1970s. And that is just what some people suspect. "I think there is a loss of amphibians," said ecologist James McMahon of Utah State University, who was invited to the workshop as a critic, "but whether there is one major, nefarious, worldwide, unknown factor is not so clear. It looks like a lot of individual factors."

McMahon, along with others, believes that the destruction of natural habitats, which affects many types of plants and animals other than amphibians, may be a significant factor in the amphibian declines. "Amphibian species are going extinct, but so is everything else," McMahon said.

> ***"[Amphibians] were here when the dinosaurs were here, and [they] survived the age of mammals. They are tough survivors. If they're checking out now, I think it is significant."***
>
> —David Wake

Wilbur agreed that "habitat destruction is clearly the dominant thing going on." But he added that it's "not the whole story, because we have a lot of pristine areas where [amphibian] populations are going down the tubes as well."

Indeed, news that amphibians are disappearing from nature preserves where there is little human perturbation is what many herpetologists find most alarming. Such evidence suggests to some herpetologists, Wake included, that there is a single, unitary cause of the many observed declines. "I am personally dubious of any proximal explanation," he says. "[Amphibians] were here when the dinosaurs were here, and [they] survived the age of mammals. They are tough survivors. If they're checking out now, I think it is significant."

One thing that makes it plausible to see amphibians as global "canaries in a coal mine" is that they are likely, in a physiological sense, to be good early indicators of environmental decay. Their skin is permeable to airborne gases, they live on both land and water at different stages of their life, and they are high in the food chain. In addition, amphibians have been relatively well studied and all their life stages are amenable to experimentation.

But if amphibians are indicating the early stages of some significant global change, what might that change be? None of the possibilities raised at the workshop seems like a single satisfactory explanation. One possible culprit that was discussed is an increase in ultraviolet (UV) radiation. It has been suggested that a reduction in the ozone layer might lead to increases in UV radiation (to which amphibian embryos are known to be sensitive). But that hypothesis breaks down, Harte says, because although ozone levels have fallen in the past decade, the predicted increase in UV radiation has not been observed.

In the absence of a full consensus, both believers and skeptics at the workshop agreed on one thing: the need for more data. One of the most crippling problems in studying amphibian declines is a dearth of historical data on the size of amphibian populations. Without these baselines, normal fluctuations could easily be interpreted as population declines. To deal with the problem, the workshop recommended reviewing old studies and museum records and revisiting sites for which good population data have been collected.

They also stressed the need for long-term studies of amphibian populations that are declining or have characteristics that would make them good indicators (such as living in harsh habitats that push their tolerance to its limits). The participants drew up lists of the kind of data that should be collected to supplement population surveys, including environmental chemistry, bioassays on the animals present, and pathology and toxicology on dead animals.

But McMahon cautioned that while long-term studies are valuable, they may be a luxury science cannot afford. "We don't have much time to do this," he said. "By the time we can get enough data, the problem may be past us and unsolvable." For that reason he urged researchers to come up with short-term experiments. For example, if an amphibian species has recently disappeared from a habitat, he suggested reintroducing it and intensively studying its fate.

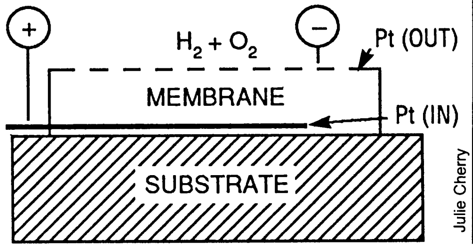
It is not yet clear whether the Irvine workshop will spur the National Research Council to investigate the significance of the amphibian data and produce a report. Even if it does, some other agency will have to pick up the ball and fund the necessary studies. Tired of the perennial struggle for funding, Michael Soule of UC Santa Cruz, expressed hope that such a report could set the wheels in motion for the creation of a new agency, public or private, to provide reliable funding for long-term biodiversity research.

■ MARCIA BARINAGA

Electricity by Serendipity

Christopher Dyer wasn't trying to invent a new type of fuel cell. "It was one of those things that just happen," he says. But the electrochemist at Bell Communications Research in Morristown, New Jersey, discovered a previously unknown way to coax electrical energy from oxygen and hydrogen while trying to build a miniature battery. The new fuel cell may make possible a number of applications, including such things as on-board power supplies for integrated circuits and small generators for portable phones.

Originally, Dyer says, he was experimenting with a battery that contained a palladium electrode and a platinum electrode separated by a thin film. To charge the battery he exposed it to hydrogen gas, which gradually seeps into palladium and stays there. One time, however, he got careless and used hydrogen that had been contaminated with oxygen. The battery went haywire. "I found I got the potentials the wrong way around, and it was a much higher voltage than I expected," Dyer says. Intrigued, he experimented with the device and found he had stumbled upon a method to make a fuel cell that worked in a fundamentally new way.



Julie Cherry

Fuel cells, which convert chemical energy directly into electrical energy, generally must keep their two fuels separate. The hydrogen/oxygen fuel cells used on spacecraft, for instance, have two electrodes which lie on opposite sides of a liquid electrolyte, and hydrogen is directed at one electrode while oxygen is piped to the other. A voltage is created between the two electrodes as hydrogen atoms at the first electrode give up their electrons, while oxygen atoms at the other electrode take up electrons. If the two gases are allowed to mix, the voltage disappears because the electrodes no longer sit in different atmospheres.

