alism. Building on theoretical work by Greenberger, Horne, and Zeilinger, Lucien Hardy at the University of Durham in the United Kingdom constructed a test that, says Kwiat, is "brilliant in terms of being able to explain the whole thing to your grandmother."

That's the scheme that Mandel and his colleagues, Justin Torgerson and David Branning at Rochester and Carlos Monken at the Universidade Federal de Minas Gerais in Brazil, describe in the 28 August issue of *Physics Letters* A. The group sent ultraviolet laser light through a crystal of lithium iodate, a nonlinear material that can split a photon into a longer wavelength pair with identical polarizations. They then passed one photon in an occasional pair through a polarization rotator, which turned its polarization by 90 degrees, then mixed it back together with its mate at a beam splitter—a step that entangled the quantum-mechanical wavefunctions of the rotated and unrotated photons. The result was two photons composed of mixed-up pieces of the original two.

The beam splitter then sent the mixed wavefunctions down two separate arms of the apparatus. At the end of each arm lay an adjustable polarization filter and a light detector. The filter served as a measuring device by letting a photon reach the detector or blocking it, depending on its polarization.

Because each photon is a mixture of two orthogonal polarizations, it can exhibit any polarization when measured. And because the two photons are entangled, their polarization angles have a statistical correlation. When quantum theory is applied to the entangled wavefunctions, it makes specific predictions about how often the two detectors should record photons simultaneously for particular polarizer angles in the setup's two arms. If, for example, detector 1 records a photon when its polarizer is set to 74.3 degrees, then the theory predicts that detector 2 should always record a photon when its polarizer is set to −33.2 degrees. The Rochester group found that these quantum mechanical predictions hold up nicely, says Mandel.

That result doesn't create a serious problem for local-reality holdouts. For them, the real trouble comes when the experimenters look for other pairs of polarizer angles that also yield perfect coincidences. Torgerson and Branning liken the measurements to watching the opening of Dutch doors, which are split in the middle so that trays of food can be served through the top without opening the entire door. "Opening a door is like making a photodetection," says Branning. If the sections of a Dutch door represent two polarizer angles that always yield a coincidence, the top half of the door will always open along with the bottom.

Having found two pairs of polarizer angles corresponding to two doors that must swing open in this way, the researchers started checking the coincidences when one angle was chosen from each door. For certain sets of angles, they found, the bottom halves of both doors sometimes opened together. And here's the rub: The top halves never did. Yet the top and bottom of each door had swung open together in the earlier set of measurements. If the polarizations exist irrespective of measurement, detecting the bottom polarizations in both arms implies that the top polarizations should also be present, unmeasured, in the opposite arms. But in quantum mechanics, which makes no assertion at all about one set of polarizations while others are being measured, there's no contradiction at all.

"These experiments remind us not to fall into [a] comfortable, local-realistic picture," says John Rarity of the Defense Research Agency in the United Kingdom. Rarity and others point out, however, that such work rigorously eliminates local realism only under the "fair sampling" assumption, which takes the photons captured in the still-inefficient detectors to be representative of all photons present. That sends up a red flag to EPR advocates like Augusto Garuccio of the University of Bari in Italy, who collaborated for a time on the Mandel experiment. The fair-sampling assumption, if incorrect, "could be the cause of the claimed violation of the locality," says Garuccio.

That criticism is almost—but not quite—put to rest by a paper in press at *Physical Review Letters* by Kwiat along with Klaus Mattle, Harald Weinfurter, and Zeilinger at Innsbruck, and Alexander Sergienko and Yanhua Shih at the University of Maryland, Baltimore County. Using related techniques in an experiment based on Bell inequalities, these authors have observed the most extreme statistical violation of local realism ever reported. The overall detection efficiency is also the highest on record, and members of this group, along with Philippe Eberhard of the Lawrence Berkeley National Laboratory, believe this may be a step toward a loophole-free experiment within the next few years. And in independent work, Edward Fry of Texas A & M University is now building what he hopes will be a loophole-free experiment based on atomic spins rather than photons.

