Quantum Physics

Elite Retreat Takes the Measure Of a Weirdly Ordinary World

At a remote lodge in the rural Midwest, physicists, philosophers, and historians confront the stubborn mysteries of quantum mechanics

STILLWATER, MINNESOTA—Two men sit at a long table, oblivious to the breakfast-time commotion. One moves a coffee cup from one side of a water glass to the other. "If I look *here* and don't see the cup," he says to the other, "then I know it must be *there*."

It sounds like a "deep" exchange between swotty young philosophy majors. But the fellow moving the cup has gray hair—and a Nobel Prize in physics. Sliding the porcelain, Anthony Leggett of the University of Illinois, Urbana-Champaign, explains how scientists might try to see past the strictures of quantum mechanics, the bizarre theory that governs the behavior of tiny objects and clashes with our everyday notions of reality. "None of the existing interpretations of quantum mechanics as a theory of the entire world is satisfactory," Leggett says to John Preskill, a physicist at the California Institute of Technology in Pasadena.

Leggett, Preskill, and 22 other physicists, philosophers, and historians have gathered here for the Seven Pines Symposium.* Packed into a wonderfully rustic lodge in a wooded state park, the scholars—all of them men—will share their insights, suites of rooms without telephones, and meals of roast quail and pheasant at a long communal table. Perhaps not since the famous Solvay Conferences of the early 20th century, at which Niels Bohr and Albert Einstein debated the meaning of quantum theory in their free time, has physics seemed so genteel.

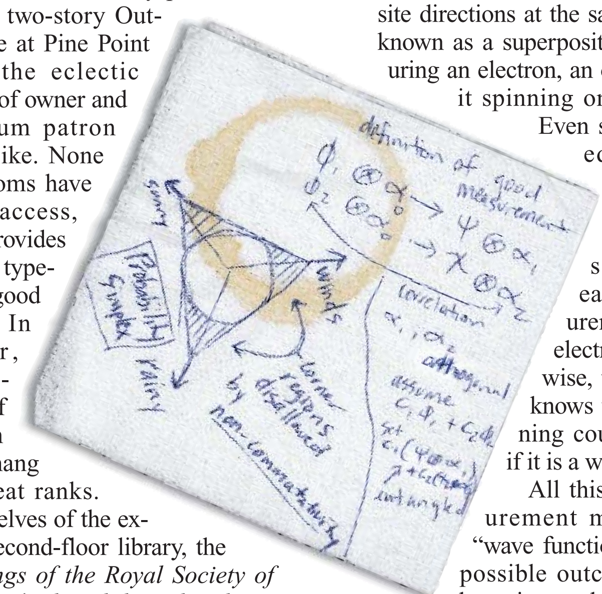
Each year, the symposium tackles another of physics' enduring puzzles: the nature of the vacuum, the concept of a field, the meaning of time. The aim is not to resolve the mysteries but to seed new lines of inquiry, says Roger Stuewer, a historian at the University of Minnesota, Twin Cities, and chair of the symposium's advisory board. "When we get the best people together," he says, "ideas are planted that in some intangible way will influence what they do in the future." Those germinating ideas are watered with a mellow Zinfandel and nourished with succulent steak.

This year, attendees spent 5 days grappling with the implications of quantum mechanics, which have perplexed physicists and philosophers since the theory was invented in the 1920s. The theory explains phenomena ranging from chemical bonding to the structure of neutron stars, and it may open the way to uncrackable quantum communications and superefficient quantum computers. Yet the strange quantum rules clash with our most basic experience of reality. In fact, no one knows how our boring old "classical world," in which a thing can be in only one place at a time, arises from the weirdness of quantum theory, says Gerard Milburn, a physicist at the University of Queensland in St. Lucia, Australia: "The fundamental question remains, Why do we have classical behavior in a quantum world?"

* The Seven Pines Symposium VIII, 5 to 9 May.

Fast cars and philosophy

Once home to the county poor farm, the two-story Outing Lodge at Pine Point reflects the eclectic character of owner and symposium patron Lee Gohlike. None of the rooms have Internet access, but one provides a manual typewriter in good repair. In another, six portraits of Marilyn Monroe hang in two neat ranks. On the shelves of the expansive second-floor library, the *Proceedings of the Royal Society of London* and *The Philosophical Magazine* mingle with Oscar Wilde's comedies, Einstein's letters, and a book entitled *The Mysteries of Pittsburgh*.



An amateur philosopher of science, Gohlike made his money restoring classic Mercedes-Benz racing cars. He befriended historian Stuewer 20 years ago and several years later proposed—and offered to pay for—the symposium. The invitation-only affair provides "a kind of demilitarized zone where people are allowed to get into more fundamental issues without being embarrassed," Gohlike says. Nonetheless, scholars must brace themselves for dizzying discussion and some spirited ribbing when they gather in the cool quiet of the library.

"Would you call *that* wave-function collapse?" asks one physicist as he explains how he and colleagues apply quantum theory to the state of the entire universe at once.

"You *don't* call that wave-function collapse," says a historian.

"Then we don't have wave-function collapse."

"They probably do," another physicist chimes in.

"*He* said they didn't," says a philosopher, gesturing toward the historian.

"I know, but I think he's in error about what he would say."

The scholars are debating a deceptively simple question: What does it mean to make a measurement?

According to quantum mechanics, a tiny object does not follow a continuous trajectory. Instead, it must be described by oscillating quantum waves that reveal only the probability of finding it here or there. An object such as an electron may also be in two different places at once or spin in opposite directions at the same time, a condition known as a superposition. But when measuring an electron, an observer always finds it spinning one way or the other. Even stranger, two separated electrons can be "entangled" so that both spin both ways at once, but in opposite directions from each other. If a measurement shows that one electron is spinning clockwise, the observer instantly knows that the other is spinning counterclockwise, even if it is a world away.

