Maybe. Los Alamos computer scientist Christopher Langton, another coorganizer of the workshop, devoted his own talk to an approach that he hopes may lead to exactly such a theory. To begin with, he says, look at the species that are frozen in models such as Kauffman's. Mathematically, such behavior is reminiscent of the rigid way atoms are organized in a crystal. If that were all there was to living systems, says Langton, then they wouldn't be very interesting. The mathematics would describe cells that couldn't differentiate, ecosystems that couldn't adapt to a changing environment, and organisms that couldn't evolve.

At the opposite extreme, says Langton, look at those species involved in constantly shifting evolutionary turmoil. Their behavior is reminiscent of the way molecules are constantly banging around in a gas. This kind of behavior is described by the mathematical theory of chaos, says Langton, and if *that* were all there was to living systems, then they wouldn't be very interesting either. Cells, organisms, and ecosystems would have no structure or stability whatsoever.

However, says Langton, what the models at the workshop seem to suggest is that evolution drives living systems to a critical point halfway between these two extremes, where they can maintain a vital mix of stability *and* change. At that point, he says, the random-seeming avalanches of stasis and change are mathematically similar to what happens in a piece of matter right on the brink of a phase transition, where submicroscopic regions of solid and fluid are constantly forming and dissolving everywhere in the system. Langton calls this hypothetical critical point "the edge of chaos," and suggests that it may be a fundamental characteristic of *any* complex dynamical system, whether it be a piece of matter, a computer, or a living organism.

Through a systematic set of computer simulations he has verified that such a critical point does exist in simple, two-dimensional dynamical systems known as cellular automata. (For computer afficionados perhaps the best known cellular automaton is "The Game of Life," which gives rise to astonishing complex patterns from just a few simple rules, and which turns out to lie very close to the critical point.) Langton is currently trying to understand whether this transition can occur in more general situations.

He is also the first to admit that this idea is still a long way from being a complete theory. Nonetheless, it has an undeniable appeal—if only because of the irresistible way he describes it: "Life," says Langton, "exists at the edge of chaos."

■ M. Mitchell Waldrop

The Chase Continues for Metallic Hydrogen

In pursuit of a strange beast found only at extremely high pressures, researchers disagree about whether it has been spotted

In theory, it's a simple experiment. Just squeeze a sample of hydrogen gas between the two faces of a diamond press. At about 57,000 times normal atmospheric pressure the hydrogen turns solid. Keep squeezing. At some point well over a million atmospheres, a dramatic change will occur. The hydrogen, originally an insulator, suddenly becomes a conductor—metallic hydrogen. It's a far cry from the usual image of hydrogen as the lightest and least substantial of all the elements, and theorists have predicted a number of strange properties for it. Metallic hydrogen might be a room-temperature superconductor, for instance, or it could be a liquid at absolute zero.

That's the theory. Unfortunately, the practice is not nearly so simple. In addition to the technical difficulties of squeezing a sample with millions of atmospheres, researchers have found it tricky to determine exactly what it is they are producing in the tiny space between the two diamonds. With no chance to touch the sample directly, they must rely on measurements made through the diamonds, which themselves are affected by the intense pressures.

Despite these obstacles, there have been at least two recent reports from teams that think they may have seen hydrogen turn metallic. In the 23 June issue of *Science*, Ho-Kwang "Dave" Mao and Russell Hemley at the Carnegie Institution of Washington wrote that above 2 million atmospheres hydrogen starts to become opaque, a good sign of the transition to a metal. And at a meeting* of the American Physical Society last month, Isaac Silvera claimed that his team at Harvard University has solid evidence that one special form of metallic hydrogen appears at 1.5 million atmospheres.

However, the difficulties with interpreting these experiments remain so huge that scientists are arguing among themselves about exactly what they have pressured hydrogen into doing. At the APS meeting, for example, some scientists said they found Silvera's evidence far from convincing. On the other hand, the Carnegie Institution team claimed the Silvera result is nothing new. They spotted the transition to a metallic state last year, they said.

