

Caltech

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Seeing Quantum Motion

Consider the pendulum of a grandfather clock. If you forget to wind it, you will eventually find the pendulum at rest, unmoving. However, this simple observation is only valid at the level of classical physics—the laws and principles that appear to explain the physics of relatively large objects at human scale. However, quantum mechanics, the underlying physical rules that govern the fundamental behavior of matter and light at the atomic scale, state that nothing can quite be completely at rest.

For the first time, a team of Caltech researchers and collaborators has found a way to observe—and control—this quantum motion of an object that is large enough to see. Their results are published in the August 27 online issue of the journal *Science*.

Researchers have known for years that in classical physics, physical objects indeed can be motionless. Drop a ball into a bowl, and it will roll back and forth a few times. Eventually, however, this motion will be overcome by other forces (such as gravity and friction), and the ball will come to a stop at the bottom of the bowl.

"In the past couple of years, my group and a couple of other groups around the world have learned how to cool the motion of a small micrometer-scale object to produce this state at the bottom, or the quantum ground state," says [Keith Schwab](#), a Caltech professor of applied physics, who led the study. "But we know that even at the quantum ground state, at zero-temperature, very small amplitude fluctuations—or noise—remain."

Because this quantum motion, or noise, is theoretically an intrinsic part of the motion of all objects, Schwab and his colleagues designed a device that would allow them to observe this noise and then manipulate it.

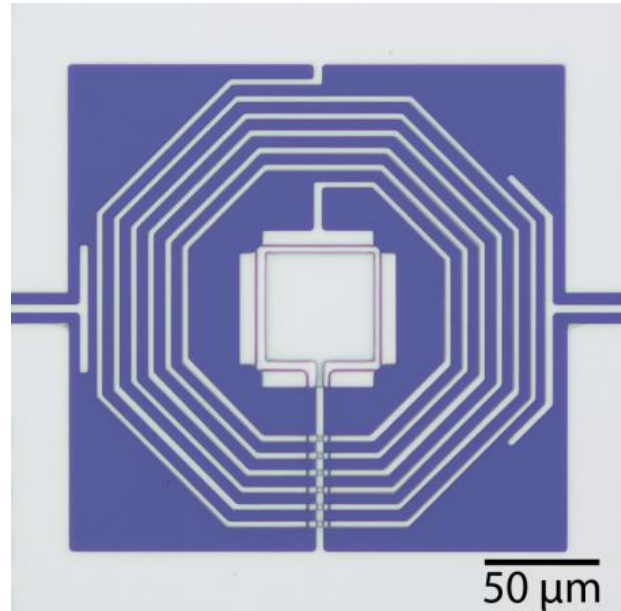
The micrometer-scale device consists of a flexible aluminum plate that sits atop a silicon substrate. The plate is coupled to a superconducting electrical circuit as the plate vibrates at a rate of 3.5 million times per second. According to the laws of classical mechanics, the vibrating structures eventually will come to a complete rest if cooled to the ground state.

But that is not what Schwab and his colleagues observed when they actually cooled the spring to the ground state in their experiments. Instead, the residual energy—quantum noise—remained.

"This energy is part of the quantum description of nature—you just can't get it out," says Schwab. "We all know quantum mechanics explains precisely why electrons behave weirdly. Here, we're applying quantum physics to something that is relatively big, a device that you can see under an optical microscope, and we're seeing the quantum effects in a trillion atoms instead of just one."

Because this noisy quantum motion is always present and cannot be removed, it places a fundamental limit on how precisely one can measure the position of an object.

But that limit, Schwab and his colleagues discovered, is not insurmountable. The researchers and collaborators developed a technique to manipulate the inherent quantum noise and found that it is possible to reduce it periodically. Coauthors Aashish Clerk from McGill University and Florian Marquardt from the Max Planck Institute for the Science of Light proposed a novel method to control the quantum noise, which was expected to reduce it periodically. This technique was then implemented on a micron-scale mechanical device in Schwab's low-temperature laboratory at Caltech.



Credit: Chan Lei and Keith Schwab/Caltech

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"There are two main variables that describe the noise or movement," Schwab explains. "We showed that we can actually make the fluctuations of one of the variables smaller—at the expense of making the quantum fluctuations of the other variable larger. That is what's called a quantum squeezed state; we squeezed the noise down in one place, but because of the squeezing, the noise has to squirt out in other places. But as long as those more noisy places aren't where you're obtaining a measurement, it doesn't matter."

The ability to control quantum noise could one day be used to improve the precision of very sensitive measurements, such as those obtained by LIGO, the Laser Interferometry Gravitational-wave Observatory, a Caltech-and-MIT-led project searching for signs of gravitational waves, ripples in the fabric of space-time.

"We've been thinking a lot about using these methods to detect gravitational waves from pulsars—incredibly dense stars that are the mass of our sun compressed into a 10 km radius and spin at 10 to 100 times a second," Schwab says. "In the 1970s, Kip Thorne [Caltech's Richard P. Feynman Professor of Theoretical Physics, Emeritus] and others wrote papers saying that these pulsars should be emitting gravity waves that are nearly perfectly periodic, so we're thinking hard about how to use these techniques on a gram-scale object to reduce quantum noise in detectors, thus increasing the sensitivity to pick up on those gravity waves," Schwab says.

In order to do that, the current device would have to be scaled up. "Our work aims to detect quantum mechanics at bigger and bigger scales, and one day, our hope is that this will eventually start touching on something as big as gravitational waves," he says.

These results were published in an article titled, "[Quantum squeezing of motion in a mechanical resonator.](#)" In addition to Schwab, Clerk, and Marquardt, other coauthors include former graduate student Emma E. Wollman (PhD '15); graduate students Chan U. Lei and Ari J. Weinstein; former postdoctoral scholar Junho Suh; and Andreas Kronwald of Friedrich-Alexander-Universität in Erlangen, Germany. The work was funded by the National Science Foundation (NSF), the Defense Advanced Research Projects Agency, and the Institute for Quantum Information and Matter, an NSF Physics Frontiers Center that also has support from the Gordon and Betty Moore Foundation.

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