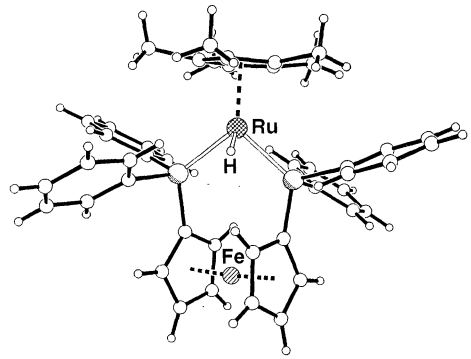
The success of these experiments may finally prove Einstein's "common sense" view to be wrong. But they won't ease discomfort with quantum mechanics. Einstein "was driven [to his conclusions] because he realized how strange quantum mechanics is," says Zeilinger. Experiments like Zeilinger's insist that the strangeness is a fact of life.

–James Glanz

BIOCHEMISTRY

Model Enzyme Takes Hydrogen Apart

Splitting hydrogen molecules into their components, two electrons and two protons, may seem like a simple reaction. But the exact process—a life-or-death one for many anaerobic bacteria, which depend on the reaction for energy—has remained mysterious to biochemists. They've known for a long time that enzymes called hydrogenases are involved, yet the unwieldy size of these enzymes has prevented researchers from documenting the breakup step by step with conventional spectroscopic techniques; intermediate complexes in the breakup are cloaked by the enzymes' complexity. So investigators have been struggling to design simpler and more easily observable compounds that mimic this hydrogen-splitting ability.



SOURCE: R. HEMBRE

New metal, new model. Substituting ruthenium (Ru) for nickel made this molecule a hydrogenase mimic.

Now a group of researchers from the University of Nebraska, Lincoln, led by chemist Robert Hembre, report creating the first hydrogenase model that performs hydrogen-splitting duties. In addition to shedding light on how the enzymes work, the new molecules may be inexpensive catalysts for power systems, known as fuel cells, that convert the chemical energy in hydrogen gas directly into electricity.

The research, which will be published in the *Journal of the American Chemical Society* in January, is already drawing praise from colleagues. "It's really dynamite work," says chemist James Collman of Stanford University in Palo Alto, California. Even though the new structures are different from the natural protein, "they imitate the function of the real thing," says Collman.

The compounds, known as metal hydrides, are such good mimics because they borrow a key element from hydrogenase itself: a closely knit pair of electron-hungry atoms from a so-called transition metal. Researchers have long thought that an atom of nickel, a transition metal that's part of the hydrogenase molecule, steals electrons from hydrogen. But hydrogenases also carry an iron atom located near the nickel, which

may also play a role in the theft. So researchers have been trying to make model compounds with both nickel and iron, but the task is "extremely difficult," says Hembre. The reason, in part, is that nickel and iron have similar chemical reactivities, causing them to form clusters during synthesis and yield a variety of different compounds.

So Hembre and his colleagues J. Scott McQueen and Victor Day opted to use ruthenium, another transition metal, instead of nickel, because its chemical reactivity differs from that of iron. To better control the synthesis, they made their ruthenium-iron model compound by attaching each transition-metal atom to ring-shaped groups known as cyclopentadienes. These groups help stabilize the reactivity of the transition metals, making them easier to bring together. And because these models only have a pair of transition-metal atoms, while hydrogenase has many, it's much easier for researchers to use electrochemistry and spectroscopy to track changes in electronic behavior: The signal doesn't get lost in the noise.

First, the researchers determined how closely the models mimic hydrogenase. When placed in solution with hydrogen, both the enzymes and the new models grab electrons from H_2 and parcel them out one at a time to electron acceptors, such as methyl viologen, causing the viologens to change color from yellow to bright blue. The researchers were then able to get a closer look at the process using electrochemistry and nuclear magnetic resonance spectroscopy. The studies show that H_2 releases a proton after it binds to ruthenium. Next, the metal steals H_2's electron pair, and finally the remaining proton falls away.

"The final question is, does the real thing work that way?" asks Collman. To find the answer, Hembre and his colleagues are currently working to create new model compounds that contain nickel and iron in the core, hoping to see those compounds split H_2 in the same fashion as the real protein. They hope the stabilizing effects of the cyclopentadiene groups will make this synthesis easier.

