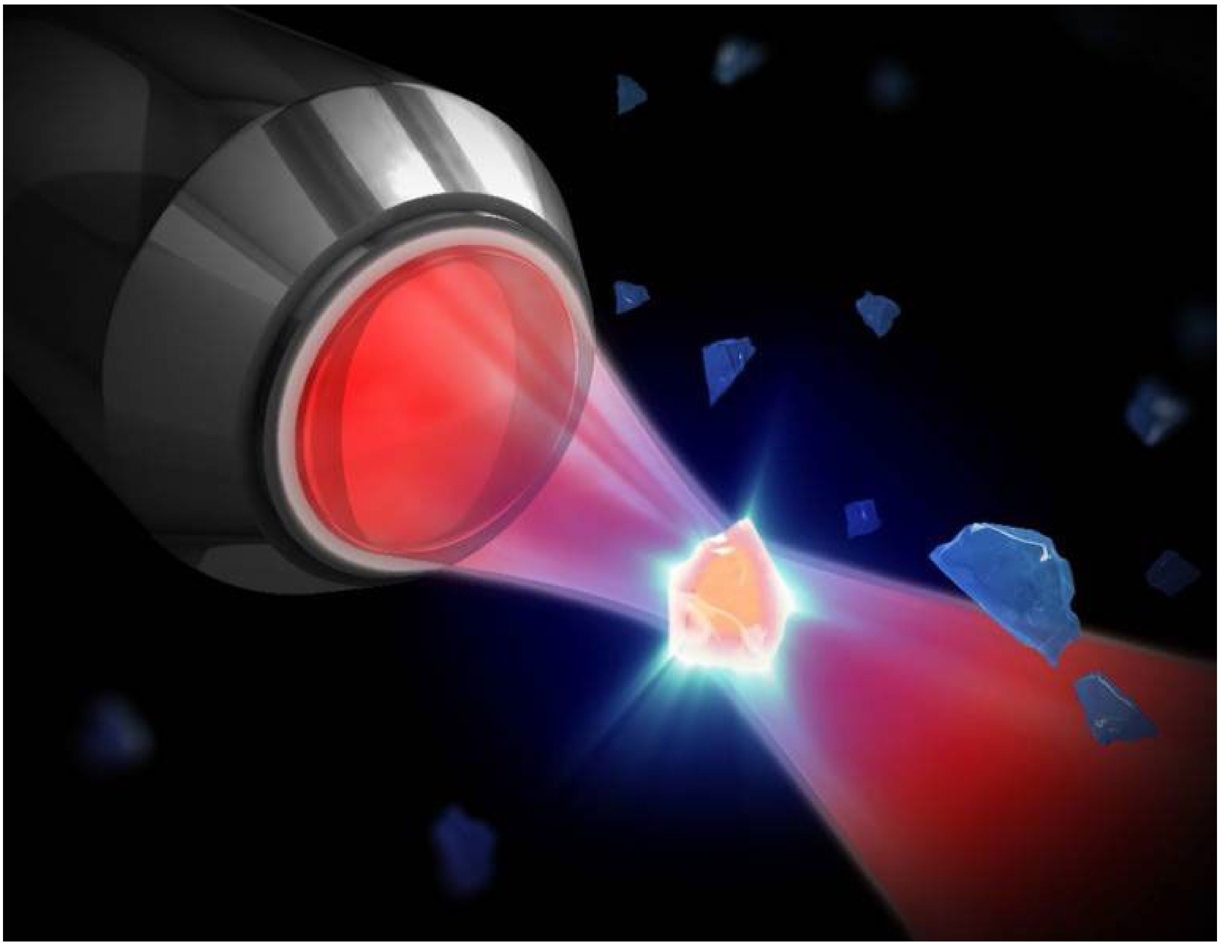
A New Experiment Hopes to Solve Quantum Mechanics' Biggest Mystery

Physicists will try to observe quantum properties of superposition—existing in two states at once—on a larger object than ever before



The TEQ experiments will attempt to induce a quantum collapse with a small piece of silicon dioxide, or quartz, measuring nanometers across—tiny, but much larger than individual particles. (University College London)

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The quantum revolution never truly ended. Beneath the world of classical physics, at the smallest scales, tiny particles don't follow the usual rules. Particles sometimes act like waves, and vice versa. Sometimes they seem to exist in two places at once. And sometimes you can't even know where they are.

For some physicists, like Niels Bohr and his followers, the debates surrounding quantum mechanics were more or less settled by the 1930s. They believed the quantum world could be understood according to probabilities—when you examine a particle, there's a chance it does one thing and a chance it does another. But other factions, led by Albert Einstein, were never fully satisfied by the explanations of the quantum world, and new theories to explain the atomic realm began to crop up.

Now, nearly a century later, a growing number of physicists are no longer content with the textbook version of quantum physics, which originated from Bohr's and others' interpretation of quantum theory, often referred to as the Copenhagen interpretation. The idea is similar to flipping a coin, but before you look at the result, the coin can be thought of as both heads and tails—the act of looking, or measuring, forces the coin to "collapse" into one state or the other. But a new generation of researchers are rethinking why measurements would cause a collapse in the first place.