These arguments aren't mere arcana. If one could make metallic hydrogen, astronomers could study a material that may make up large parts of Jupiter and other superheavy planets. Fusion scientists see metallic hydrogen as a possible fuel—if a stable form exists, as some theories predict, it could be made at several million atmospheres and then handled at normal pressures, providing a nearly ideal fuel for reactors. And condensed matter physicists would love to study what is likely to be a structurally simple yet exceedingly strange material. What could be stranger than the same element that lifted zeppelins over the ocean turning out to be a superconductor at room temperature or a liquid at absolute zero?

So plenty of scientists are waiting to see just how closely reality matches up with the current theory. In essence, theorists calculate that it should take somewhere between 2.5 million and 4 million atmospheres to make "atomic metallic hydrogen," the form of hydrogen that is predicted to be a room-temperature superconductor. Such high pressures would cause the hydrogen molecules to dissociate into pairs of single atoms. But it may not be necessary to squeeze quite so hard to get metallic hydrogen. According to some calculations, "molecular metallic hydrogen" should form at a significantly lower pressure—somewhere between 1.7 million and 2.5 million atmospheres. In this case, the molecules would remain intact.

Carnegie's Mao and Hemley have attempted to test these predictions by taking hydrogen to over 3 million atmospheres. Their report in *Science* last year of hydrogen's opacity above 2 million atmospheres indicated that some of the electrons attached to the hydrogen molecules move into new energy levels and become conduction electrons at these pressures. The existence of conduction electrons would make the hydrogen sample a metal, or at least a "semimetal," Mao said at the time.

Now Silvera says he has evidence that hydrogen becomes metallic at only 1.5 million atmospheres, significantly lower than predicted. At this pressure, the hydrogen sample shifts its structure into what Silvera

*The 1990 March meeting of the American Physical Society, 12 to 16 March, Anaheim, California.

calls the hydrogen-A phase. That phase had already been detected by Raman spectroscopy, which uses lasers to measure how the atoms inside the hydrogen molecules vibrate against each other. At about 1.5 million atmospheres the vibrations change abruptly, indicating some major change in the hydrogen's structure. But what? The conventional interpretation was that it was a shift in the packing of the hydrogen molecules inside the solid hydrogen and that the move to metallic hydrogen would come at a higher pressure. Not so, said Silvera.

"At this time, we think the hydrogen-A phase is probably the metallic phase of hydrogen," he said at an APS press briefing. As evidence, he pointed to his team's studies on pressurized hydrogen at temperatures down to 4.5 K, much colder than other labs can achieve with high-pressure hydrogen. If the phase transition were caused by a change in the physical structure, then the transition should occur at much lower pressures when the temperature got close to absolute zero. But Silvera's lab found that even at 4.5 K, the transition came at 1.48 million atmospheres. This makes the formation of metallic hydrogen the most likely interpretation of the data, said Jon Eggert, a co-worker of Silvera's. "There are very few other things it could be," he said.

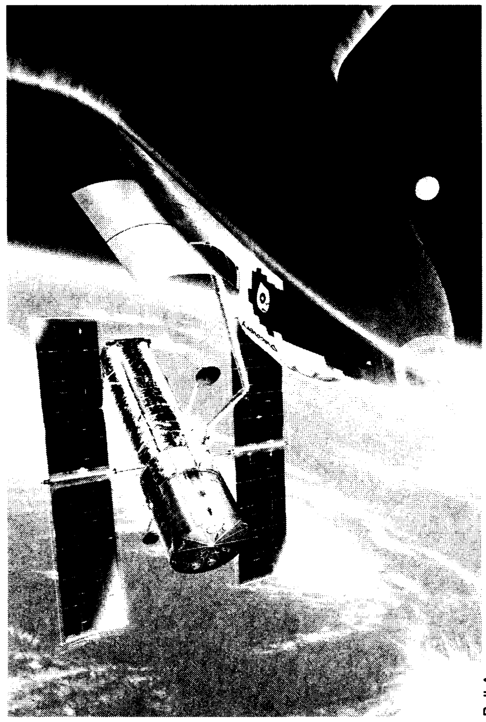
At the same APS briefing, Mao and Hemley retorted that their *Science* paper last summer pointed at the same conclusion Silvera is now approaching. At that time, they were relatively confident that hydrogen was metallic above 2 million atmospheres, but only hinted that hydrogen may become a "semimetal" at 1.45 million atmospheres. Since then, Mao said, they have been carefully examining the range between 1.5 million and 2 million atmospheres for conclusive evidence of the metallization. "To us, that is a lower pressure range now," he added, in a not so subtle reminder that the Carnegie group can still put higher pressure on hydrogen than its competitors.

