made some inroads into confirming CPT invariance. But once investigators have their hands on a complete atom of antimatter, they should be able to make even more precise comparisons. Like normal atoms, an atom of antihydrogen should absorb and emit light at characteristic wavelengths, allowing investigators to exploit the advances in the high-resolution spectroscopy of hydrogen that have come from investigators such as Ted Hansch of the Ludwig Maximilian University in Munich. And because an atom's spectrum is a kind of blueprint of its electronic structure, Los Alamos' Hughes and Bernard Deutch of the University of Aarhus recently suggested that antihydrogen spectroscopy should make it possible to compare the charges of the proton and antiproton with a precision of 1 part in 100 billion.

Another fundamental test on the agenda for future batches of antihydrogen will be a study of how it falls under gravity. Specifically, researchers would like to test the weak equivalence principle, a cornerstone of general relativity that says that all particles accelerate at the same rate under gravity. "It's never been tested for antiprotons or positrons," says Hughes, primarily because their electric charges complicate the measurements. As a result, scientists have not been able completely to rule out fanciful theories that suggest antimatter "falls up" in a gravitational field. Given a neutral atom of antihydrogen, however, investigators could clock its fall directly or—and this appears more practical—search for "gravitational redshifts" in its spectrum.

Before the antimatter researchers can perform their 21st-century equivalent of Galileo's experiment at the Leaning Tower of Pisa, though, they'll have to surmount some bureaucratic hurdles as well as the technical ones. For one thing, the future of LEAR itself is far from assured. "Something small like LEAR might get lost in the drive for the bigger machine [the proposed Large Hadron Collider]," worries Hughes. And some researchers see that as a potential calamity. "If you don't have LEAR, you would have to fold up your tents," says Kleppner. Over the next few months, an advisory committee at CERN will begin deciding LEAR's future.

As part of their plea to the committee, antihydrogen researchers have made certain its members know just how far the research has come in the past 7 years. Before Gabrielse's collaboration captured antiprotons and cooled them to 4 degrees Kelvin, the possibility of studying full-fledged atoms of antimatter would have been labeled science fiction. Laughs Hughes, "If you had talked about making antihydrogen, people would have said your ideas were weird." But no longer. In spite of the remaining hurdles, Dirac would be proud to see where his musings have led.

–John Travis

EVOLUTIONARY BIOLOGY

30-Million-Year-Old DNA Boosts an Emerging Field

B. FARRELL

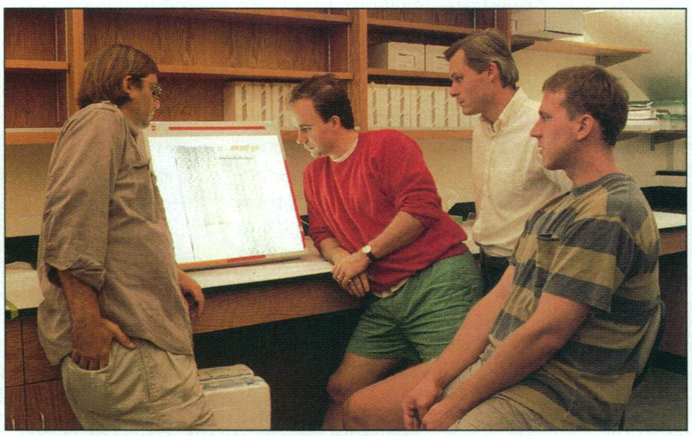
Eons-apart look-alikes. Specimens of a leaf beetle of the genus *Delocrania*. One specimen (*left*) was recently captured in the Peruvian rain forest; the other is a 30-million-year-old specimen in Dominican amber.

When does a novel scientific technique cease to be a virtuoso trick and become central to a discipline's technical repertoire, helping solve some outstanding fundamental problems? One indication may be that lab jokes stop. Take the case of entomologist Dave Grimaldi and his colleagues at the American Museum of Natural History in their effort to get DNA from ancient termites trapped in amber. "We used to joke about it in the lab: 'Yeah, it's probably just another one of those stupid PCR tricks,'" says Grimaldi. The reason for the jokes was that the polymerase chain reaction, or PCR, had been used to amplify minute DNA samples from all kinds of unlikely specimens, but those feats were nothing more than technical star turns: The information from the DNA hadn't been correlated with anatomical changes—and hence hadn't advanced evolutionary knowledge all that much.

