A Chaotic Cat Takes a Swipe at Quantum Mechanics

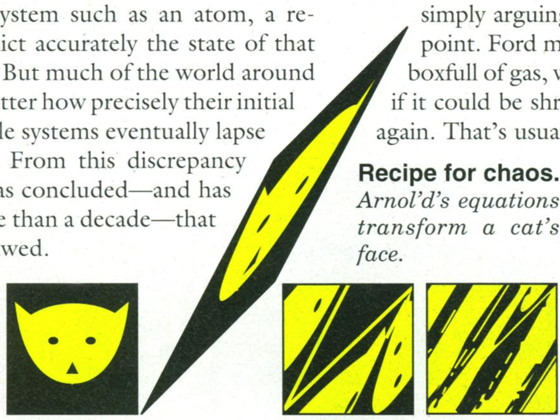
Since quantum mechanics was formulated in the 1920s, a host of distinguished physicists, from Einstein on, have flinched at some of its more outlandish predictions—its assertion that a particle can be in two places at the same time, for example. But in the face of the theory's astounding agreement with observation, such complaints have been easy to discount. "Quantum mechanics will never be rejected on the basis of internal inconsistencies," shrugs Harvard University physicist Sidney Coleman. "It would take a wrong experimental prediction."

Enter chaos theorist Joseph Ford of the Georgia Institute of Technology, who has long harbored doubts about quantum mechanics and thinks he is now armed for an experimental showdown. In a paper being published this month in *Physica D,* Ford has demonstrated that when an odd physical system called Arnol'd's cat is taken on a mathematical round trip into the quantum world and back, it loses one of its key attributes—chaotic behavior.

But quantum mechanics is supposed to agree precisely with classical physics even when it is extended to the large-scale world. That is, if the cat was chaotic in "our" world, it shouldn't have lost its stripes during its sojourn in another. So, says Ford, something is amiss—and some physicists agree. "This is an interesting and unanticipated result," says Leslie Ballentine, a quantum mechanics expert at Simon Fraser University in Vancouver. "It should stimulate people into taking a closer look at how well classical physics can be recovered from quantum mechanics."

Ford's longstanding doubts about quantum theory grow from his own academic specialty, chaos theory. Quantum mechanics is strictly deterministic: Given the right information about a quantum mechanical system such as an atom, a researcher should be able to predict accurately the state of that system at any time in the future. But much of the world around us is indisputably chaotic. No matter how precisely their initial states are known, most large-scale systems eventually lapse into complete unpredictability. From this discrepancy with the classical world, Ford has concluded—and has vociferously maintained for more than a decade—that quantum mechanics must be flawed.

But it's been a lonely decade. Even Ford will concede that his arguments have so far had little impact on the physics community. So he decided to find a system whose classical behavior could be compared directly to the behavior predicted by quantum mechanics—and that's when he pounced on Arnol'd's cat.



Recipe for chaos. *Arnol'd's equations transform a cat's face.*

The system consists of a set of equations devised by Vladimir Arnol'd of Moscow State University as a model for studying chaos. Arnol'd's equations take a well-ordered set of points and methodically fold and chop it into an unrecognizable mess—traditionally, a cat's face serves in this thankless role. The underlying mathematics, though, is best thought of as a description of the motion of a particle roaming over the surface of a donut, motion that becomes completely unpredictable over time.

Ford began by "quantizing" the cat—a process that roughly corresponds to mathematically shrinking the system to atomic or subatomic dimensions, where quantum rules swamp classical behavior. Along the way, the particle gets smeared out into a quantum mechanical wave, which follows the same orbits around the donut as the particle. But because waves interfere with themselves, some orbits are ruled out. The remaining discrete orbits are the only ones allowed in the quantum version.

Having done this, Ford found, as he had expected, that the quantized cat is nonchaotic: The wave follows precisely predictable patterns around the donut. But when a quantized system is restored to classical dimensions, it should regain all its classical behavior—including chaos. Thus Ford's next move was to "reclassicize" his quantum system. Physicists typically do so by gradually bringing Planck's constant—a number that recurs throughout quantum mechanics—to zero, which is analogous to "growing" the system back to macroscopic size.

To Ford's surprise, the reclassicized Arnol'd's cat continues to eschew all chaotic behavior. One telltale sign: it precisely retraces its path when time is reversed, something that neither the original cat nor any chaotic system can do. Quantum mechanics is in effect incorrectly predicting the cat's behavior. "If quantum mechanics isn't in agreement with an observed classical phenomenon," says Ford, "then it's wrong."

Michael Berry, a quantum mechanical theorist at the University of Bristol in England, thinks it is Ford who is wrong. He charges that Ford's proof is marred by a technical glitch. Ford's particular argument, he says, requires taking the system into the infinite future—to make sure chaos doesn't eventually pop up—while bringing Planck's constant to zero. But, says Berry, "everything is supposed to be held constant when you take Planck's constant to zero." Because Ford didn't hold time constant, says Berry, "he hasn't proven anything."

Ford maintains Berry has misunderstood him. But rather than simply arguing with Berry, Ford has decided to prove his point. Ford maintains that a real physical system, such as a boxfull of gas, would give the same results as the abstract cat if it could be shrunk to quantum dimensions, then enlarged again. That's usually out of the question, of course. But there are a few small collections of particles that straddle the line between the quantum and classical worlds, opening the way to a direct comparison between quantum mechanical predictions and classical behavior.

One is a Rydberg atom, a highly stimulated hydrogen atom in which the electron orbits so far from the proton that the atom approaches classical dimensions. Another is a superconducting quantum interference device, or SQUID, a tiny but still macroscopic device in which electrons behave quantum mechanically. Using one system or the other, Ford says, "I plan to propose an experiment well before the end of the year."

Since the quantum mechanical description of the system would preclude chaos, any chaotic behavior it might show would represent a deviation that, if upheld, would send shock waves through physics. Short of that, Ford doesn't expect a lot of physicists to join him in his critique. "It's clear to me and a growing number of physicists that something is wrong with quantum mechanics," he says. "But coming out and attacking it directly puts you on the lunatic fringe." ■ DAVID H. FREEDMAN

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