"There has always been a lot of discussion about the relationships between these termites, the cockroaches, and the mantids; it's been one of the larger conundrums in entomology," explains Barbara Thorne, an entomologist at the University of Maryland in College Park. Thorne and James Carpenter, an entomologist at the American Museum of Natural History, recently addressed the issue using morphological comparisons and concluded *Mastotermes* was a separate genus and not a missing link between cockroaches and termites, as some evolutionary biologists argued. Their verdict is supported by Grimaldi and DeSalle's DNA study: "Their study is a nice complement to ours; it's a wonderful independent assessment," exults Thorne.

Thorne is eager to see Grimaldi and DeSalle's work extended to other species. "We have so many amber specimens which people have studied from a morphological standpoint. But that work is dependent on the position of the insect in the amber, and the amber's clarity. So there was always this fairytale possibility of extracting the DNA—a 'wouldn't it be nice, if' possibility. Now that the 'if' has turned out to be a reality, it opens up a whole new window into the past."

A clouded window?

Some researchers interested in molecular evolution suspect the window could be cloudier than the enthusiasts are letting on, however. Aside from the problems of contamination, there's the fundamental question of whether enough DNA can really survive in these ancient specimens to produce meaningful results. "Most dead DNA is degraded," explains Rebecca Cann, a molecular geneticist at the University of Hawaii who was a collaborator of Wilson's in work on (modern) DNA sequences that led to the "mitochondrial Eve" hypothesis. "It's nasty, damaged stuff. We know from chemical experiments that it degrades and how fast it degrades. After 25 million years, there shouldn't be any DNA left at all."

Even the enthusiasts are stumped by the question. For the Dominican Republic specimens, however, the answer may lie in the amber itself. George Poinar points out that the preservative powers of resin have been known for millennia: "The ancient Egyptians coated the wrappings of their mummies with it, and the Greeks put it in their wine." Poinar notes that when an insect is trapped in the resin, "encasement happens very quickly. The sugar and terpenes in the amber inhibit bacterial growth, and act as a preservative on the tissue, so that the DNA is 'fixed.'" Poinar, who says his colleagues put him "in the crazy chair" when he announced plans to extract DNA from amber-preserved insects, concedes, however, that "we don't understand the chemistry in detail," because "no one has been able to imitate how resin becomes amber in the lab."

It is harder to explain the survival of DNA in other specimens, however—especially those found in a wet environment, for as Cann and others note, DNA is particularly susceptible to damage from moisture. For that reason, Golenberg's magnolia DNA, which came from leaves fossilized in a deep, freshwater lake, was initially greeted with great wariness. But, as Grimaldi and DeSalle have now done, Golenberg has largely silenced his critics by comparing the extinct magnolia's DNA sequences with those of a modern magnolia and showing that the two are too close for the ancient DNA to be a contaminant. To substantiate his work on the 30-million-year-old bees, Poinar went one step further: He amplified DNA from five specimens. By comparing these sequences with each other, as well as with extant species, he concluded his prehistoric genes were authentic.

But even though they cannot fully explain how ancient DNA can survive for so long, researchers haven't been slowed in their old DNA goldrush. Grimaldi and DeSalle's group hopes to perfect its technique so that it can retrieve DNA from such tiny insects as 30-million-year-old wood gnats and fruit flies. Poinar, on the other hand, is eyeing 80-million-year-old biting flies encased in amber from Alberta, in Canada. Golenberg, too, is trying to further smash the time barrier, with 100-million-year-old fossilized leaves from a Nebraska site. Brian Farrell, a systematics entomologist at the University of Colorado, Boulder, reports preliminary "positive results" in extracting DNA from 200-million-year-old fish fossils—a tentative record that could soon fall by the wayside, if Noreen Tuross at the Smithsonian Institution succeeds in her project: amplifying 400-million-year-old DNA from brachiopods.

