

# What is quantum squeezing?

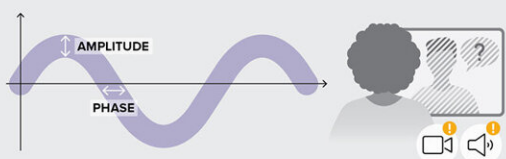
September 25 2023, by Kevin Jackson

## QUANTUM SQUEEZING

A technique for measuring signals with greater precision



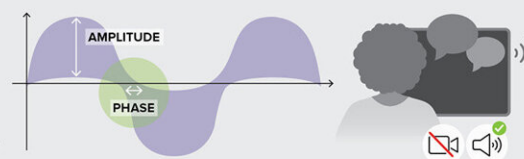
A system has **uncertainty** of amplitude and phase.



The thickness of the line in this wave function indicates **uncertainty for both phase and amplitude**. To better understand what's happening in this system, we pick which metric matters more to us and sacrifice the other.

For example, in a poor-quality video call, we may decide that audio is more important than video and that we need to sacrifice video in order to hear others clearly.

Increased **uncertainty** of amplitude yields a **decreased uncertainty** of phase.



In quantum squeezing, scientists increase the uncertainty of either amplitude or phase to decrease the uncertainty (increase the precision) of the other variable. Here, the amplitude uncertainty is increased in order to **decrease the phase uncertainty**.

Even though we're now less sure of the system's amplitude, we can get a **more precise reading of the wave function's phase**. This is akin to tuning out or eliminating a call's video feed in order to increase the clarity (decrease the uncertainty) of the audio feed.

Argonne National Laboratory. Credit:

How many times have you shown up to a video meeting with people at work only to find you have terrible internet that day? Maybe the others on the call are cutting in and out, or maybe your own signal is being corrupted on their screen. Regardless, many remote workers have found a simple solution—turn down the video quality and focus on audio.

In a very general sense, this is the same technique that researchers

leverage when using quantum squeezing to improve the performance of their sensors. Mark Kasevich, a professor of physics and applied physics at Stanford University and a member of Q-NEXT, uses quantum squeezing in his work developing [quantum sensors](#).

Q-NEXT is a U.S. Department of Energy (DOE) National Quantum Information Science Research Center led by DOE's Argonne National Laboratory. Center researchers use quantum squeezing to make better measurements of quantum systems.

## **Tuning out the noise**

Quantum physics describes the nature of the quantum realm—molecules, atoms and subatomic particles—and it's completely unlike the physics you're used to.

If you drop a bowling ball a hundred times under the same conditions and measure its falling speed, you'll get the same measurement every time. Quantum physics doesn't work this way. In fact, the simple act of making a measurement can change the outcome.

One foundational law of [quantum physics](#) states that when it comes to making measurements, certain pairs of physical properties are in a seesaw relationship with one another: reducing the uncertainty, or noise, of one measurement increases that of the other. It's a principle exploited by physicists who use quantum squeezing.

Two fundamental measurements of quantum systems are the most important when discussing quantum squeezing: amplitude and phase.

Amplitude is the magnitude or strength of a quantum wave or particle. Amplitude describes the size or intensity of a wave. Taller waves have a larger amplitude, while shorter waves have a smaller amplitude.

Phase, on the other hand, is the relative timing or alignment of a quantum wave or particle. The term refers to the point on the wave cycle where the measurement takes place—at the peak, the trough or somewhere in between. Phase affects how separate waves interact and interfere with each other and so affects behaviors in quantum systems.

As is the case with any quantity, measurements of amplitude and phase have a level of uncertainty that must be accounted for. The uncertainty of a quantum wave's amplitude and phase are in that seesaw relationship: when the noise of one goes up, that of the other goes down.

"In quantum squeezing, you basically trade the amount of amplitude noise for phase noise, or vice versa," Kasevich said. "If you're interested in measuring phase, then it's OK to have that noisy amplitude, because phase is what you care about."

Think back to our [video call](#) gone wrong from earlier. You need to be able to hear what your colleagues are saying, so you make a choice to decrease audio uncertainty and increase video uncertainty by lowering the [video quality](#). The faces of the other participants on the call may become too pixelated and distorted to see, but you can hear them clearly now. Conversely, if someone on the call is trying to show you a visual detail, you may want to decrease audio quality in favor of increasing the video's clarity.

Scientists do something like this when employing quantum squeezing. If a researcher needs to know a quantum signal's amplitude, they can use devices called "squeezers" to squeeze a quantum system—such as a [beam of light](#)—and decrease amplitude uncertainty at the cost of increased phase uncertainty. Much like your video call, it's about deciding where measurement precision can be sacrificed.

Quantum squeezing has enormous potential for [future technologies](#),

providing a method to improve the measurement sensitivity of properties at nature's tiniest scales.

## Practical applications

While our video call analogy here is meant to help you understand quantum squeezing using something that exists at the human scale, true quantum squeezing happens at a minuscule scale that is hard for humans to imagine.

High-precision timekeeping is a good example of quantum squeezing's value. The watch on your wrist is accurate enough for many activities, but it's too imprecise to measure ultrashort time lapses. For instance, clocks in space run a tiny bit faster than clocks based on Earth, thanks to variations in gravity. This gravitational time dilation is a part of Einstein's theory of general relativity, where time is experienced slower the closer one is to a massive object like the Earth.

A simple wristwatch can't detect these minuscule alterations of time. But an atomic clock can. The most accurate of these are so precise that if they'd been running since the Big Bang, they wouldn't be off by more than a single second today. This level of precision is why GPS satellites rely on atomic clocks to stay in contact with Earth-bound devices. For instance, a clock on a passenger plane will tick slightly faster in the air than it will on the ground, and an atomic clock on a satellite can help correct these tiny variations.

These useful gadgets work by taking atoms—[cesium atoms](#) are common—and counting their electrons' oscillations under specific conditions. Every cesium atom in the entire universe will oscillate at the exact same rate, which means a cesium atomic clock on Earth will keep the same time as a cesium atom that we've shot out into space.

Within this system, noise can interfere with accurate readings of the clock. Scientists use quantum squeezing to lower that noise. The oscillations of the electron can be seen as similar to the swinging pendulum of a grandfather clock. In this analogy, the phase of the electron refers to the starting point of each swing of the pendulum. By squeezing the phase at the expense of an uncertain amplitude, the scientists are able to ensure that each swing of the pendulum—each oscillation of the electron—is predictably measurable.

The applications for quantum squeezing also reach for the stars. Kasevich describes how the Laser Interferometer Gravitational-wave Observatory (LIGO) squeezes light from distant celestial objects. The technology allowed the LIGO team to be the first in history to physically sense the gravitational waves created by two colliding black holes about 1.3 billion light-years away.

"The LIGO gravitational wave detectors are using squeezing on their beams of light to improve the precision of the interferometers, which measure the phase differences between two beams of light," Kasevich said. "This has fantastic science consequences because you get more precision. The better the precision, the greater the volume of the universe where we can actually detect a gravitational wave source. By just getting a factor of two more precision, when they use squeezing, they improve their ability to make a discovery by nearly a factor of 10."

And that's the beauty of quantum squeezing—we simply don't know what observations we're missing right now. The most beautiful song in the world means nothing if the lawnmower next door is drowning it out. Similarly, we can't know what [gravitational waves](#) we're missing in the quantum realm until we reduce uncertainties.

Provided by Argonne National Laboratory

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