Grimaldi and his colleagues Rob DeSalle, John Gatesy, and Ward Wheeler are no longer joking—at least not about PCR. Using that method, they have now succeeded in extracting and amplifying tiny remnants of DNA from a 30-million-year-old termite fossilized in amber from the Dominican Republic—and published their results in this issue of *Science* (p. 1933). The feat of obtaining ancient DNA from specimens in amber, which many in the field thought was impossible, makes it feasible to correlate specific aspects of body size and shape with DNA sequences. As paleoentomologist Conrad Labandeira at the Smithsonian Institution says, specimens preserved in amber "were always special, because the specimens are three-dimensional, enabling you to see things such as the mouth parts and genitalia in detail. But [having the DNA] will allow us to get a molecular handle" on the evolutionary history of those specimens.

In their effort to be the first to extract and amplify DNA from amber specimens, Grimaldi and his colleagues have arrived at the finish line in a virtual dead heat with George Poinar, an entomologist at the University of California, Berkeley, who published a report in the latest issue of *Medical Science Research*, a British journal, announcing his team's success in extracting and sequencing DNA from a 30-million-year-old amber-preserved stingless bee. And in extracting this prehistoric DNA, the two groups haven't just smashed the world's record for the oldest genetic sequences (the former record-holder being a 17-million-year old-magnolia leaf), they've begun to throw light on the perplexing, but fundamental, question of why insects are so conservative in evolutionary terms.

Naturally, this potential of PCR coupled with well-preserved ancient specimens hasn't been lost on other investigators, who are at this moment speeding to extract older and older examples of genetic information. Among them: DNA from 200-million-year-old fishes, perhaps even a dinosaur or two. And the researchers crowding into this area could even be in the process of defining a new discipline. Says Michael Clegg, a plant



AMERICAN MUSEUM OF NATURAL HISTORY

Genetic screening. Rob DeSalle, Ward Wheeler, Dave Grimaldi, and John Gatesy examine DNA sequences from insects trapped in amber.

geneticist at the University of California, Riverside, "If you can only reclaim ancient DNA in a few cases, this will remain a curiosity. But if you can do it sufficiently often, then it will become a real tool for evolutionary biological research. It could even lead to a whole new field: molecular paleontology."

If there is a new field emerging, the extraction of DNA from specimens in amber could turn out to be an essential step in its genesis. Grimaldi set out on the oldest DNA quest last year after discovering a new species of termite preserved in a chunk of Dominican Republic amber, which he dubbed *Mastotermes electrodominicus*. *Mastotermes* once ranged from Europe to the Americas, but today the sole species (*M. darwiniensis*) lives in Australia. Like its surviving relative, *M. electrodominicus* was large (3 cm), dark-brown, and hairy—"almost like a cockroach in appearance," says Grimaldi.

The amberized oldster was equipped with powerful, wood-eating jaws, like its Australian counterpart. "They are serious pests in northern Australia," says Grimaldi, explaining that the termites' voracious appetites have forced the Australians to replace wooden utility poles with concrete ones. "And that's the enigma: *Mastotermes* does very well there, but at the same time it is a relic species," Grimaldi says. "Yet 30 million years ago it was abundant in the Caribbean." Why did all of these species become extinct, Grimaldi wondered, and why is there only one remaining—highly successful—species left today?

Grimaldi reasoned that if he could extract DNA from the amber-preserved insects, he would be able to examine the molecular differences between the extinct and living species directly—perhaps giving a new view of how these creatures evolved and disappeared. And if he succeeded with the termites, Grimaldi hoped to be able to extend his analysis to other insects preserved in Dominican Republic amber. These specimens suggest that a wide array of species inhabited the island during the Miocene epoch, but many subsequently became extinct. "Today, their relatives are in Central or South America, or only in Australia or the Old World," Grimaldi notes. "At this point, there's no apparent ecological pattern to these extinctions. Finding that pattern is my long-term research interest."

In the effort to extract and sequence the ancient DNA, Grimaldi built on a line of research initiated in the pioneering lab of Allan Wilson at Berkeley. Researchers began attempting to extract DNA from specimens of extinct creatures in 1980, but it wasn't until 1984 that Wilson's team members announced two stunning successes: They had cloned DNA from the preserved tissue of a quagga, a zebra-like animal from southern African that became extinct 111 years ago, and from a 40,000-year-old mammoth. Five years later, Edward Golenberg, a Wayne State University geneticist, smashed the age record to smithereens by extracting DNA from 17-million-year-old fossilized magnolia leaves from Idaho shale.

