Quantum Upsizing

Mirror, mirror on the wall, what is the largest quantum object of them all? Aspelmeyer, Schwab, and Zeilinger have teamed up to find out.

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by GRAEME STEMP-MORLOCK

FQXi Collaboration: Markus Aspelmeyer, Keith Schwab & Anton Zeilinger August 15, 2008

They say that bigger is better. Keith Schwab, Anton Zeilinger, and Markus Aspelmeyer certainly agree. They are applying the adage to both quantum devices and scientific collaborations.

Defying the standard wisdom of the nanotechnology crowd, the team wants to scale their nanotools up. They hope to create quantum effects in ever larger objects, to test how far they can push the boundary between the quantum and classical realms.

But that's only part of it. Stretching across continents, the collaboration itself is an exercise in bigger and better. Schwab and a small army of grad students operate out of his lab at Cornell University in Ithaca, New York, while Aspelmeyer, Zeilinger, and another crew of grad students work in Austria, at the University of Vienna. The group leaders rarely see each other face-to-face, yet they regularly share ideas, students, and even lab equipment.

Quantum Breakdown

Quantum effects are mysterious, says Schwab. "Why do they work on a small scale but not at a big scale?" This, he says, is the major question that the group plans to answer: "Can we start to observe quantum behavior in bigger and bigger objects?"

To investigate where quantum mechanics breaks down and classical mechanics begins, the team is investigating two weird quantum properties: *entanglement* and *superposition*. When two particles become entangled, they become inextricably intertwined, so that changing the properties of one has an immediate effect on the properties of its partner. Superposition is another feature that is peculiar to quantum systems. Before a quantum object is measured, it does not have definite characteristics. Instead, it exists in a superposition of multiple mutually contradictory states—allowing it to be in two places at once, for example.

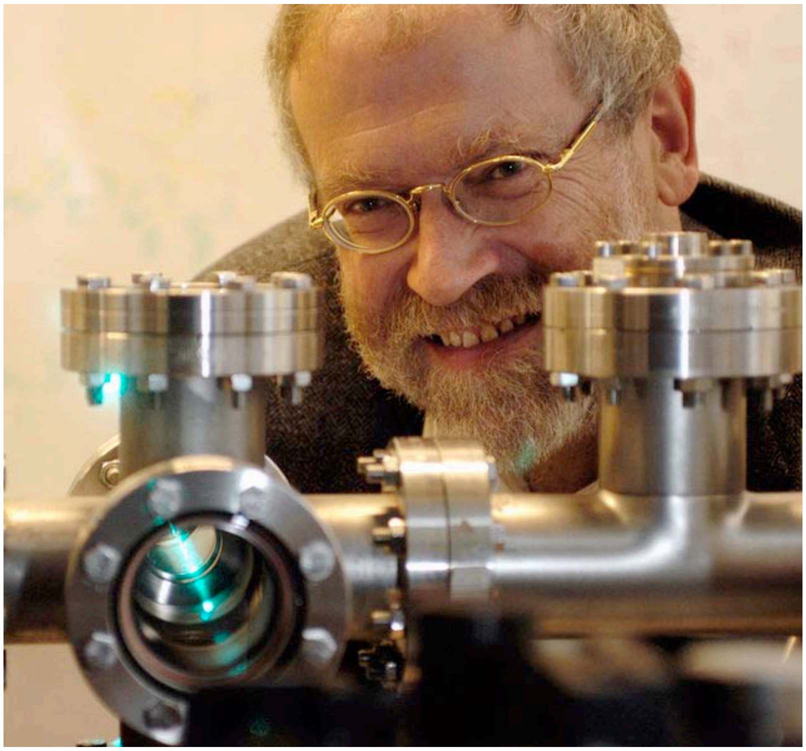
If the team can create a quantum effect in an object that is big enough to see with our eyes, it would have major implications for our understanding of how the laws of physics work.

