Quantum Pot Watching

A test of how observation affects a quantum system verifies theoretical predictions and proves the truth of an old maxim

A WATCHED POT NEVER BOILS, at least not if it's a quantum pot. That's the gist of a recent experiment by Wayne Itano, Daniel Heinzen, John Bollinger, and David Wineland at the National Institute of Standards and Technology in Boulder, Colorado. The work is the first unambiguous confirmation of a phenomenon that theorists had predicted in the 1970s, and it highlights one of the strangest aspects of quantum physics—the way an observer can influence the behavior of a system merely by sneaking a peek.

The pot that the NIST scientists watched was a magnetic trap holding several thousand beryllium-9 ions—the "water." At the beginning of the experiment, the ions were ordered so that they were almost all in a single electronic state, which was called Level 1. By exposing the ions to a radio-frequency field for exactly 256 milliseconds, the researchers caused them to move to another state, Level 2. The water had boiled.

At least that's what happened when no one was watching. It was a different story if someone took a look before the 256 milliseconds were up, says Wayne Itano, a member of the NIST team.

The researchers made their observations by exposing the beryllium ions to very short pulses of laser light whose photons had an energy equal to the energy difference between Level 1 and a third atomic state of the beryllium ions, Level 3. When the laser light hit the ions in Level 1, it would force them briefly into Level 3. The ions would then quickly decay back to Level 1, each emitting a photon that could be counted with a photon detector. In this way, the researchers could tell how many of the 5000 or so beryllium ions in their pot were in Level 1 at any given time, and could thus estimate the number in Level 2. (The Level 2 ions were not affected by the laser pulses.)

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Itano and his colleagues found that the number of ions in Level 2 at the end of 256 milliseconds depended on how often they looked at the ions. If they waited the full period to shine a laser pulse at the ions, all had moved to Level 2. If they looked once after 128 milliseconds and then again at 256 milliseconds, only half of the ions were in Level 2 at the second measurement. If they made four evenly spaced observations, only about a third of the ions were in Level 2 at the end. And if they peeked 64 times—or once every 4 milliseconds—almost none of the ions were found in Level 2. The pot refused to boil.

The reason, Itano explains, lies in the way in which this quantum "water" boils. When an individual atom in Level 1 is exposed to the radio-frequency field, its quantum state gradually shifts from Level 1 to Level 2. If one waits the full 256 milliseconds before taking a look, the ion will be completely in the Level 2 state when the laser pulse hits it.

But what happens if someone peeks early—say after only 128 milliseconds? At this point, an ion is in a composite state, half Level 1 and half Level 2. Observing it forces it to be in either one state or the other, much as a tossed coin suddenly goes from an indefinite state to being either heads or tails once it hits the ground. A single ion observed after 128 milliseconds will have equal probability of going into Level 1 or Level 2, so roughly half of the several thousand ions in the trap will be seen to be in Level 1 and the other half in Level 2.

After only 4 milliseconds, however, the quantum state of any given ion is about 99.99% Level 1. This means that shining the laser at the trap will reveal all but about 0.01% of the ions to still be in Level 1. The water has not yet started to boil.

But the act of looking has done more than reveal the state of the system. It has also sent all the ions, except for the few that made it to level 2, back to the starting point in Level 1. If the observer continues to peek every 4 milliseconds, the system is reset again and again, with an average of only 0.01% of the ions moving to Level 2 each time. At the end of 256 milliseconds, only about 0.6% of the ions have moved to Level 2, and the system looks very nearly the same as at the beginning. Making more frequent observations would reduce the percentage in Level 2 even more, Itano says.

The NIST experiment provides experimental confirmation of an effect noted by several observers, including B. Misra and Ennackel Sudarshan at the University of Texas in Austin in the late 1970s. These two researchers showed that in theory a continuously observed quantum state can never decay and called this the "quantum Zeno effect." That was in reference to a famous paradox conceived by the ancient Greek philosopher Zeno, in which he argued that motion is impossible. Consider an arrow in flight, Zeno said: At any given instant it cannot be at two places, so it must be at one point, but if it is in one spot it is at rest. This implies that the arrow is at rest at every moment of its flight, so it cannot be moving after all.

Until the NIST experiment, no researchers had demonstrated the quantum Zeno effect directly and unambiguously, although some experiments involving continuous observation of certain quantum systems may have exhibited it indirectly, Itano says. The key to the NIST group's success was use of a system in which the transition from one state to another proceeded slowly enough so that observations could significantly reduce the probability of it happening. For instance, in order to slow radioactive decay, researchers would have to make measurements that are less than one-trillionth the duration of the 2.4-millisecond pulses used in the NIST work. This is way out of the range of experimental capabilities.

Although in theory one could suspend any quantum transition—even the decay of a radioactive atom—by keeping a constant watch on it, in practical terms this is impossible, Itano notes. Because any observation takes a finite period of time, there will always be in-between times when the atom is not being watched and can decay. The NIST researchers could probably improve their result by several orders of magnitude by using a more powerful laser, which would permit shorter laser pulses and more observations, Itano says, but even then a few atoms would still make it to Level 2. And please don't call their experiment the "quantum pot-watching effect." To Itano *et al*, "Quantum Zeno effect" sounds more erudite and catchy. ■ ROBERT POOL