of the fossils. "Everybody would say yes, these are small shellies," agrees paleontologist Douglas Erwin of the National Museum of Natural History in Washington, D.C., who has seen Azmi's paper. The question is what they mean for the age of the tracks.

In the early 1980s, Azmi found similar fossils in another Indian basin, boosting its accepted age by 400 million years into the Cambrian. He thinks the new fossils hold a similar message about the sandstone layer they overlie. As he argues in a letter on page 627, there's not much rock separating the 540-million-year-old fossils from Seilacher's trace fossils—implying that the tracks must be about 600 million, not 1.1 billion, years old. That would make them no older than other known traces of early animals.

Azmi and others add that the radiometric dates aren't as impressive as they might seem. As geochronologist Samuel Bowring of the Massachusetts Institute of Technology notes, the dates might accurately reflect the age of individual mineral grains, but those grains may have formed long before they eroded from parent rock and washed into the sea to become part of the Vindhyan sedimentary rocks. Indeed, the radiometric dates of grains from the formation containing the Cambrian fossils are also about 1.1 billion years old, suggesting that the dates may not reflect the age of the rock layer itself.

Seilacher, Pflüger, and their colleague Pradip Bose of Jadavpur University in Calcutta are just now seeing the details of Azmi's paper, but they already have some reservations. Pflüger speculates that perhaps Azmi's Cambrian fossils are not close in time to the trace fossils after all. Thick layers of sediment may be laid down in one place but not in another, and rocks can be eroded away before the next layer is laid down, making it look as if little time has passed when in fact hundreds of millions of years have gone by. Pflüger also notes that Azmi's fossils come from a part of the basin different from the one that contained the tracks, increasing the chances that fracturing and jumbling of rock layers could confuse interpretations.

And Indian researchers, including paleontologists Anshu Sinha of the Birbal Sahni Institute of Paleobotany in Lucknow and B. S. Venkatachala of the Wadia Institute, say that they are reluctant to adopt a young age for Vindhyan rocks, given the radiometric dates. They also report signs of pre-Cambrian single-celled algae and other fossils in the rocks. To prove the age of the Vindhyan, geologists may have to find and date rocks such as volcanic ash layers, which offer secure dates because they are deposited as soon as they're formed. Until then, the age of the first animals remains in question. **–RICHARD A. KERR**

With reporting from India by Pallava Bagla.

PHYSICS

Particle Decays Reveal Arrow of Time

In the everyday world, time is a one-way street. Unlike characters in Martin Amis's novel *Time's Arrow*, we never exit a taxi and salute while it retreats down the street or awake in the evening and see our clothes come flying from the corners of the room. The microscopic level where particles collide and decay, however, has seemed indifferent to the direction of time. But two groups of researchers, at Fermi National Accelerator Laboratory (Fermilab) in Illinois and CERN in Switzerland, have now directly detected the forward march of time in the decays of subatomic particles.

Physicists once thought that the equations of the subatomic world would look the same if time were reversed. A movie of an atom decaying into bits, when run in reverse, would show a process that—although unlikely—still obeys the laws of physics: the bits converging to form a full atom. But they also knew that this time-reversal symmetry was part of a larger, more powerful package known as CPT (for charge, parity, and time reversal) symmetry, which sits at the heart of modern physics: Swap antimatter for matter, view the universe (essentially) in a mirror, and reverse the direction of time, and all the experiments should come out the same way they do in the real world. The CPT theorem (which has now been tested to an impressive 18 decimal places) meant that time-reversal symmetry could hold only if charge-parity (CP) symmetry holds as well.

In 1964, physicists found that it doesn't. They noted that neutral particles called kaons occasionally decayed in a way that blatantly violated CP symmetry. The CPT theorem could be saved only if making time flow backward changed things in a way that canceled out the CP asymmetry. No one could gather enough data to isolate the rare decays that would show this directly, however.