In the quest to do this, Aspelmeyer is using micro-mirrors, just half a millimeter across and a hundredth of a millimeter wide, to pick up quantum effects. That may sound small, but one micro-mirror contains billions of atoms, making the system several orders of magnitude larger and more complex than anything that has been used to test quantum mechanics before. The team will bounce entangled photons off the mirrors. The trick is to see if the photons transfer their quantum nature to the mirror.

Micro Diving Boards

"If one photon hits the mirror, it kicks the mirror, which then oscillates with a certain amplitude," says Aspelmeyer. He likens the situation to the motion of a diving board. "If there were two people on the diving board it goes up and down more strongly," he says. Similarly, you can work out how many photons have hit the mirror, by how much it vibrates.

Sounds straightforward. But what happens if the number of photons that hit the mirror is not an exact number?



ANTON ZEILINGER
University of Vienna
(© *Jaqueline Godany*)

KEITH SCHWAB
Cornell University

That would be the case if a superposition of an indefinite number of photons hits the mirror. Now the diving board doesn't know exactly how many people are standing on it. "The mirror can't decide how far it will move, and you've created an entangled state," says Aspelmeyer. And a quantum effect would have been demonstrated on a larger scale than ever before.

Quantum Milestone

For the experiment to work, the researchers need to keep their cool—or at least, keep their apparatus at a low temperature because heat causes the mirror to shake on its own.

This is where Schwab comes in. Not only will Schwab build the micro-mirror at his lab, he has also spent years using cryogenics and laser cooling trying to get tiny mechanical systems as cold as possible.

One of the techniques used to cool particles (and small mechanical devices) is to hit them with laser light. When hit with just the right frequency of laser light, the particles temporarily absorb the light, gaining energy. However, they quickly lose this again, releasing more energy than they absorbed in the process, and cooling down to a temperature that is lower than where they started.

Using this technique and others, Schwab has cooled mechanical devices to just above their lowest possible energy level, known as the *ground state*. "We want to hit some basic quantum mechanical milestones like cooling mechanical devices with light down to ground state," said Schwab.

Zeilinger was the matchmaker who brought Schwab and Aspelmeyer together. He believes they work so well together not only because they share the same interest but also because "their personalities get along well together."

"Coming from different backgrounds there are so many different things to share and exchange," says Aspelmeyer. "We have learned a great deal from Keith already concerning mechanical systems and low temperature physics, and there were many good discussions where the quantum optics from our side brought new perspective to the experiments."

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>
> *- Markus Aspelmeyer*

Schwab also agrees that collaboration is the key to success. "The techniques we use are pretty deep in the amount of years it takes to master each," he says. "Combining forces is the only way to do this."

Aashish Clerk, of McGill University in Montreal, Canada thinks the work will have far-reaching applications. The fragility of quantum states has been a big obstacle for building quantum computers. Understanding the quantum-classical crossover could help us learn how to prevent quantum effects from breaking down, says Clerk.

Nobel Laureate Tony Leggett, of the University of Illinois at Urbana-Champaign, is keenly watching the team's work. "It's important to probe quantum mechanics on various frontiers, and one frontier not probed enough is in the direction towards the real world," he says.

Crossing Continents

It's one thing to share theories and ideas with researchers overseas, but how tough is it to carry out cross-continental experiments? No stranger to international scientific collaboration, Zeilinger has worked with scientists in New York and Boston, while being based in Vienna. He believes the ability to work for the common good, rather than competing, is a simple but essential element.

"International collaborations work well as long as both sides appreciate the importance of the other and that working together is more important than whether the other side is slightly ahead," he says.

Currently, students from Vienna regularly travel to New York to fabricate the nanotools and learn some cooling techniques, while some Cornell students will also begin to travel to Vienna soon to do some measurements. Technologies such as Skype and email also allow the group to stay connected despite being spread across a big area geographically.

MARKUS ASPELMEYER
University of Vienna

"I really think this is the best that could happen when people with very different backgrounds meet and collaborate," said Aspelmeyer. "It's been great discussing ideas with Keith. Huge fun."

And the fruits of their collaboration will begin to ripen as temperatures continue to drop.