Through the Looking Glass

Markus Aspelmeyer hopes his microscopic mirrors and entangled photons will reveal secrets at the interface of classical and quantum mechanics.

Editor's Choice

by KATE BECKER

FQXi Awardee: Markus Aspelmeyer, IQOQI May 11, 2007

Ask any student of Physics 101: The laws of classical physics may seem complicated, but they make sense. Objects at rest tend to stay at rest, objects in motion tend to stay in motion—you can intuit most of this without ever cracking a textbook.

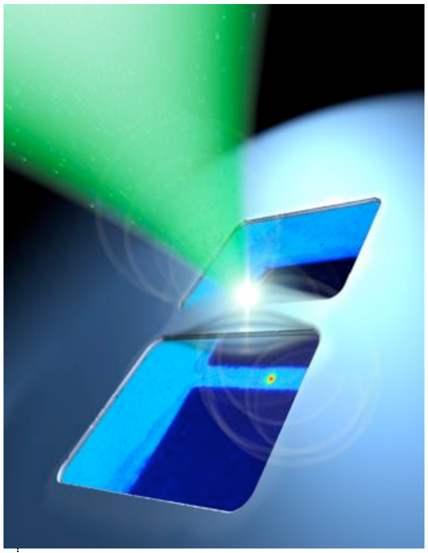
But deep in the tiniest structures of our physical world, a different set of laws takes over. In this regime, fundamental particles that make up the universe routinely cheat the rules of classical physics, tunneling through seemingly impenetrable walls and apparently refusing to truly *be* anywhere, or anything, unless a scientist measures them.

This is the world of quantum mechanics, where questions like, ‘Where is the particle located?’ can only be answered with probabilities: ‘The particle is most likely found in a particular range of locations, but it could be anywhere in the universe, and the only way to know for sure is to measure it.’

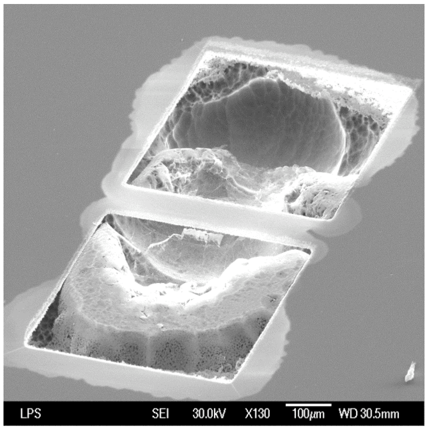
For decades, physicists have wondered why quantum mechanics fails to provide straight answers to questions like these. Is it because a particle, strictly speaking, is not anywhere until someone pins it down by observing it? Or is it that quantum physics itself is incomplete—that there exist some undiscovered variables that could answer these questions, if only one knew what the variables were?

Hidden Bell?

In 1964, the physicist John Bell showed that if hidden variables do exist, they must defy the logic of everyday experience. Why? Imagine this: A particle decays, spitting out two photons (light particles) in opposite directions. To satisfy the conservation of angular momentum—one rule that even quantum physics may not break—the photons must have opposite values of a property called spin. In the terminology of quantum mechanics, the photons are said to be "entangled:" that is, the measured properties of one depend on the measured properties of the other.



MICROMIRROR The “bridge” in the middle is the mirror. The structure was fabricated using laser ablation techniques and standard microfabrication tools. Image Credit (above): ARKITEK; Electron Microscope Credit (below): IQOQI



For example, if a scientist in Vienna intercepts one particle and checks its spin, the measurement of the other particle, which has now made it to, say, New York, instantaneously yields the opposite spin.

But how can a photon suddenly "know" what is happening to its entangled partner? Einstein and other “realist” colleagues called the whole thing "spooky" and dismissed it as too weird to be true, believing that particle properties should be determined upon their creation, and should only be influenced by their ‘local’ surroundings.

Yet Bell showed that any hidden variables that abide by the rules of locality and realism are fundamentally inconsistent with the principles of quantum mechanics. So what about hidden variables that don’t respect these rules?

With a team of scientists worldwide, FQXi Awardee Markus Aspelmeyer will take that question to the laboratory, with the help of a grant worth $48,819. Using entangled photons, his team will test for the first time whether hidden variables that work across great distances are compatible with quantum physics.