Even if the strategy fails, some ruthenium-based compounds themselves may still prove useful. The hydrogen-splitting reaction is crucial in some fuel cells, which power things such as hospital generators. The cells strip the electrons from hydrogen to generate an electric current. At present, however, fuel cells typically perform this reaction with the help of a costly, but efficient, platinum catalyst. If Hembre's compounds based on ruthenium—a much less expensive metal—convert hydrogen to electricity just as efficiently, their relatively low cost may make these model compounds part of a model power source.

–Robert F. Service

MEETING BRIEFS

Geoscientists Contemplate a Fatal Belch and a Living Ocean

NEW ORLEANS—Paleontologists may deal with dusty fossils, but they also ponder some of the planet's greatest catastrophes. At last month's annual meeting of the Geological Society of America in New Orleans, one eye-opening presentation argued that the extinctions at the end of Permian period might have been triggered by a belch of deep-sea carbon dioxide. Another suggested that the scope of the Cretaceous-Tertiary catastrophe at the end of the age of the dinosaurs needs to be scaled back, at least in the oceans.

Another Killer Charged With Mass Extinction

No wonder life took a beating—its worst ever—250 million years ago at the end of the Permian period. Just months ago, researchers determined that the largest known volcanic eruption on land took place in present-day Siberia at the same geological moment as the extinctions, which wiped out 90% of all genera in the oceans. Now they've stumbled on evidence of another assault—a sudden surge of carbon dioxide from the deep sea that allegedly poisoned marine life.

Paleontologists studying the extinctions don't yet know how much to blame the eruptions or the gas belch—assuming it happened. And researchers in other fields aren't fully convinced by the scenario that paleontologists Andrew Knoll of Harvard University and Richard Bambach of Virginia Polytechnic Institute and State University and sedimentologist John Grotzinger of the Massachusetts Institute of Technology (MIT) have sketched out as the driving force behind their postulated carbon dioxide surge. But the idea, and the circumstantial evidence that Knoll and his colleagues are marshaling, is capturing imaginations. "It isn't as yet backed up by a tremendous amount of data," says paleontologist Douglas Erwin of the National Museum of Natural History, a leader in studies of the extinction, but "I think it's an interesting, even fascinating, hypothesis."

Knoll and his colleagues were drawn into the fray when a paleontologist colleague showed a slide of a layered rock from late in the Permian. The paleontologist assumed it was a fossil stromatolite, a mound of sediments glued together by primitive blue-green algae. But Knoll and Grotzinger immediately recognized it as an inorganic carbonate precipitate, a rock type that rarely formed in the past 500 million years but was common in earlier times. Carbonates are usually formed from the remains of once-living animals, but during five cycles of glaciation in the late Precambrian between 600 million and 800 million years ago, carbonates precipitated directly from seawater without any help from living things, presumably when the concentration of dissolved carbonate—that is, dissolved carbon dioxide—became exceedingly high. As it turned out, these anomalous carbonates are also relatively common at the time of the mass extinction, and Knoll and Grotzinger saw them as a sign of climate and geochemistry gone awry.

DOUGLAS ERWIN/NMNH

Trace of a killer? Did the high seawater carbon dioxide that precipitated this carbonate also trigger a mass extinction?

The ultimate cause, they propose, was a shutdown in the circulation of the deep ocean. Toward the end of the Permian, all the continents were huddled in a single supercontinent, Pangaea. That would have left a globe-girdling ocean with some narrow seas within the supercontinent. With no continental ice sheets to chill surface waters and send them diving into the deep sea, as they do today around Antarctica, the group argues, deep waters grew sluggish and even stagnant. As phytoplankton in surface waters continued to extract carbon dioxide from the atmosphere, converting it to organic matter that sank and oxidized to carbon dioxide, the deep sea's carbon dioxide content would have soared.

The deep ocean's gain was the atmosphere's loss, according to the Harvard-MIT scenario. As the "biological pump" of phytoplankton kept driving atmospheric carbon