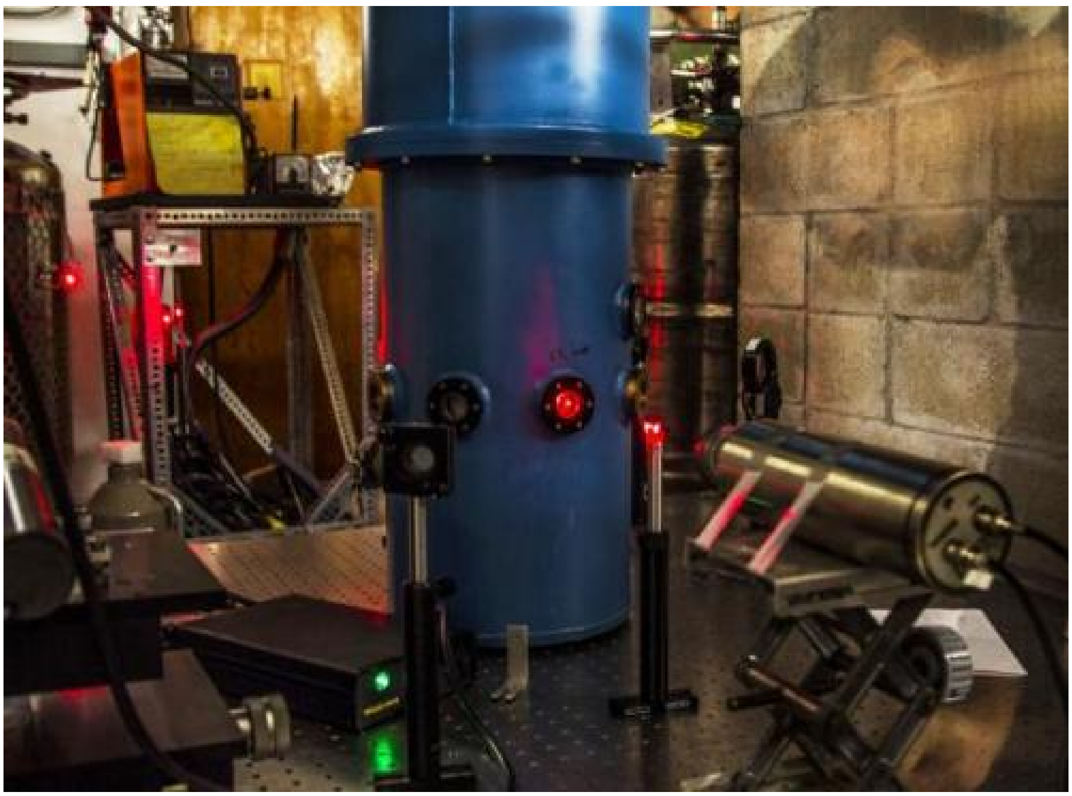
Can the wave function of an electron be divided and trapped?

October 28 2014, by Kevin Stacey



A canister of liquid helium inside the blue cylinder allowed researchers to experiment with tiny electron bubbles only 3.6 nanometers in diameter. The work suggests that the wave function of an electron can be split and parts of it trapped in smaller bubbles. Credit: Mike Cohea/Brown University

New research by physicists from Brown University puts the profound strangeness of quantum mechanics in a nutshell—or, more accurately, in a helium bubble.

Experiments led by Humphrey Maris, professor of physics at Brown, suggest that the quantum state of an electron—the electron's wave function—can be shattered into pieces and those pieces can be trapped in tiny bubbles of liquid helium. To be clear, the researchers are not saying that the electron can be broken apart. Electrons are elementary particles, indivisible and unbreakable. But what the researchers are saying is in some ways more bizarre.

In quantum mechanics, particles do not have a distinct position in space. Instead, they exist as a wave function, a probability distribution that includes all the possible locations where a particle might be found. Maris and his colleagues are suggesting that parts of that distribution can be separated and cordoned off from each other.

"We are trapping the chance of finding the electron, not pieces of the electron," Maris said. "It's a little like a lottery. When lottery tickets are sold, everyone who buys a ticket gets a piece of paper. So all these people are holding a chance and you can consider that the chances are spread all over the place. But there is only one prize—one electron—and where that prize will go is determined later."

If Maris's interpretation of his experimental findings is correct, it raises profound questions about the measurement process in quantum mechanics. In the traditional formulation of quantum mechanics, when a particle is measured—meaning it is found to be in one particular location—the wave function is said to collapse.

"The experiments we have performed indicate that the mere interaction of an electron with some larger physical system, such as a bath of liquid helium, does not constitute a measurement," Maris said. "The question then is: What does?"

And the fact that the wave function can be split into two or more bubbles is strange as well. If a detector finds the electron in one bubble, what happens to the other bubble?