Still Hidden?

To create a pair of entangled photons, the researchers will pass a single parent photon through a crystal, where a decay process splits the photon in a pair of photons of lower energy. The properties of the twin photons will then be recorded by a detector configuration that, Aspelmeyer says, “belongs to a new class of experiments” that go beyond older tests.

“It is the first experiment to test whether a certain plausible class of nonlocal realistic theories could provide a basis for a possible extension of quantum theory,” says Aspelmeyer.

“The question of the completeness of quantum theory is essentially as old as quantum theory itself,” says Jens Eisert, a lecturer with Imperial College London’s Department of Physics. The puzzle, he says, is figuring out whether “there is a hidden reality that rules the outcomes of measurements in quantum mechanics."

If Aspelmeyer is successful, comments Eisert, "spectacular results should be expected." And so they were: recently, Aspelmeyer's team successfully completed the first set of experiments, with results published in the April 19 edition of the scientific journal *Nature*.

Mirror, Mirror

Aspelmeyer and his team are also exploring the boundary between classical and quantum regimes. Is it possible to reconcile the rules of classical physics, so firmly established in every day experience, with quantum mechanics? Could classical physics be just a wide-angle approximation of quantum mechanics — or is it that once enough particles get together to form an object, nature flips a switch that turns classical mechanics "on" and quantum mechanics "off," exempting that new system from the counterintuitive codes of quantum physics?

> Progress in science often comes in surprises. I am already looking forward to being surprised by nature and by our experiments.
>
> - *Markus Aspelmeyer*

Aspelmeyer hopes to answer these questions by looking in a very small mirror: that is, a "micro mirror" just half a millimeter across and a hundredth of a millimeter thick. Although tiny by most standards, Aspelmeyer says that the mirror is "more than a billion times more atoms than the largest objects on which quantum experiments have been performed." If the experiment succeeds, it will be one of the first ever to demonstrate quantum behavior on such a large object.

The mirror will be set to vibrate by the feeble pressure of laser light, with each photon that hits the mirror giving it another nudge. "When a photon hits the (suspended) mirror and is reflected," Aspelmeyer explains, "it gives a momentum kick to the mirror. This means that the mirror is displaced by a certain amount. The more photons hit the mirror, the more strongly the mirror will be displaced. If the number of photons that hit the mirror is not an exact number state but is a superposition state of numbers of photons, the mirror position ends up to be entangled with the photon number."

At room temperature, though, the mirror is already buzzing with thermal motion. To get the mirror to stand still enough for the tiny photon-driven vibrations to register, Aspelmeyer's team first devised a new way to cool the mirror using radiation pressure. They published the details of their technique in the November 2 edition of *Nature*; the paper was later honored by editors of the rival journal *Science* as a "highlight of the recent literature."

"This promises to probe quantum effects in systems that one might think to be describable in terms of classical physics" says Eisert, "opening up a new arena for studying the diffuse 'border' of the classical to the quantum world."

"Whatever the answer will be," says Aspelmeyer, "we can expect that our understanding of quantum theory *will* change in the light of macroscopic quantum experiments. Progress in science often comes in surprises. I am already looking forward to being surprised by nature and by our experiments."

Schrödinger's Cat & Aspelmeyer's Micro-Mirror

Erwin Schrödinger, author of the most fundamental equation of quantum mechanics, recognized that quantum physics and classical physics meet in a paradox. He posed a morbid thought experiment to illustrate the problem.

Imagine a tiny amount of a radioactive substance, which, within an hour, has a fifty-fifty chance that one atom will decay. Now imagine a device rigged such that, should decay occur, a cylinder of cyanide will be broken, releasing poison which – now for the morbid part – will kill a cat unfortunate enough to have been conscripted into this bizarre experiment.

According to the principles of quantum mechanics, until an observer steps in at the end of the hour to check how the cat fared, not only does the cat have equally good chances of being alive or dead, it is both alive *and* dead, simultaneously.

Schrödinger's cat paradox is, of course, just a physicist's daydream. Testing the real-world manifestations of quantum entanglement can be done more humanely; in this case, using a micro-mirror.

EXPERIMENTAL SETUP Photo Credit: IQOQI