The race for the oldest DNA makes a good story, but the investigators involved insist the horse race is the least important aspect of their work. "It's fun, but it's not that important to be the first with the oldest," says Farrell, who, in addition to his work on the 200-million-year-old fish, is completing a DNA analysis of six species of 30-million-year-old amber-preserved beetles. "What's truly exciting about this work is what we can learn about evolution. With this technique, we're able to compare on a molecular level one of the most primitive animals in a group with one of the most advanced—which means that what we are really studying is a great period of evolutionary history. It's a wonderful opportunity, and it's up to us to make the most of it." And if the recent burst of activity in this field of molecular paleontology is any indication, these researchers are indeed making the very most—and the very oldest—of it.

–Virginia Morell

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PARTICLE PHYSICS

Could Protons Be Mortal After All?

Perhaps the most disturbing piece of speculation to come out of theoretical physics recently is the prediction that the whole universe is in decay. Not only do living things die, species go extinct, and stars burn out, but the apparently immutable protons in the nucleus of every atom are slowly dissolving. Eventually—in more than a quadrillion quadrillion years—nothing will be left of the universe but a dead mist of electrons, photons, and neutrinos.

This death sentence, threatened first in the 1960s by Soviet physicist Andrei Sakharov and later by other theorists, has been in suspension in recent years. Massive underground experiments set up to detect the signature of decaying protons have come up with nothing. But in the past few months, physicists have gotten newly excited about this dismal prospect.

Tufts University physicist Anthony Mann thinks that a Japanese experiment called Kamiokande, designed long ago to measure proton decay and since diverted to other uses, may finally be registering protons' death throes. Mindful of the 10 years of frustration that searchers for proton decay have experienced, Mann concedes that his idea, presented in last week's *Physics Letters*, is a long shot. And most other physicists think the apparently anomalous signals that have intrigued Mann come from the elusive particles called neutrinos, which pelt Earth from nuclear reactions in the sun and from cosmic rays. But because the implications of proton decay would be so momentous, not just for the ultimate fate of the universe but for theories of physics in the here-and-now, Mann thinks the possibility is worth further study, and many of his colleagues agree. Anything that could push physics beyond the now well-entrenched "standard model," says Oxford University physicist Donald Perkins, would be a "gift from the gods. We shouldn't turn our noses up at it."

The quest for unity. If Mann's proposal is borne out, it might fulfill a quest that has been stymied in recent years: the search for a "grand unified theory." Over the past 20 years, theorists have proposed a handful of these theories, which draw deeper connections among the various particles and forces of nature than existing theories do. As their main testable prediction, all of these theories suggest that protons decay—albeit into different byproducts, depending on the theory. The prospect of testing these grand unified theories was enough to send physicists underground into deep mines where, sheltered from background signals, they could wait and watch for protons to decay.

To cut down the wait, the experimenters designed huge detectors, containing thousands of tons of water and, hence, astronomical numbers of protons. If any one of those protons kicked off, it would release decay products that might travel faster than the speed of light in water. The resulting shock wave, or "sonic boom," would generate a ring of light known as Cherenkov radiation, triggering photodetectors in the tank.

Both of the major proton decay experiments—the Kamiokande detector and the Irvine-Michigan-Brookhaven (IMB) detector in a salt mine near Cleveland—recorded about one Cherenkov ring each day since


KARL LUTTRELL/UNIVERSITY OF MICHIGAN

Something fishy? Are protons decaying in the IMB detector's 7000 tons of water?

they started running around 1980. But based on the energies of the signals, investigators soon concluded that they came not from decaying protons but from the one kind of incoming particles—neutrinos—that can easily reach the deeply buried detectors. When investigators subtracted this "background," there was nothing left. Even if protons do decay, the researchers concluded, experiments couldn't capture the process.

So the researchers shifted focus: The once-annoying background of neutrinos became the main object of study at IMB and Kamiokande. But now anomalies in the neutrino measurements are reviving the possibility of proton decay. It's a strange twist, says David Ayres of Argonne National Laboratories. "At first we worked hard to separate neutrinos as background. Then we say that this background was interesting. Now, ironically, the proton decay is a possible background [for the neutrino studies]."