"It really raises all kinds of interesting questions," Maris said.

The new research is published in the *Journal of Low Temperature Physics*.

Electron bubbles

Scientists have wondered for years about the strange behavior of electrons in liquid helium cooled to near absolute zero. When an electron enters the liquid, it repels surrounding helium atoms, forming a bubble in the liquid about 3.6 nanometers across. The size of the bubble is determined by the pressure of the electron pushing against the surface tension of the helium. The strangeness, however, arises in experiments dating back to the 1960s looking at how the bubbles move.

In the experiments, a pulse of electrons enters the top of a helium-filled tube, and a detector registers the electric charge delivered when electron bubbles reach the bottom of the tube. Because the bubbles have a well-defined size, they should all experience the same amount of drag as they move, and should therefore arrive at the detector at the same time. But that's not what happens. Experiments have detected unidentified objects that reach the detector before the normal electron bubbles. Over the years, scientists have cataloged 14 distinct objects of different sizes, all of which seem to move faster than an electron bubble would be expected to move.

"They've been a mystery ever since they were first detected," Maris said. "Nobody has a good explanation."

Several possibilities have been proposed. The unknown objects could be impurities in the helium—charged particles knocked free from the walls of the container. Another possibility is that the objects could be helium ions—helium atoms that have picked up one or more extra electrons, which produce a negative charge at the detector.

But Maris and his colleagues, including Nobel laureate and Brown physicist Leon Cooper, believe a new set of experiments puts those explanations to rest.

New experiments

The researchers performed a series of electron bubble mobility experiments with much greater sensitivity than previous efforts. They were able to detect all 14 of the objects from previous work, plus four additional objects that appeared frequently over the course of the experiments. But in addition to those 18 objects that showed up frequently, the study revealed countless additional objects that appeared more rarely.

In effect, Maris says, it appears there aren't just 18 objects, but an effectively infinite number of them, with a "continuous distribution of sizes" up to the size of the normal electron bubble.

"That puts a dagger in the idea that these are impurities or helium ions," Maris said. "It would be hard to imagine that there would be that many impurities, or that many previously unknown helium ions."

The only way the researchers can think of to explain the results is through "fission" of the wave function. In certain situations, the researchers surmise, electron wave functions break apart upon entering the liquid, and pieces of the wave function are caught in separate bubbles. Because the bubbles contain less than the full wave function, they're smaller than normal electron bubbles and therefore move faster.

In their new paper, Maris and his team lay out a mechanism by which fission could happen that is supported by quantum theory and is in good agreement with the experimental results. The mechanism involves a concept in quantum mechanics known as reflection above the barrier.

In the case of electrons and helium, it works like this: When an electron hits the surface of the liquid helium, there's some chance that it will cross into the liquid, and some chance that it will bounce off and carom away. In quantum mechanics, those possibilities are expressed as part of the wave function crossing the barrier, and part of it being reflected. Perhaps the small electron bubbles are formed by the portion of the wave function that goes through the surface. The size of the bubble depends on how much wave function goes through, which would explain the continuous distribution of small electron bubble sizes detected in the experiments.

The idea that part of the wave function is reflected at a barrier is standard quantum mechanics, Cooper said. "I don't think anyone would argue with that," he said. "The non-standard part is that the piece of the wave function that goes through can have a physical effect by influencing the size of the bubble. That is what is radically new here."

Further, the researchers propose what happens after the wave function enters the liquid. It's a bit like putting a droplet of oil in a puddle of water. "Sometime your drop of oil forms one bubble," Maris said, "Sometimes it forms two, sometimes 100."

There are elements within quantum theory that suggest a tendency for the wave function to break up into specific sizes. By Maris's calculations, the specific sizes one might expect to see correspond roughly to the 18 frequently occurring electron bubble sizes.

"We think this offers the best explanation for what we see in the experiments," Maris said. We've got this body of data that goes back 40 years. The experiments are not wrong; they've been done by multiple people. We have a tradition called Occam's razor, where we try to come up with the simplest explanation. This, so far as we can tell, is it."

But it does raise some interesting questions that sit on the border of science and philosophy. For example, it's necessary to assume that the helium does not make a measurement of the actual position of the electron. If it did, any bubble found not to contain the electron would, in theory, simply disappear. And that, Maris says, points to one of the deepest mysteries of quantum theory.

"No one is sure what actually constitutes a measurement. Perhaps physicists can agree that someone with a Ph.D. wearing a white coat sitting in the lab of a famous university can make measurements. But what about somebody who really isn't sure what they are doing? Is consciousness required? We don't really know."

Provided by Brown University

Citation: Can the wave function of an electron be divided and trapped? (2014, October 28) retrieved 27 April 2024 from https://phys.org/news/2014-10-function-electron.html