

resonant frequency, the researchers excited the spins and subsequently measured their state. From the strength of their signal, they determined that the spin-circuit coupling should be strong enough to make spontaneous emission the dominant mechanism for spin relaxation.

To prove it, they measured the emission rate directly: To a sample cooled to 20 mK, they applied a microwave pulse to excite all the spins, waited an adjustable time  $T$ , then measured the fraction that remained in the excited state. In the ab-

sence of enhanced spontaneous emission, the excited-state population decays exponentially, via nonradiative mechanisms, with a lifetime of about half an hour. But when the spin-flip transition energy was tuned into resonance with the circuit, the excited-state lifetime dropped to just 0.35 s.

Nor was the enhancement all or nothing. By slightly detuning the transition from the circuit resonance, Bertet and company achieved a range of intermediate excited-state lifetimes, as shown in figure 3.

## Reset button

Although specific applications may be a long way off, enhanced spontaneous emission from electron spins may find use in numerous areas. Of most interest to Bertet and colleagues is the ability to make ESR experiments faster and easier. In the current state of the art, once some spins are excited, there's no easy way to return the system to thermal equilibrium to begin again. Circuit-enhanced spontaneous emission could function as a kind of reset button that can be activated on demand.

## PHYSICS UPDATE

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

### BORON NITRIDE NANOTUBES REINFORCE POLYMER MATERIALS

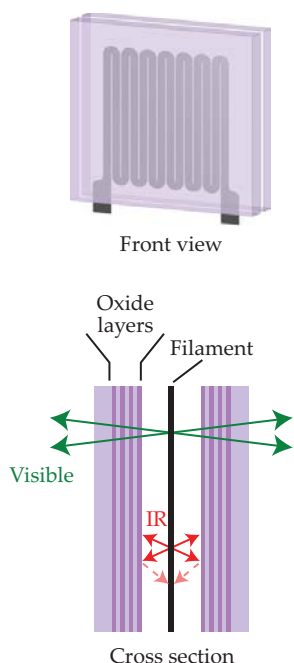
One form of boron nitride is a white, lubricious, flaky material whose material properties resemble graphite's. By contrast, its nanotube form, like carbon's, is strong, tough, and light. Exploiting those desirable properties in a bulk material entails embedding the nanotubes in a light-weight matrix—provided the

nanotubes bind strongly enough to the matrix material that they don't slip. Quantifying that binding was the goal of an investigation led by Changhong Ke of Binghamton University and Xian-qiao Wang of the University of Georgia. The researchers created thin polymer films—of epoxy and of PMMA—and embedded them with boron nitride nanotubes (BNNTs). Cleaving the films left some BNNTs poking out from the surface. By welding a nanotube's protruding tip to an atomic force microscope, the team could determine how much force was needed to pull it out. For tubes buried deeper than about 200 nm, the force turned out to be 250 nN for the BNNT-epoxy composite and 190 nN for BNNT-PMMA. Less force was needed to extract carbon nanotubes (CNTs) from the same materials. Molecular dynamics simulations revealed the source of the BNNTs' stronger binding. Because BNNTs are made of two different elements—as opposed to one in the case of CNTs—their bonds are polar. And thanks to that polarity, BNNTs bind to the polymer matrix not just with van der Waals interactions but with Coulomb interactions too. Ke and Wang's findings suggest that BNNTs are excellent fillers for light-weight, high-strength composites. (X. Chen et al., *Appl. Phys. Lett.* **107**, 253105, 2015.) —CD

### RECYCLING LIGHT

Conventional incandescent lightbulbs reach the 3000 K needed to emit in the visible range thanks to ohmic heating of a resistive tungsten filament. That process is extremely inefficient at producing light, though, because most of the spectrum of a 3000 K blackbody lies in the IR. Tailoring the spectrum by suppressing all but the wavelengths of interest can avoid the wasted energy. To that end, MIT researcher Ognjen Ilic, his postdoctoral adviser Marin Soljačić, and their colleagues surrounded the filament with interference filters that transmit visible light but reflect the IR. The

idea of recycling unwanted IR emission to provide an additional source of heat to the filament isn't new. Two features distinguish the team's implementation: First, unlike earlier filters, which were



300 layers of four oxides can reach efficacies as high as 270 lum/W, far surpassing that of the best commercial lights. (O. Ilic et al., *Nat. Nanotechnol.*, in press, doi:10.1038/nnano.2015.309.) —RMW

### NEUTRINO MAGNETOHYDRODYNAMICS

Neutrinos interact only weakly with ordinary matter. Yet in certain astrophysical contexts, such as supernova explosions, the coupled interactions between neutrinos and dense, highly ionized plasmas contribute significantly to a system's evolution. Modeling such systems is complicated enough even in the absence of neutrinos, and it normally requires analytic approximations or detailed numerical simulations. Adding neutrino effects entails further compromises; past approaches, for example, typically consider energy exchange between neutrinos and a neutral fluid. Now Fernando Haas and Kellen Alves Pascoal (Federal University of Rio Grande do Sul, Brazil) and Tito Mendonça (University of Lisbon, Portugal) propose a new framework for integrating relevant aspects of neutrino and plasma physics. Their approach, which they

A similar benefit could accrue to the field of quantum information. Normally, it's desirable for qubits to retain their state for as long as possible, but sometimes it's necessary to wipe the slate clean and start again.