Many observers, like Arthur Ruoff of Cornell University, remain unconvinced that metallic hydrogen has been seen by either group. The acid test would be to pass an electric current through the samples, Ruoff noted, but so far no one has done conductivity measurements above about 1 million atmospheres. Barring that, he said, researchers need a better theoretical understanding of hydrogen at high pressures, so that the optical measurements can be used convincingly to imply other properties.

■ ROBERT POOL

Hubble Space Telescope Takes Aim at the Stars

Don't look for pretty pictures right away; even if the launch goes perfectly, it will take months to get Hubble going



Ball Aerospace

Free at last! *An artist captures the moment when Hubble sets out on its own.*

AFTER ALMOST TWO DECADES of technical snafus, huge cost overruns, and a seemingly unending series of delays, the National Aeronautics and Space Administration's $1.55-billion Hubble Space Telescope is finally headed for the launch pad. The space shuttle Discovery is standing by to carry the telescope aloft at 9:21 EDT on the morning of 12 April (or as soon thereafter as weather and technical glitches permit). And if all goes well, astronomers and NASA officials will breathe a collective sigh of relief.

But that doesn't mean that the wait will be over: Before the telescope begins routine observations, NASA has penciled in at least 8 months of engineering tests and scientific calibration. Points out Peter Jakobsen, Space Telescope project scientist for the European Space Agency, which contributed the telescope's ultrasensitive Faint Object Camera, Space Telescope is the most complex and exquisitely precise scientific instrument ever built. So getting it operational in space entails exploring an engineering Twilight Zone: "There's only so much you can do on the ground beforehand."

Those 8 months will hardly be boring, however. Here are some milestones to watch for:

■ **Reaching orbit.** Since the launch comes just after the peak of the current sunspot cycle, when the earth's tenuous upper atmosphere has been warmed and expanded to its greatest extent, NASA's most urgent priority will be to keep the telescope from spiraling earthward too quickly due to atmospheric drag. Discovery's target altitude has therefore been set at 611 kilometers, which it should reach in under an hour. This altitude is roughly twice as high as shuttles usually go, and right at the ragged edge of where Discovery can carry a payload as heavy as the telescope with its engines going flat out. Assuming Discovery makes it, however, Space Telescope should be safe for about a decade.

But what if, say, an engine fails during launch and forces Discovery into a lower orbit? If that orbit is lower than 526 kilometers, then the astronauts will have no choice but to bring the telescope home again—otherwise, the atmospheric drag would bring the telescope down to a fiery death within 12 months. But if the orbit is higher than 526 kilometers, then the astronauts will go ahead and deploy the telescope anyway. Despite extensive engineering studies showing that the telescope's precision optics should survive the shock of a forced landing, no one wants to try it unless they absolutely have to. Instead, shuttle planners back on the ground would prepare for an emergency mission to reboost the telescope in 6 months to a year.

■ **Deployment.** Even if the launch goes perfectly, says Orbital Verification manager Michael Harrington of NASA's Marshall Space Flight Center, it will still be another full day before the telescope is ready for free flight. Starting about 4½ hours after launch, when the astronauts first supply power to run the telescope, ground controllers will spend the next 19 hours activating its communications systems, thermal controls, computers, scientific instruments, gyroscopes, pointing systems, and tape recorders.

Only when the telescope has been fully brought to life, about 23½ hours after