Quantum Mechanics Gets Real

By DAVID LINDLEY

Writing to Niels Bohr in 1935, physicist Erwin Schrödinger lamented his inability to understand a principle that Bohr deemed essential to the interpretation of quantum mechanics: "It must belong to your deepest conviction—and I cannot understand on what you base it," Schrödinger complained.

Bohr's principle concerns the way in which a measurement of a quantum mechanical system—the position of an electron, for example—produces a specific result. Quantum mechanics requires that a system exist in a range of possible states, a superposition, until a measurement is made, at which point one of those states takes on a definite reality. But how?

To illustrate his perplexity, Schrödinger imagined placing a cat in a closed box, along with an atom that could be in one of two states and a device to measure its state. If the measurement goes one way, the cat stays alive; if it goes the other way, the unfortunate cat dies. The quantum system starts as a superposition of two possible states, Schrödinger noted, but does that mean that the cat is simultaneously dead and alive? If not, what is it about a cat that requires it to be dead or alive rather than some unimaginable combination of the two?

Laurie Painter

Last year, scientists at the National Institute of Standards and Technology (NIST) in Boulder, Colo., created a small-scale scenario resembling the box with the fanciful cat. They trapped a single atom in such a way that it could occupy either of two distinct states. Then, using lasers, they nudged the two states in opposite directions, physically separating the two halves of the superposition.

Great precision was needed to maintain coherence between the separated states. Even the tiniest disturbance could have upset the system, forcing the atom to take up a definite position in one place or the other. Theoretical investigations in recent years suggest that the delicacy of such states holds an explanation for why atomic superpositions—let alone superpositions of cats—are not normally seen.

The atoms of a real purring, yowling, or napping cat constantly jiggle around, preventing a quantum mechanically coherent state from encompassing the entire animal, except perhaps for an instant. Moreover, the aliveness or deadness of a cat are qualities that have durable meaning, even though the cat's internal quantum disposition is in a perpetual state of flux.

These insights have been mathematically refined to form the basis of a physical process called decoherence. According to its proponents, decoherence confers long-term stability only on those properties of a macroscopic system that correspond to what an observer would recognize. A cat, in other words, remains dead or alive long enough for that state to be recorded; a superposed dead-and-alive cat, however, can never exist long enough to be noticed.

In a broad way, says Wojciech H. Zurek of Los Alamos (N.M.) National Laboratory, decoherence vindicates Bohr's "brilliant stroke of reasoning" in concluding that measurement—an act of noticing—must somehow impose stability on quantum systems. Bohr may not have altogether liked the idea of decoherence, adds Zurek, because it fails to provide the absolute definition of classical behavior that Bohr would have wanted. As last year's NIST experiment shows, single atoms can sometimes behave in a quantum mechanical way, as well as in the classical style that most experiments portray.

Not everyone agrees that these new ideas resolve Schrödinger's long-standing perplexity. Decoherence may explain why observable states are classical states, but it nevertheless leaves open a range of possibilities. "It says you'll never get any wrong answers, but it still doesn't say how you get an answer at all," contends Anthony J. Leggett of the University of Illinois at Urbana-Champaign. Leggett believes that as experimenters construct increasingly large quantum mechanically coherent systems, they may find discrepancies indicating flaws in quantum mechanics itself.

Zurek responds that arguments over the value of decoherence may result in part from disagreement as to what questions physics should ultimately answer. Applied to the universe as a whole, decoherence limits the possible cosmic histories, or series of events constituting the universe's evolution, to those consistent with the laws of classical physics. This screening may not be useful, he says, for anyone who wants to know why the universe is the way it is, but it may be comforting to know that the universe we perceive is explicable by the laws of physics.

Quandaries of this sort arise largely because of the dichotomy between intuitive thinking and the way quantum mechanics works, says Andreas J. Albrecht of Imperial College in London, "but I have yet to see that amazement translated into practical questions." He suggests that speculation about quantum computers—much discussed but so far unrealized—can usefully illuminate the inner workings of quantum mechanics.

The bits of a quantum computer would be superpositions of quantum states rather than strictly defined binary states. A computation proceeds as an interaction of superposed states, yielding an answer in response to a measurement. Although quantum computers remain "far-fetched" for now, says Albrecht, understanding how they would work is tantamount to understanding how classical properties emerge from quantum systems.

Ultimately, the practical and cosmic questions may be one and the same. After all, Albrecht observes, the entire universe is fundamentally a quantum computer, and we ourselves are among the products of its computation. ☐

1964 High-yield rice launches Green Revolution

1964 Excavation of fossils from 1.8-million-year-old *Homo habilis*

1964 Idea of quarks introduced

1965 Detection of the cosmic microwave background

1967 Human heart transplanted

1967 Discovery of pulsars

1968 Development of plate tectonics theory

1968 Genetic code explained

1969 First gene cloned

1969 Men walk on the moon

1972 Detection of a candidate black hole