The next logical target was the 30-million-year-old amber-preserved insects from the Dominican Republic, well known among evolutionary geneticists for their translucent beauty. During the Miocene epoch the now-extinct tropical Hymenaea tree (a member of the legume family) bordered the lagoons of what is now the Dominican Republic. Wood-boring insects caused the trees to exude their sticky sap, and many of the insects were trapped and instantly embalmed in the resin. Wilson's group had already attempted to clone DNA from them, 10 years before, but with mixed results. "I was in Wilson's lab [as a postdoc] when they opened up some of the first pieces of amber," says DeSalle. "And Russ Higuchi [another postdoc] managed to get a tiny amount of DNA, but it seemed to be only bacterial. The sample seemed to be contaminated."

Indeed, contamination is one of the biggest bugaboos for ancient DNA seekers, and it is directly related to PCR's greatest asset: sensitivity. The technique is so sensitive that it can pick up and amplify a single DNA molecule. Yet the same sensitivity means the technique can give very misleading results if there is any extraneous biological material in the area where the work is being done. For example, it would not be surprising to see horse DNA turn up in a sequence for a fruit fly if a horse sample had previously been amplified in the same lab. For that reason, DeSalle carefully extracted the termite DNA in a lab far from his PCR room.

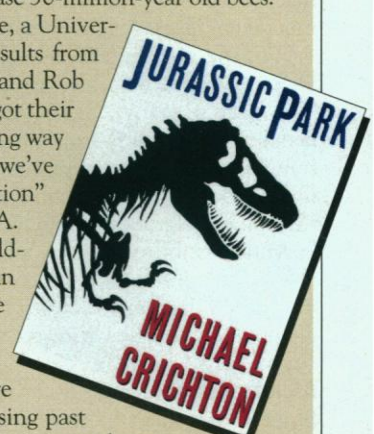
Getting the DNA proved to be a tough job. "We pulled out every bit of the insect from the amber, and even with all of that tissue we got very little DNA." But they did get enough to amplify and then sequence a 200 base-pair segment of a gene that carries the code for a single protein essential for producing ribosomes, the organelle that synthesizes proteins. They compared the nucleotide sequence of this fragment to that of the same stretch of DNA in the modern species. "We could see enough shared and derived features that we're confident [the DNA] can't be anything but termite," says DeSalle.

While this little piece of termite DNA hasn't yet enabled DeSalle to say why the species trapped in amber have largely gone extinct, it is already helping to answer a basic taxonomic question: Is the genus *Mastotermes*, based on the characteristics of the sole Australian species, a valid category?

Science Imitates Art Imitating Science

In Michael Crichton's 1990 sci-fi thriller *Jurassic Park*, a deranged millionaire collaborates with a reckless scientist to bring ravenous dinosaurs back to life. Their methodology: cloning DNA from blood-sucking insects encased in amber. (One insect's last meal was on *Tyrannosaurus rex*.)

Fertile as Crichton's imagination is, he's also keen on research—his own and the scientific variety—and the idea for *Jurassic Park* didn't come to him fullblown. In fact, it was stimulated by papers from the "Extinct DNA Study Group"—a Berkeley cell that included George Poinar, a University of California entomologist. Crichton began pursuing the topic in 1983, when extracting and amplifying DNA from amber-bound specimens was no more than a twinkle in the scientific eye. But no more. In fact, George Poinar is among the scientists who've just finished a breathtaking race to obtain genes of insects trapped in Dominican Republic amber (see main text)—in Poinar's case 30-million-year old bees.



"It's like a living *Jurassic Park*," enthused Barbara Thorne, a University of Maryland entomologist, when she heard of the results from Poinar's lab and that of his competitors, David Grimaldi and Rob DeSalle at the American Museum of Natural History, who got their DNA from a termite in amber. Well, not quite. "We're a long way from recreating the termite," says DeSalle. "At this stage we've extracted only a fraction of a gene. . .It's obviously science fiction" to think of assembling a whole termite from this bit of DNA.

But Poinar, who set Crichton off on his fictional wild-dinosaur chase, is more inclined to let his imagination run wild. In a just-published book called *Life in Amber*, he envisions researchers "reviving single-celled organisms such as bacteria, fungi, and protozoa." From there, he says, they might even begin to think about reassembling larger, more complex creatures. So if a big green flesh-eater goes cruising past your bedroom window one of these dark nights, you'll know just who to blame: Michael Crichton and George Poinar.

–V. M.

"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

Virginia Morell is a science writer living in Oregon.

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 test-