Now two groups have finally managed this feat, by measuring the rate of a particular decay and showing that it differs from the rate of the same process done in reverse. "I think it's truly spectacular work," says Alan Kostelecky of Indiana University, Bloomington. "This is the most important experimental advance since" 1964 for testing time symmetry.

One of the groups, the CPLEAR collaboration at CERN, collided antiprotons and hydrogen atoms to make kaons and their antimatter counterparts, antikaons. As they travel, antikaons can transform into kaons and vice versa. In results to appear in an upcoming issue of *Physics Letters B*, the team used a large tracking chamber to count the kaons and antikaons as they decayed—each to an electron, a pion, and a neutrino. The charge of the electron revealed which type of kaon had decayed. The team found that the rate for antikaons transforming into kaons was a fraction of a percent higher than for what would be the time-reversed process—kaons becoming antikaons. "This shows that you can't turn the clock backward" and always get the same results, says CPLEAR spokesperson Panagiotis Pavlopoulos.

Only in the movies. New findings would leave H. G. Wells's time machine (here, in a 1960 version) with nowhere to go.

CREDIT: MGM/THE KOBAL COLLECTION

The other group, the KTeV collaboration at Fermilab, also studied kaons, but watched for much rarer events—the 1-in-10-million decay of a single kaon into pairs of electrons and pions. The team, which presented its results at a Fermilab workshop earlier this month, mapped out the directions of the electrons and pions. Here, time asymmetry revealed itself in a subtler way. Because reversing time also reverses a particle's momentum, the team looked for time asymmetries by comparing the rates of some decays to others where the direction of the emerging particles looked as they would if time had been reversed. The rates differed by about 13%. "It's a huge effect," says Fermilab physicist and KTeV collaborator Vivian O'Dell.

Both experiments observe time asymmetry at about the level that would compensate for the CP asymmetry first observed over 3 decades ago. "I don't think anyone is sur-

prised, but everybody is very happy," says University of Chicago theorist Jonathan Rosner. Why the decays should look any different forward and backward is still a fundamental mystery. It's possible, he says, that the reigning theory of the microworld, called the Standard Model, can explain this if some of its parameters are just right. Other possibilities include a new "superweak" force that would break time-reversal and CP symmetry. Eagerly awaited studies of other kaon decays at KTeV or another experiment called NA48 at CERN may reveal which is right, Rosner says. CP asymmetry may also explain why the universe is not filled with equal parts of matter and antimatter.

Could a microscopic arrow of time also explain why humans perceive a past, present, and future? Maybe, Kostelecky says, but "that's pretty ambitious." Such questions may be too deep for physics to answer, he says.

–DAVID KESTENBAUM

PALEONTOLOGY

Young Dinos Grew Up Fast

SNOWBIRD, UTAH—The giant dinosaurs known as sauropods were the most massive creatures ever to tread on land. Now a detailed look at one species' bones, described here earlier this month at the annual meeting of the Society of Vertebrate Paleontology, suggests that these hulking beasts could grow to full size—tens of tons and longer than a tractor-trailer—in just a decade. By clocking the sauropod childhood, the work "provides a whole new dimension to sauropod studies," says Philip Currie of the Royal Tyrrell Museum of Palaeontology in Drumheller, Alberta.

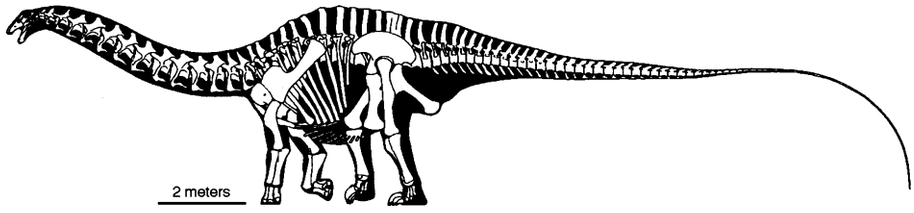
Paleontologists had estimated that it would take more than a century for a modern reptile to reach the size of an adult sauropod. But under the microscope, dinosaur bone seems to tell a different story: It looks more like the fast-growing bones of mammals and birds than that of reptiles. To sharpen the age estimate, Kristina Curry, a graduate student at the State University of New York, Stony Brook, examined forelimbs and shoulder blades from specimens of *Apatosaurus* (once known as *Brontosaurus*), a sauropod that roamed North America some 150 million years ago.

