|0\rangle$, the second was in $|1\rangle$, and vice versa. But that observation is not enough to prove entanglement. The atoms could have been produced half the time in the unentangled state $|01\rangle$ and half the time in $|10\rangle$.

A quantum statistical ensemble is characterized by the density matrix ρ. The matrix's diagonal elements $\rho_{k,k}$ are the probabilities P_k of finding the system in state k, where in this case k is one of the four pure states $|11\rangle$, $|10\rangle$, $|01\rangle$, and $|00\rangle$. The off-diagonal element relevant to verifying the entangled state $(|01\rangle + |10\rangle)/\sqrt{2}$ is $\rho_{10,01}$. Called the coherence between $|10\rangle$ and $|01\rangle$, it's a measure of how tightly the phase is constrained between those two components.

The fidelity, $F = (P_{01} + P_{10})/2 + \rho_{10,01}$, quantifies both how close a process comes to reliably producing the state $(|01\rangle + |10\rangle)/\sqrt{2}$ and how much entanglement it produces. When $F > ½$, the atoms are entangled in the sense that their state can't be represented as a statistical ensemble of products of local wavefunctions. (An accessible proof is given in reference 5.) There's a second threshold at $F > \sqrt{2}/2$, corresponding to violation of Bell's inequalities.

In an experiment that entangles the spins of two particles, off-diagonal elements can be measured, and entanglement verified, by measuring the spins in multiple directions. A process that prepares the state $(|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle)/\sqrt{2}$, where $\uparrow$ and $\downarrow$ are the spins in the z direction, produces particles that are opposite in spin in every direction. But if the process randomly produces either $|\uparrow\downarrow\rangle$ or $|\downarrow\uparrow\rangle$, the spins measured in the x direction would appear uncorrelated.

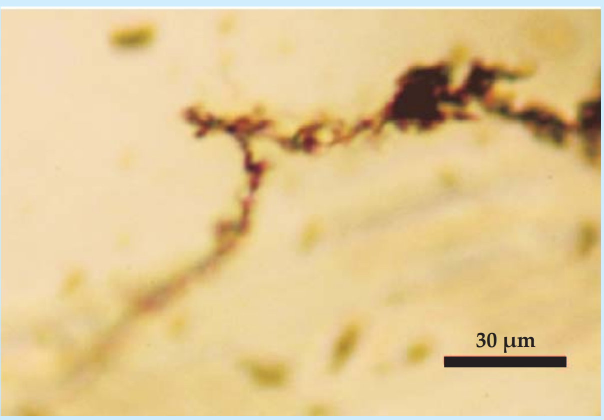
The two-state system that comprises the relevant hyperfine states is mathematically equivalent to a spin-½ particle. Coherent pulses of light do the equivalent of rotating the spins to allow them to be probed in different directions. The Wisconsin researchers ap-

physics update

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

A carbon halo. In most nuclei the protons and neutrons form a roughly spherical core of approximately uniform density. But along the edges—the so-called drip lines—of the chart of nuclides, a handful of light nuclei have more nucleons than can be accommodated in the nuclear core. The excess, usually one or two neutrons, form a dilute distribution called a halo that extends far beyond the core. At the RIKEN Nishina Center for Accelerator-Based Science, a Japanese team has studied the reaction of heavy carbon nuclei with hydrogen and identified the extremely neutron-rich carbon-22, with its 6 protons and 16 neutrons, as a halo nucleus, the heaviest one yet found. Nuclear radii generally scale as the cube root of the total number of protons and neutrons, yet based on their cross-section data, the researchers calculated the radius of ^{22}C to be twice that of the much more common isotope ^{12}C; indeed, at 5.4 fm it exceeds the radius of lead-208. The halo of ^{22}C comprises two valence neutrons; determining their distribution and other aspects of the halo structure will require experiments with different target nuclei and different beam energies. (K. Tanaka et al., *Phys. Rev. Lett.*, in press.) —RJF

A template for microwire self-assembly. Several methods exist for growing nanowires, whether attached to a substrate or dispersed in a liquid. Using those wires to make designated electrical connections in a circuit, however, has been difficult. Yves Galerne and his colleagues at the University of Strasbourg, France, now demonstrate a procedure that produces conducting wires across a gap between two electrodes. The chemical physicists first paint the electrodes with a polymer so as to create "anchors" in predetermined locations; when the gap is filled with nematic liquid crystals, an isolated defect line—a disclination—connects the anchors and therefore the electrodes. Next, silica particles coated with a conducting polymer are introduced and gather along the disclination like beads on a necklace. In the third step, a voltage across the electrodes welds the necklace beads together into a robust wire. Although ragged with extra polymer aggregates, the central region of a 150-micron-long wire, shown in the photo, demonstrates the team's initial result. The researchers note that the wire's size, smoothness, and conductivity can be improved—for example, by decreasing the silica particles' size and concentration and by electroplating them. (J.-B. Fleury, D. Pires, Y. Galerne, *Phys. Rev. Lett.* **103**, 267801, 2009.) —SGB



Imaging light with electrons. In recent years, notions of the ultrafast, the ultraintense, and the ultrasmall have been recurring themes in physics as those envelopes have been relentlessly pushed to reveal new phenomena. Caltech's Brett Barwick, David Flannigan, and Ahmed Zewail have combined all three notions into a new technique they dub photon-induced near-field electron microscopy. PINEM exploits the fact that free–free interactions of electrons and photons are greatly enhanced when a third body, like a nanostructure, is present and when the electrons are more energetic than the photons. The physicists illuminated a carbon nanotube with an intense femtosecond laser pulse that generated an evanescent plasmonic field at the CNT's surface. Simultaneously, a similar-duration pulse of 200-keV electrons from an electron microscope passed through the sample. During the few-hundred-attosecond interaction time, some of those electrons absorbed energy quanta from the 2.4-eV photon field. By selecting only those electrons that gained energy, the researchers could image the evanescent surface field with the spatial resolution of electron microscopy. That field extends about 50 nm into the vacuum from the dark surface of the roughly