

Maths, Physics & Chemistry

Silencing a quantum drum

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ABSTRACT

Using a trick inspired by noise-cancellation headphones, we have been able to control the motion of a millimeter-sized drum at the "quantum level", even though it is big enough to see with our bare eyes.

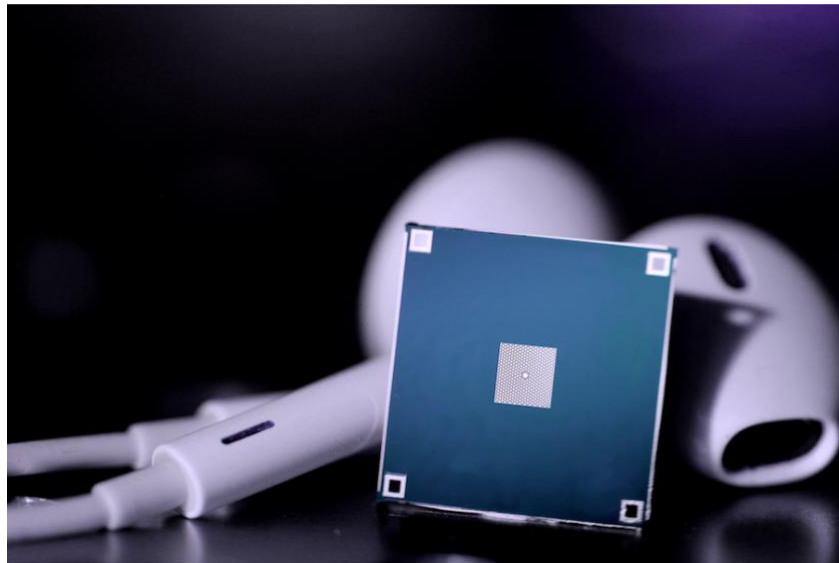


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To a classical physicist, there is no fundamental limit to how well you can measure something. A classical object, for example, always exists in a well-defined position; if you want to know that position with better accuracy, you simply build a better microscope. The story is more subtle from the perspective of quantum physics, in which objects are fundamentally described by waves, spreading out over many locations simultaneously. Quantum mechanics also obeys Werner Heisenberg's famous [uncertainty principle](#), which says that certain properties of an object (for example its position and [momentum](#)) cannot both be known exactly at the same time. A measurement of an object's position will inevitably disturb its velocity (adding so-called "backaction"), in line with Heisenberg's principle. That is, the very act of measurement will affect the thing being measured, and no matter how carefully

you build a microscope, it will be unavoidably imprecise.

While these ideas were born a century ago, it wasn't until recently that it became possible to see them in action beyond the microscopic world of atoms and electrons. Larger objects generally appear more classical, and the backaction of a normal microscope would be tiny. But by carefully designing the kind of object being measured and the microscope being used, our team at the Niels Bohr Institute can now measure the motion of that object at a level where quantum mechanical limits really matter.

The vibrating object we designed is a millimeter-sized membrane made of the ceramic silicon nitride, stretched tightly over a silicon frame. It resembles a miniature version of a drumhead, except that it can

oscillate about 10,000-times faster. We punch a pattern of holes in the membrane, implementing a special trick we invented to isolate the vibrational motion from the environment. This works so well that the drum swings about a billion times once excited. Instead of a conventional microscope, we then use lasers to precisely measure the membrane motion.

We observe strong measurement backaction, as the random impacts of laser photons (single particles of light) shake up membrane vibrations. Thanks to the extreme isolation achieved by the hole pattern of the membrane, this backaction is not hidden by other sources of noise. This measurement of the vibrations of our drum differs from an ideal measurement (at the Heisenberg uncertainty limit) by only 35% -- ten times better than previous studies.

This ultra-precise position measurement enables us to go a step further and control the drum's motion in a way that's never been possible before. When measuring our membrane, we see large, random motion, caused by measurement backaction as well as some thermal jiggling due to the temperature of the object. Since we have such a precise measurement of this motion, we can apply a force that is specially tailored to cancel this motion, effectively cooling the object.

Noise-cancellation headphones rely on precisely such feedback, in which a microphone measures the background acoustic noise, and a speaker produces sound waves designed to cancel it out at the eardrum. In our case, the noise is *much* smaller, but thanks to our ultra-sensitive laser 'microphone', we can still cancel it out. Our feedback force cools the

drum from millions of phonons (the quantum unit of sound energy) to just above half a phonon, known as the quantum ground state. Even though this feedback force is applied through very *classical* tools (voltage signals, processed by a computer), we are still able to tamp down the *quantum* noise, thanks to our near-ideal measurement.

This achievement is representative of an ongoing revolution in quantum physics. Experimental verifications of quantum mechanics are no longer constrained to single atoms or single particles of light. Mechanical systems like the drum studied here can now be treated definitively as quantum systems – a remarkable feat, given that they are visible to the naked eye. Looking forward, such mechanical systems could be a promising platform for studying fundamental physics questions at the intersection of gravity and quantum mechanics. For instance: if one could place a mechanical object into a [quantum superposition](#) (in two places at the same time), would it [gravitationally interact with itself](#)? These devices might also serve as useful tools in the growing field of [quantum computing](#) (acting as a quantum memory), or as ultra-precise sensors, enabling [MRI-like imaging at a microscopic level](#). Our results present an important step on this path, by demonstrating a 'microscope' of which Heisenberg could be proud.

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