But Dyer discovered, serendipitously, how to make fuel cells that can function in a mixed hydrogen/oxygen atmosphere and thus avoid the complications associated with two separate gas delivery systems. As described in the 8 February *Nature*, the fuel cells consist of three thin layers laid down on a quartz surface: first a thin film of platinum that serves as one electrode; then a gas-permeable membrane less than 0.5 micrometer thick; and finally an outer film of platinum that serves as the second electrode and is porous enough to allow gases to pass through. When the cell is bathed in a hydrogen/oxygen mixture, hydrogen atoms donate electrons at the outer electrode while oxygen atoms accept them at the inner electrode.

No one who was familiar with fuel cells would have ever thought a cell could operate without separating the two gases, Dyer says. "Not in a million years." Even after having made the fuel cells, it took him a while to understand how the inner and outer electrodes differentiate between the two gases. It is a "new type of catalysis" that is "closer to biochemistry than classical chemistry," Dyer says, and it depends on the fact that the gases come in contact with the inner electrode only through the membrane but touch the outer electrode directly. Dyer declines to give more details, but says he is writing a second paper that will clear up the mystery.

However it works, the new battery promises a number of applications. Since it can be fabricated with standard semiconductor processing techniques, integrated circuit chips could be made with the power sources built in, thus eliminating the need for power leads and the heat they generate. Putting the chip in a hydrogen/oxygen atmosphere would automatically power up the built-in batteries.

The major limitation now on Dyer's fuel cells is their relatively low power levels—they put out only 1 to 5 milliwatts per square centimeter. However, the flexibility in their shape offers a way around this, he says. By making the cell in the form of an open spiral, for instance, it should be possible to get a high surface area, and thus high power, from a small volume. Still greater increases in surface area and power output might be achieved by roughening the electrode surfaces. It should be "relatively easy" to get power levels of 1 kilowatt per kilogram of fuel cell, Dyer predicts. This would allow 10-watt generators compact enough to be used with portable phones, he suggests, and larger batteries could be used to power small electric vehicles or as emergency generators.

The cells could also be used as gas sensors. If placed in a hydrogen atmosphere, for instance, a cell will respond to even tiny amounts of oxygen by generating a voltage across the electrodes. ■ ROBERT POOL

Packing Your *n*-Dimensional Marbles

Some of the questions mathematicians ask sound silly: How many pennies can you lay on a tabletop? How many marbles will fit into a semi-trailer?

At other times the same basic question takes a somewhat more serious form: How many digital signals can occupy a noisy channel?

A recent discovery by Noam Elkies, a mathematician at Harvard University, has given researchers new insight into the mathematical theory that encompasses all three questions. Elkies's result is an unexpected application of a branch of number theory to a geometric problem known as sphere packing.

Sphere packing, in mathematical parlance, is a problem of cramming an n-dimensional space with n-dimensional "spheres," all of the same size, with the least amount of empty space in between. Coins are a good example of two-dimensional "spheres" (circles); marbles are examples in three-dimensional space.

In the mathematical theory that underlies telecommunication, a digitized signal is encoded as the coordinates of the center of a higher dimensional sphere packed in a higher dimensional space. After transmission down a noisy channel, the signal may no longer be exactly at the center, but as long as it's still within the sphere, the receiver can restore it to the center and read the signal exactly.

The easiest way to keep the signal clear would be to space the spheres far apart. But that's wasteful. The phone company can satisfy its customers and stockholders simultaneously by finding efficient ways to pack the signals. Similar problems crop up in other places: data compression, antenna design, and x-ray tomography. What everyone wants is the best way to pack spheres into the space their problem occupies.

Surprisingly—given its wide applications—the problem has so far only been solved in the simplest case: that of two dimensions, where the pennies fill 90.69% of the tabletop. In three dimensions the obvious candidate is the face-centered cubic packing of spheres beloved of crystallographers and fruit vendors.

Now, nobody is betting against the face-centered cubic packing as the best possible solution, but so far no one has been able to give a rigorous proof that there's nothing better. And in the really formidable dimensions—above a thousand, say—mathematicians are at a loss. "We don't know a better way of packing spheres than just picking them at random until there's no room left," Elkies says.

Although new sphere packings are discovered all the time, most of them have come from standard techniques in the subject. Elkies's approach, on the other hand, is brand new. It is based on the theory of elliptic curves, a branch of number theory that is concerned with finding solutions of certain polynomial equations. Though a newcomer to sphere packing, Elkies is an expert on elliptic curves; 2 years ago he applied the same theory to solve a 200-year-old problem related to Fermat's Last Theorem.

Elkies's result uses the theory of elliptic curves to construct a regular array of points, called a lattice, to serve as the centers for his spheres. These lattices have been long familiar to number theorists, but no one had looked at their sphere-packing properties before. Not every elliptic curve has the right kind of lattice, and part of the trick was finding the ones that do.

"Theoretically it's quite exciting," says Andrew Odlyzko, head of the Mathematics of Communication and Computer Systems Department at Bell Laboratories in Murray Hill, New Jersey. "It's a new way of approaching a famous unsolved problem."

Elkies' new packings may or may not be the best possible—his work doesn't address that issue—but they do give improvements on the best methods known so far in a number of dimensions, the largest being 1024. In several other cases his approach agrees with the previous best known packings—notably in dimension 24, which has a surprisingly efficient packing known as the Leech lattice. (Some new computer modems make use of the Leech lattice sphere packing.)

Elkies's discovery has no immediate practical application, says Odlyzko, "but that might change." For one thing, theoreticians are toying with the idea of upgrading modems to work in higher dimensional spaces. But whether it has immediate applications or not, Elkies' new discovery certainly gives mathematicians more space to play around in. ■ BARRY CIPRA

Barry A. Cipra is a contributing correspondent of Science.