The surprise observation that has revived the question of proton decay is the mounting evidence at Kamiokande and IMB of an apparent deficit of one type of neutrinos produced by cosmic rays—so-called muon neutrinos—relative to another type, the electron neutrinos. The detectors see only about half the expected proportion of muon neutrinos. One possible explanation for the discrepancy, Mann notes, is that the predictions are wrong—after all, they depend on many poorly understood factors, including the number of cosmic rays that hit the atmosphere, how many neutrinos of each type they make, and how those neutrinos register in the detector. Another, far more exciting possibility is that the expected muon neutrinos are "oscillating," or changing identity, into electron neutrinos, skewing the detected proportions (*Science*, 21 August, p. 1044). Neutrino oscillations, like proton decay, would violate the standard model and point to new physics.

But Mann thinks that the imbalance might have a third, still more momentous, explanation: Signals now being chalked up to electron neutrinos might be coming from proton decay. The potential for confusion arises, he says, because the detector doesn't pick up neutrinos directly; instead it detects Cherenkov light from the high-energy particles (electrons in the case of electron neutrinos, muons for muon neutrinos) kicked out when the neutrinos strike nuclei in the water. And the positrons that would be given off in certain types of proton decay could leave signatures deceptively like those of electrons that come from electron neutrinos.

To test the proton decay possibility, Mann compared calculations of the expected numbers of neutrino-produced electrons and muons with data from Kamiokande. One set of calculations suggested that the Japanese detector is actually registering the predicted number of muons; the imbalance comes entirely from an excess of electrons. To Mann, that opens the possibility that both kinds of neutrinos really are arriving in the predicted numbers, and the apparent excess of electrons is due to proton decay. What's more, says Mann, the energy spectrum of the electrons detected at Kamiokande is compatible with the spectrum expected from one mode of proton decay.

A likely story? To some physicists, that interpretation is far-fetched. Schmuel Nussinov of the University of Tel Aviv points out that the only mode of proton decay that fits the data is a theoretically remote one. "If it exists there would be other decay modes that would swamp this," he says. And experimenters at both the Japanese and the U.S. detectors have searched carefully for those. "This is all too speculative," he says of Mann's hypothesis. "I like speculative things, but this is too much."

Larry Sulak, who as head of the IMB collaboration is a veteran of the search for proton decay, thinks so too, though he cites different objections. He doesn't trust the calculations of expected neutrino counts that Mann relied on, saying that they would not be most investigators' first choice. Sulak also faults Mann for not including IMB data in his analysis. "If you put in IMB data, it's not nearly as compelling," he says. Explains John LoSecco, an IMB collaborator from the University of Notre Dame, the electrons detected at IMB have too much energy to come from proton decay of any kind. "The official feeling" about the neutrino imbalance, says LoSecco, "is that something is funny but it's not necessarily new physics."

For theorist Jogish Pati of the University of Maryland, however, Mann's proposal is a potential vindication. In 1983, as part of a grand unified theory known as SU(4) color symmetry, Pati predicted the mode of proton decay that Mann thinks could be at work. To Nussinov's objection that if one mode of proton decay takes place, so should others, he replies that other processes could "damp out" the added modes. "I would not be surprised if this turns out to be the case," says Pati.

Even physicists who take a more agnostic view agree with Pati that Mann's proposal makes it urgent to pin down just what is responsible for the neutrino anomaly. In case the problem lies in the predictions of the neutrino signals, Oxford's Don Perkins suggests measuring the rate of cosmic ray bombardment from a high-altitude airplane. To test the possibility that neutrinos can oscillate, other researchers plan to generate a known number of neutrinos with Fermilab's proposed main injector, send them in a beam through the ground to either Brookhaven or Minnesota, and search for changes along the way. A more direct test of a possible role for proton decay, says Argonne's Ayres, will come from an iron-based detector in Minnesota called Soudan II. Because Soudan is sensitive to the recoil of protons and neutrons struck by neutrinos—a signal not produced by proton decay—it should help physicists disentangle the two kinds of events.

If protons really are decaying, physicists will be elated. And that's not as cold-blooded as it sounds; for British physicist and author Freeman Dyson, there's room for hope even in a universe ruled by a grand unified theory. In his 1988 book *Infinite in All Directions*, Dyson proposes that as matter decays, humans will be able to transfer their intelligence to new media, eventually learning to live as part of the electrons and photons that are left over. "The supreme test of life's adaptability," he calls it.

–Faye Flam