A new experiment, known as the TEQ collaboration, could help reveal a boundary between the weird quantum world and the normal classical world of billiard balls and projectiles. The TEQ (Testing the large-scale limit of quantum mechanics) researchers are working to construct a device in the next year that would levitate a bit of silicon dioxide, or quartz, measuring nanometers in size—still microscopic, but much larger than the individual particles that scientists have used to demonstrate quantum mechanics previously. How big can an object be and still exhibit quantum behaviors? A baseball won't behave like an electron—we could never see a ball fly into left field and right field at the same time—but what about a nanoscale piece of quartz?

The renewed effort to pin down how matter behaves on an atomic level is partly driven by interest in technological advancements, such as quantum computers, as well as by increasing support for new theoretical physics interpretations. One of those alternatives is known as the Ghirardi-Rimini-Weber theory, or GRW, named after three physicists who fleshed out the theory in the 1980s. In GRW, microscopic particles exist in multiple states at once, known as superposition, but unlike in the Copenhagen interpretation, they can spontaneously collapse into a single quantum state. According to the theory, the larger an object, the less likely it is to exist in superposition, which is why matter on the human scale only exists in one state at any given time and can be described by classical physics.

"In GRW, collapses happen randomly with fixed probability per particle per unit time," says Tim Maudlin, a philosopher of physics at New York University. In the Copenhagen theory, on the other hand, collapses only happen when a measurement is made, so "one would need a clear physical criterion for both when a measurement occurs and what is measured. And that is precisely what the theory never provides." GRW explains this "measurement problem" by suggesting that the collapse isn't unique to the act of measuring itself—rather, a microscopic particle has a given probability to collapse at any time, and that collapse is much more likely to happen (essentially guaranteed) when examined in a macroscopic experimental device.

GRW is one kind of collapse model, and if physicists are able to measure this collapse in action, "then it would suggest that the collapse model is correct," says Peter Barker, a physicist at University College London. "We can say, this is where quantum mechanics ends and classical mechanics begins. It would be amazing."

Barker is a member of a group of the TEQ collaboration, which will put these ideas about GRW and quantum collapse to the test. The small piece of quartz, one-thousandth of the width of a human hair, will be suspended by an electric field and trapped in a cold, confined space, where its atomic vibrations will slow to near absolute zero.

The scientists will then fire a laser at the quartz and see whether the scattering of the light shows signs of the object moving. The motion of the silicon dioxide could indicate a collapse, which would make the experiment a compelling confirmation of GRW predictions. (The theory predicts that objects of different masses have different amounts of motion related to a collapse.) If the scientists do not see the signals predicted from a collapse, the experiment would still provide valuable information about the quantum world of particles as it blurs with the classical world of everyday objects. Either way, the findings could be a quantum leap for quantum physics.

The idea that particles could exist in multiple states as once unsettled Einstein and a few others. But many physicists ignore these fundamental questions of what actually happens and characterize their own attitude as a "shut-up-and-calculate" one, Maudlin says. "Very few physicists want to understand foundational issues in quantum mechanics. And they don't want to admit that it's a pretty scandalous situation."

Those who do investigate the foundational realities of atomic matter, however, seem to agree there's likely more going on than existing theories cover, even if it's not clear yet exactly what happens on such miniscule scales. In addition to GRW, rival theories include the speculative "many-worlds interpretation," an idea that every experimental outcome can and does happen as particles endlessly collapse into all possible states, spawning an infinite number of parallel universes. Another alternative known as Bohmian mechanics, named after its originator David Bohm in the 1950s, argues that the probabilities involved in quantum experiments merely describe our limited knowledge of a system—in reality, an equation with variables currently hidden to physicists guides the system regardless of whether someone makes a measurement.

But the data from previous quantum experiments still don't point toward a single interpretation, making it hard to pick one as a more accurate picture of reality. Thanks to TEQ though, physicists could finally provide evidence for or against collapse theories like GRW, breaking the impasse with the measurement problem. "Collapse models are actually experimentally falsifiable," says Matteo Carlesso, a physicist at University of Trieste, who studies quantum theories. Even though no experiment has been sensitive enough to successfully verify or falsify a collapse model, such an experiment should be possible with the sensitivity of something like TEQ.

The experiment won't be easy. The precise apparatus, frozen to near absolute zero, can't eliminate all uncertainty, and the scientists involved have to rule out other, mundane physics explanations of the levitated particle's motion before they can presume to attribute what they see to quantum motions. Physicists refer to the kind of energy signals they measure as "noise," and it will be incredibly difficult to isolate "collapse noise" from sources of background noise that might work their way into the sensitive experiment. And it doesn't help that the measurement itself heats the particle, making it harder to distinguish the very quantum motions the researchers are looking for.

Despite these uncertainties, TEQ physicists are now building and testing the device, and it will all come together at the University of Southampton in the U.K. where they'll run the most sensitive versions of the experiment within a year. They have the chance to finally see quantum behavior firsthand, and if not, perhaps push the limits of quantum mechanics and shed light on what kinds of quantum behavior *don't* happen.

The experiment is similar to the decades-old search for dark matter particles: physicists haven't detected them directly yet, but they now know more than before about how massive the particles can't be. One difference, though, is that physicists know dark matter's out there, even if they don't know exactly what it is, says Andrew Geraci, a physicist at Northwestern University. The quantum collapse models that Carlesso and others study aren't guaranteed to be an accurate representation of what happens to matter on the atomic scale.

"I think testing these collapse models and seeing if we can figure something out about how the measurement problem works is certainly a tantalizing possibility that this type of technology opens up," Geraci says. "Regardless of whether we see something, it's worth checking."