All this suggests that measurement makes the quantum "wave function" collapse into one possible outcome or another. Yet that view—the so-called Copenhagen interpretation of quantum mechanics—has troubled physicists for nearly 80 years. It assumes that between the bizarre realm of tiny objects and the commonsense world of everyday things lies a fuzzy border. Measurement and wave-function collapse somehow bridge the divide. But why, researchers wonder, should measurement have such unique power? The Copenhagen interpretation also tacks the classical world onto the quantum realm like a sundeck on a submarine, without explaining why it even exists. If quantum mechanics governs everything, then why don't voltmeters and people behave as oddly as atoms and photons?

Information rules

Like theologians reinterpreting scripture, physicists and philosophers have sought to resolve their quandaries by reading mind-bending new meanings into the rules of quantum mechanics. Some favor a "many worlds" interpretation, in which the wave function never collapses but merely splits into branches at each potential measurement, leading to multiple realities of which we experience only one. Other prefer so-called modal interpretations that rely on undetectable "partial hidden variables" to ensure, for example, that a voltmeter never reads 0 volts and 5 volts at the same time.

Whatever their philosophical leanings, physicists now generally agree that quantum mechanics itself makes it extremely difficult to spot really big things in superpositions. Large objects quickly entangle themselves with their surroundings, and such "decoherence" obscures a superposition in somewhat the same way that interference from a vacuum cleaner scrambles the image on a television screen. Strictly speaking, however, decoherence leaves superpositions intact, says historian Michel Janssen of the University of Minnesota. And even if they're hidden, he says, two-places-at-once coffee cups defy our sense of a single definite reality and leave us mired in "an ontology of possibilia and an epistemology of radical deceit."

To avoid that dreary fate, participants at this year's Seven Pines Symposium are taking a different tack entirely. Spurred by recent efforts to develop quantum information technologies, thinkers such as Jeffrey Bub, a philosopher at the University of Maryland, College Park, hope to prove that quantum mechanics grows naturally out of the principles of information theory.

Last year Bub and colleagues showed that three restrictions on how information can be transmitted and copied can reproduce from scratch the basic features of quantum mechanics. They assume that the world can be described by a type of mathematics known as a C* (pronounced C-star) algebra. Then they lay down the laws: no instantaneous transmission of information, no perfect copying of information, and no sharing of information in a particular way called "unconditional bit commitment." Those restrictions produce a mathematical formalism that looks like quantum mechanics, Bub says. The result suggests that the basic stuff of the universe is information, he says.

Trying to comprehend quantum mechanics is like grasping at minnows in a stream, however, and information is a particularly slippery concept. "What's it mean to say that the universe is just information?" says Philip Stamp, a physicist at the University of British Columbia in Vancouver. "To me information has to be information about something."

Mens sana. Fortified by country air, gourmet meals, and an occasional nip, scholars at the Seven Pines Symposium debate why physics seems so strange—and daily reality doesn't.

CREDITS: PAUL PETERSON

Physicist Christopher Fuchs of Lucent Technologies in Murray Hill, New Jersey, has an answer: The wave function is an observer's information about the objective world. A measurement instantly refines that information, which is all in the observer's head, giving the illusion that the wave function collapses. In Fuchs's view, the instantaneous collapse is no more mysterious than the clarity that suddenly emerges when you remember that you left your checkbook beside the toaster. "Quantum measurement is the refinement of expectations, period," Fuchs says. "The only mystery in quantum mechanics is why there is a restriction" on the completeness of knowledge.

James Hartle, a physicist at the University of California, Santa Barbara, says he likes the spirit of Fuchs's approach. But there may be a hitch, he says. Contemplating the period just after the big bang, quantum cosmologists routinely talk about the wave function of the entire universe. "If the wave function of the universe is only a characterization of somebody's information, then whose is it?" he asks.

With such questions unanswered and dinnertime approaching, the scholars opt for a stopgap solution: They head for the bar.

More craziness ahead?

Yet, with martinis in hand, many continue to talk quantum mechanics. Such is the pull of the riddles of quantum theory—especially now, as new experiments may allow physicists to probe the limits of the theory.

Driven in part by the need to make reliable "qubits"—bits that can be 0, 1, or 0 and 1 at the same time—for quantum computers, researchers are striving to put ever larger objects and systems into quantum superpositions. In 2000 two teams independently coaxed billions of electrons to flow simultaneously in opposite directions around tiny rings of a superconductor (*Science*, 31 March 2000, p. 2395). Two years ago another team proposed a scheme to place a tiny mirror in two places at once (*Science*, 11 October 2002, p. 342). Eventually, says the University of Illinois's Leggett, such experiments might reveal that laws and forces beyond quantum mechanics intervene to prevent truly macroscopic objects from being in superpositions—a notion known as macrorealism.

The trick is to thoroughly isolate a sizable thing and push back the curtain of decoherence far enough to put the object in two places at once—or fail in a way that reveals a new phenomenon. A coffee cup will likely always remain too large for such experiments, but researchers are marching toward the macro realm. "Ideas that weren't taken seriously 25 years ago are taken quite seriously now," Leggett says.

Even if some new theory lurks just over the quantum horizon, don't expect it to restore sanity and comprehensibility to physics. Any subsequent theory will still have to explain all the bizarre phenomena that quantum mechanics already does, says Robert Wald, a theoretical physicist at the University of Chicago, so it, too, will be a strange beast. "What's going to come next is going to be just as crazy or crazier," he says. "You can count on that."

Perhaps that's a good thing. A theory more comprehensible than quantum mechanics wouldn't require such a symposium. And that would spoil the fun.

–ADRIAN CHO