PHYSICS

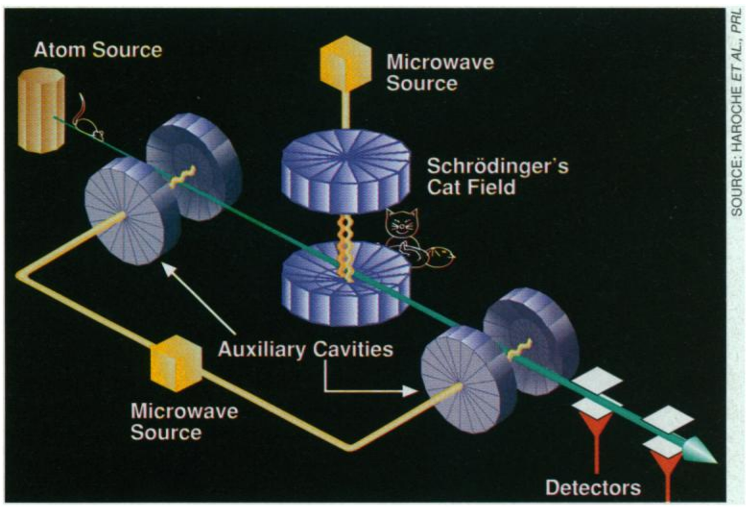
Atomic Mouse Probes the Lifetime of a Quantum Cat

How do you tell whether a cat is alive or dead without looking directly at it? Simple, answers Serge Haroche, a physicist at the École Normale Superieure (ENS) in Paris: You let a mouse run past its nose and see what happens to the mouse. Haroche is not, however, thinking of an ordinary cat. The cat in this case is Schrödinger's cat: a version of the elusive beast pictured by the Austrian physicist Erwin Schrödinger in a thought experiment. Schrödinger imagined a cat shut in a box with a radioactive atom that has a 50–50 chance of decaying in an hour. If the atom decays, it kills the cat. If it doesn't, the cat lives. This setup is supposed to transfer the quantum indeterminacy of the atom to the cat, leaving it neither dead nor alive but in a superposition of both states: dead and alive.

To detect this strange state, says Haroche, you make a small hole in the box and send in the mouse: "You should have one probability for the mouse to escape if the cat is alive and another one—presumably larger—if the cat is dead. With the cat in a quantum superposition, both dead and alive, these probabilities would combine in a strange way, incompatible with classical logic, in an effect called quantum interference." He adds, however, that such an experiment will never work with such macroscopic systems as cats or mice. A ubiquitous process known as decoherence will instantly destroy the quantum superposition, making the cat either dead or alive and washing out the quantum interference between the two outcomes.

But by constructing minute versions of Schrödinger's cat and mouse, Haroche, Jean-Michel Raimond, Michel Brune, and their ENS colleagues have actually measured this decoherence process, as they report in the 9 December *Physical Review Letters*. They created a Schrödinger's cat consisting of a few microwave photons in an indeterminate quantum state and sent in a mouse—an atom prepared so that it can react to the dead-and-alive state of the cat. Investigators have caught glimpses of Schrödinger's cat before (*Science*, 24 May, p. 1101), but the mouse allows the ENS group to monitor its condition: to see how long the quantum superposition survives before collapsing into one state or the other.

"The experiment is one of the first very controlled measurements of decoherence," says physicist Chris Monroe of the National Institute of Standards and Technology, who has also been involved in creating laboratory versions of Schrödinger's cat. "Everyone thinks that you can't have live and dead superpositions in the macroscopic world. The theory shows how these things just shouldn't last long, and this is really one of the first measurements that vindicates that point of view."



Cat and mouse. A specially prepared atom probes a Schrödinger's cat—a microwave field that exists in two different quantum states at once.

Laboratory versions of Schrödinger's cat look nothing like the original, but they do resemble it in existing in two distinct states at once. In the ENS experiment, for instance, the cat is a dead-and-alive superposition of two phases of an electromagnetic field resonating in a centimeter-sized cavity. (The phase of the field can be thought of as the timing of its crests and valleys.) What generates the superposition of phases is a passing Rydberg atom, an atom excited to such high levels that it swells to 2500 times the size of a normal atom. One such huge atom can easily create macroscopic changes in the electromagnetic field, explains Haroche.

Before reaching the cavity, the Rydberg atom encounters microwaves that excite it into a superposition of two different energy states. When the atom enters the cavity, each energy state induces its own phase shift in the electromagnetic field, resulting in the superposition of two field states, each with a different phase. In essence, the atom transfers its own indeterminacy to the electromagnetic field.

Having set up the Schrödinger's cat–type field, the physicists then probe its collapse, which is triggered by the quantum state's environment. Now they use a second Rydberg atom—the Schrödinger's mouse. "The first atom prepares this strange state," says Haroche, "and the second atom goes across the cavity and interacts with this strange state, again by shifting its phase, and then it goes out and you detect it" and compare its state with the final state of the first atom. By repeating the experiment many times, the physicists can measure the probability that the second atom emerges in a given state relative to the first atom. This "conditional probability" has a measurable quantum interference term if the electromagnetic field is in a quantum superposition when the second atom passes through.

The strategy allows for two crucial measurements of decoherence. First, the ENS physicists can determine how long the field takes to decay into one phase or the other, by changing the time delay between the two atoms. "If you have a longer delay between the two atoms," says Haroche, "the coherence decays, and the second atom does not detect it anymore." They can also measure how the lifetime of the catlike field superposition changes with its size. Injecting more microwave photons into the cavity or increasing the phase difference between the two states both make the cat more macroscopic, and the researchers found, as theory predicted, that both changes sped up the decoherence. "The decay becomes faster and faster," says Haroche.

This size effect, he continues, may be the explanation for why even Schrödinger's mouse would never be able to detect a full-grown Schrödinger's cat. "If you had a real Schrödinger's cat in a box," says Haroche, "you would never see the superposition, because the decoherence time is so short for big systems."

The ENS experiment marks the beginning of exploration of the weird and mysterious "transition from quantum to classical," says Wojciech Zurek of the Los Alamos National Laboratory. This is territory that is attracting technological interest as researchers discuss tapping into the quantum world for computation and cryptography: "What [Haroche, Brune, Raimond, and their colleagues] have established now is only a beachhead."

–Gary Taubes