

Musical pitch perception starts early

Tasked with extracting the fundamental frequency from a complex of high harmonics, three-month-old infants outperformed many adults.

When a musical instrument plays a note, the sound wave produced is not a single frequency but a spectrum of harmonics. The composition of that spectrum determines the note's timbre: the distinguishing factor between the sounds of, for example, a flute and a trumpet, or different vowel sounds in a spoken or sung syllable. Even when the fundamental frequency is absent and only the higher harmonics are present, the adult human brain can fill in the missing fundamental and perceive the note's pitch.

Now Bonnie Lau and Lynne Werner of the University of Washington have tested whether infants in different stages of development can do the same.¹ Pitch

perception is related to how infants learn to segregate different sounds occurring at the same time, an important skill in making sense of the complex environmental sounds encountered every day.

The researchers had their infant participants listen to sequences of notes drawn from a set of 10 high-harmonic complexes, 5 for each of 2 fundamental frequencies. The complexes consisted of different combinations of the 12th through 31st harmonics—between $3\frac{1}{2}$ and 5 octaves above the fundamental—and they bore little resemblance to their respective fundamental frequencies. Still, Lau and Werner were able to condition the infants to associate changes

in fundamental frequency with the activation of a mechanical toy (just outside the field of view in the figure).

Once they were conditioned, the infants responded behaviorally whenever the missing fundamental was changed—but before the mechanical toy was turned on. None of the adults involved in facilitating the experiment listened to the same notes the infants did; they had to judge whether the infants were hearing a change in fundamental from behavioral cues alone.

Curiously, three-month-old and seven-month-old infants performed equally well at the task, even though the sensory pathways in the brain change radically between those ages. At three months, the auditory cortex is not yet mature, and sounds are most likely processed in the brain stem.

Lau and Werner then repeated the experiment with adult participants, who were instructed, cryptically, to lis-

physics update

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

Zinc ore catalyzes Earth's organic chemistry. Carbon compounds are ubiquitous, even in deep ocean sediments, in subduction zones, and at mid-ocean ridges. Although the essential ingredients of the chemical reactions in such environments are well known—organic molecules, hot pressurized water, and minerals—studies of the ways in which individual

minerals influence reactivity are virtually nonexistent. That's partly because geochemical organic reactions tend to generate complex product mixtures, which can obscure the mechanism. Hilairy Hartnett and a team of researchers at Arizona State University have

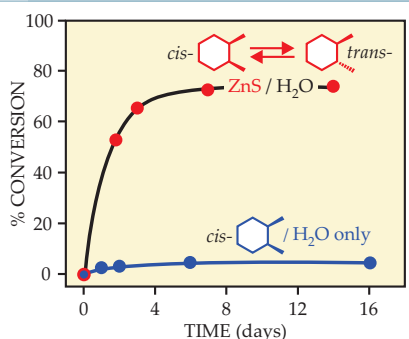
intermediate that can then reform the bond as either the *cis*- or *trans*- isomer. The catalysis of C–H bonding is not new, but the Arizona State experiments may interest industrial chemists. Unlike most organometallic catalysts, minerals are inexpensive, are robust, and require no synthesis. (J. A. Shipp et al., *Proc. Natl. Acad. Sci. USA* **111**, 11642, 2014.) —RMW

Quantum electrodynamics in a semiconductor vacuum.

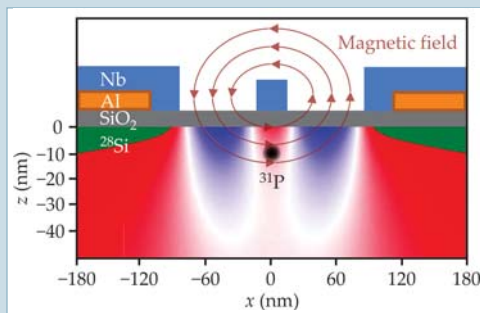
An isolated atom is, in many regards, the quintessential quantum system, but it interacts only weakly with its electromagnetic environment. As described by cavity quantum electrodynamics (QED), however, atom–photon interactions can be manipulated by placing an atom in a highly reflective optical cavity (see the article by Serge Haroche and Daniel Kleppner, *PHYSICS TODAY*, January 1989, page 24). With modern nanofabrication techniques, the coupling of an artificial atom, such as a quantum dot or superconducting qubit, to a nearby transmission-line resonator or other microwave circuit can analogously be engineered, in what's been dubbed circuit QED (see *PHYSICS TODAY*, November 2004, page 25, and the article by J. Q. You and Franco Nori, November 2005, page 42). Although many properties of artificial atoms can be readily tuned, the quantum states typically have short coherence

times. Now Andrea Morello and colleagues at the University of New South Wales in Sydney, Australia, report a promising new scheme: a lone phosphorus-31 atom embedded in an isotopically purified

substrate of silicon-28 and magnetically coupled to a superconducting niobium resonator (the figure shows the cross section). With no net nuclear or electron spin, the ²⁸Si sub-



now presented the first description of mineral catalytic effects on the most fundamental aspect of an organic reaction: the breaking and making of a covalent bond. In the group's experiments, when the model alkane *cis*-1,2-dimethylcyclohexane was placed in a chamber at 300 °C and 1000 atmospheres and allowed to react with water alone, little happened. A mere 5% of the isomer converted into the *trans*- form of the alkane over a two-week time span, as shown by the blue curve. But when the hydrothermal reaction occurred in the presence of sphalerite, a mineral form of zinc sulfide commonly found on the sea floor among black smoker vents, the conversion rate rose dramatically (red curve). The *trans*- structure was primarily produced until an equilibrium between the stereoisomers was reached. The result is consistent with a mechanism in which sphalerite breaks a C–H bond to form an