When Curry drilled samples from shoulder blades, she found regular changes in the density of microscopic canals that presumably once held blood vessels. The layers resemble the concentric rings laid down each year in manatee and sea turtle bones, so Curry assumed that they were annual and used them to age the sauropod shoulder blades. Bones from half-sized individuals were 4 to 5 years old, while the largest sauropods had apparently reached full growth in just 8 to 11 years.

That growth rate may sound extraordinary. But it implies that sauropods deposited about 10.1 micrometers of bone tissue per day—about the same rate as living ducks, which deposit an average of 10.0 micrometers of bone per day. Ducks, however, grow to full size in about 22 weeks, while *Apatosaurus* apparently kept up its growth spurt for years.

As a check, Curry used the rate derived from the *Apatosaurus* scapula to estimate the age of the forelimb bones, which have no rings, and came up with similar numbers. The bone growth rate also fits reasonably well with the lone previous estimate, by Armand Ricqlès of the Université Paris VII, who used faint layers in sauropod humerus bones to clock their growth at roughly 7 micrometers per day. "Even though *Apatosaurus* may have lived for centuries, they certainly didn't take that long to reach their full size," Curry concludes.

The finding makes sense, says Currie of the Royal Tyrrell Museum, as hatchlings wouldn't survive long if they grew slowly. Besides the threat of predators, just living with a 30-ton mother would be dangerous. "You'd probably get stepped on," he notes. Moreover, if dinosaurs took more than 30 years to mature, their populations could sink to dangerously low levels, according to 1989 calculations by Arthur Dunham of the



All grown up. Growth layers in shoulder bones suggest that an *Apatosaurus* like this one grew to full size in only about a decade.

CREDIT: (TOP) NRAL, JODRELL BANK; (BOTTOM) GREGORY PAUL

ScienceScope

COMPUTER TO PINPOINT DISTANT GALAXIES

European radio astronomers have switched on a new supercomputer that will provide some of the sharpest views of the universe ever obtained. Yesterday, researchers at the Joint Institute for Very Long Baseline Interferometry in Dwingeloo, the Netherlands, dedicated the $10 million European VLBI Network Data Processor, which will knit together data from 16 telescopes across Europe. Together, the telescopes create a virtual dish 9000 kilometers wide that can detect the faintest radio emissions from distant galaxies.

"It's a fantastic system they've built," says Jonathan Romney of the U.S. National Radio Astronomy Observatory, which runs a similar but less powerful "correlator" in Socorro, New Mexico. Still, it will take the new machine, which makes 16 trillion calculations per second, days or weeks to construct an image from a single observing session. The first images are expected later this year.

PARTY INSIDER GETS AUSTRALIAN SCIENCE POST

Australia has a new science minister with added clout as a result of a Cabinet shuffle by newly reelected Liberal leader John Howard.

South Australian Senator Nick Minchin, formerly the special minister for state, takes over the science and industry portfolio from John Moore, who will now oversee defense. A confidant of Howard and a rising star within the party, Minchin played a key role in pushing through controversial legislation limiting Aboriginal land claims and in organizing a national convention to review the country's constitution.

Science appears to have done well in the reshuffle. Its move into a ministry that includes industry and the previously separate resources "strengthens the portfolio by linking research and technology with some of the most important economic bases," says Australian Academy of Science President Brian Anderson. Anderson described Minchin, a 45-year-old career politician, as "forthright and respected for his judgment."

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