Finally, the results may be applicable to the NMR technique of dynamic nuclear polarization. Because an atom's nuclear spin states are so close in energy, even under a strong applied magnetic field, it can be difficult to coax more of them into one state than the other. In a typical MRI, for example, nuclear polarization is

measured in parts per million. Electron spins are easier to polarize because of their stronger magnetic moments, and under some circumstances it's possible to transfer electron polarization into nuclear polarization via a so-called flip-flop transition. The Bi-electron spin pairs undergo just such a transition—due to selection rules, flipping the electron spin necessarily changes the direction of the coupled Bi nuclear spin. It's possible that other flip-flop transitions could also be accelerated on demand.

Bertet and colleagues' next step is to

follow their original plan and work toward a nanoscale resonant circuit. The smaller dimensions promise not only single-spin ESR sensitivity but even faster spontaneous emission.

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## USING CARS TO GAUGE TORNADO STRENGTH

In the 1996 blockbuster *Twister*, a semi-articulated fuel truck is lofted and flung by a writhing tornado into the path of the movie's storm-chasing heroes. Doubtless the filmmakers conceived the scene to demonstrate the fake tornado's terrible strength, but as a new study concludes, the movement of vehicles can actually be used to evaluate the strength of real tornadoes. Marius Paulikas and Thomas Schmidlin of Kent State University and Timothy Marshall of Haag Engineering examined field surveys of 959 passenger vehicles struck by tornadoes in 1994–2008. After classifying the vehicles according to whether they had been unmoved, displaced, rolled, or lofted, the researchers



correlated the movements with the tornadoes' strength as determined by the damage inflicted on houses, trees, and other structures. For category EF3 and EF4 tornadoes, whose 136–200 mph winds can knock over trains and destroy entire stories of houses, 63% of cars were displaced, with 15% rolled or lofted. But for EF1 and EF2 tornadoes, whose 86–135 mph winds can upturn mobile homes and uproot trees, 65% of cars were not moved at all.

Currently, wind's impact on cars is not taken into account when assigning an EF category to a tornado. Paulikas, Schmidlin, and Marshall's study suggests that including cars could improve the scale's accuracy, especially in the absence of buildings and trees. It also suggests that cars could be safer havens than mobile homes. (M. J. Paulikas, T. W. Schmidlin, T. P. Marshall, *Weather Climate Soc.* **8**, 85, 2016.) —CD

dub neutrino magnetohydrodynamics (NMHD), systematically extends MHD, which treats a plasma's electrons and ions as fluids and considers the dynamics of the magnetic field they produce, to include the weak interaction, which in particle physics describes the coupling between neutrinos and electrons. Adopting standard simplifying assumptions from MHD theory, the researchers obtain a set of 11 coupled partial differential equations that they show should hold over a range of astrophysical conditions. In particular, they find that neutrinos can prevent magnetic field lines from freezing, even in an ideal plasma. They also derive a new, neutrino-driven plasma instability that should play a central role in a supernova's strongly magnetized environment. (F. Haas, K. A. Pascoal, J. T. Mendonça, *Phys. Plasmas* **23**, 012104, 2016.) —RJF

## COMBING FOR A SIGNAL BURIED IN NOISE

Picking out a signal from a sea of noise is a ubiquitous research challenge. If the signal recurs, multiple measurements can be appropriately averaged to improve the signal-to-noise ratio. For a single transient event, Fourier decomposition—breaking the signal down into its frequency components—can help isolate signal from noise. The signal's frequency components are correlated in phase with each other, whereas those of the noise are not. When

the components are summed as complex numbers that encode phase and amplitude, only the signal adds up coherently. Calculating the Fourier transform works well enough for slow signals lasting a few microseconds, but faster signals run up against the resolution limits of both detectors and analog-to-digital converters. Now a University of California, San Diego, group led by Stojan Radic has employed tunable optical frequency combs, developed in Radic's lab, to catch those faster signals. (For more on frequency combs, see *PHYSICS TODAY*, June 2000, page 19.) The researchers used two phase-locked combs with slightly different spacing between their teeth. They combined a test signal—an 80-ps microwave pulse laden with white noise—with the first comb to make copies of the signal at each tooth. Using the second comb's teeth as reference frequencies, the researchers measured a narrow slice of each copy and thus partitioned the data into frequency bins. The outputs of those bins could then be summed. The gain in signal-to-noise ratio is limited only by the number of copies one can generate. The researchers have tested up to 300 copies for a gain of 25 dB. The group's tunable frequency combs are already commercially available, and Radic is eager to see how other researchers put his setup to use. (V. Ataie et al., *Science* **350**, 1343, 2015.) —SC PT