Testing pitch perception. An infant participant listens to a series of harmonic complexes through an earphone. Whenever the fundamental frequency changes, a mechanical toy to the infant's right (not shown) turns on. The stuffed lion keeps the infant otherwise facing forward. An experimenter observes the infant's behavior from another room. (Courtesy of Bonnie Lau.)

ten for "the sound that makes the toy come on." "We tried to keep the testing as similar as possible," explains Lau. "Adults weren't told explicitly to respond to a pitch change because infants were not told to."

Adult participants who had had any musical training—defined loosely

with several previous studies showing that regardless of musical training, adults can indeed perceive the pitch of high-harmonic complexes.²

To reconcile that discrepancy, Lau and Werner hypothesize that adults are more easily distracted than infants by changes of timbre rather than pitch.

Perhaps infants perceive pitch and timbre with different relative priority than adults do—or perhaps they don't perceive changes in timbre at all. Says Lau, "That's an experiment we're working on right now."

Johanna Miller

References

1. B. K. Lau, L. A. Werner, *J. Acoust. Soc. Am.* **136**, 760 (2014).
2. A. J. M. Houtma, J. Smurzynski, *J. Acoust. Soc. Am.* **87**, 304 (1990); T. M. Shackleton, R. P. Carlyon, *J. Acoust. Soc. Am.* **95**, 3529 (1994); J. G. Bernstein, A. J. Oxenham, *J. Acoust. Soc. Am.* **113** 3323 (2003).

strate behaves like a magnetic vacuum, isolating the ³¹P atom's unpaired electron and enabling exceptionally long coherence times. The researchers show that for experimentally realizable configurations, the coupling between the spin and the microwave circuit should be strong enough to allow coherent control and nondemolition measurement of the spin state. (G. Tosi et al., *AIP Advances* **4**, 087122, 2014.) —RJF

An elementary particle collision never before observed.

In the standard model of particle physics, the W^+ , W^- , and Z are so-called vector bosons that transmit the weak force responsible for nuclear decay. But those bosons can also scatter off each other with a cross section that is sensitive to the many details of the theory. Vector-boson scattering is rare; for example, at the Large Hadron Collider the process happens less often

than Higgs boson production. Thus, it had never been used to probe particle theory's accepted paradigm. But ATLAS team members at the LHC have now spotted 34 candidate WW scattering events. The W bosons are neither the particles crashed together by the LHC (those are protons) nor the outgoing particles detected by ATLAS. Rather, as illustrated in the Feynman diagram, during the collision a W (here a W^+) is radiated by a quark in each of the protons. After scattering, each W^+ decays into a positron or antimuon—both members of a larger particle class called leptons—and an undetected neutrino. The outgoing quarks, which cannot exist in isolation, are manifest as particle jets. The experimental signature of the W^+W^+ scattering is thus two positive leptons, two jets, and missing neutrino energy. With sophisticated numerical calculations and background corrections, the ATLAS researchers conclude that their observations are consistent with the standard model. As the LHC collision energy rises and precision

improves, vector-boson scattering may test the Higgs mechanism of the model in detail and even point to new, nonstandard physics. (G. Aad et al., ATLAS collaboration, *Phys. Rev. Lett.*, in press.) —SKB

How a river transports sediment. Fine-grained sediment is both light enough to be carried by a river's current and heavy enough to settle on its floodplain. How far do grains travel before settling? To answer that question, Jim Pizzuto of the University of Delaware turned an episode of industrial pollution into an experiment. From 1929 to 1950, DuPont's rayon mill in Waynesboro, Virginia, used mercury as a catalyst. Mercury subsequently leaked into the nearby South River, where it remains a health hazard. Because mercury readily attaches to suspended grains, its presence in a river's floodplain can be used to trace sediment transport both in space (by extracting cores at different locations) and in time (by dating a core's layers). Pizzuto analyzed the spatial distribution of mercury taken from cores along a 37-km-long stretch of the South River downstream of Waynesboro. A previous study had established that the concentration of mercury averaged along the same stretch peaked sharply between



1940 and 1960. Mercury-tagged sediment evidently made its way downstream in a single, decades-wide pulse. Indeed, Pizzuto found that the mercury concentration falls off exponentially as a function of downstream distance, consistent with a moving, gradually depleting pulse. The derived decay length of just 10 km suggests that fine sediment moves down the South River in a sequence of short hops that occur only when flood conditions strengthen the river's current. (J. E. Pizzuto, *Geophys. Res. Lett.*, in press.) —CD