Smart atomic cloud solves Heisenberg's observation problem

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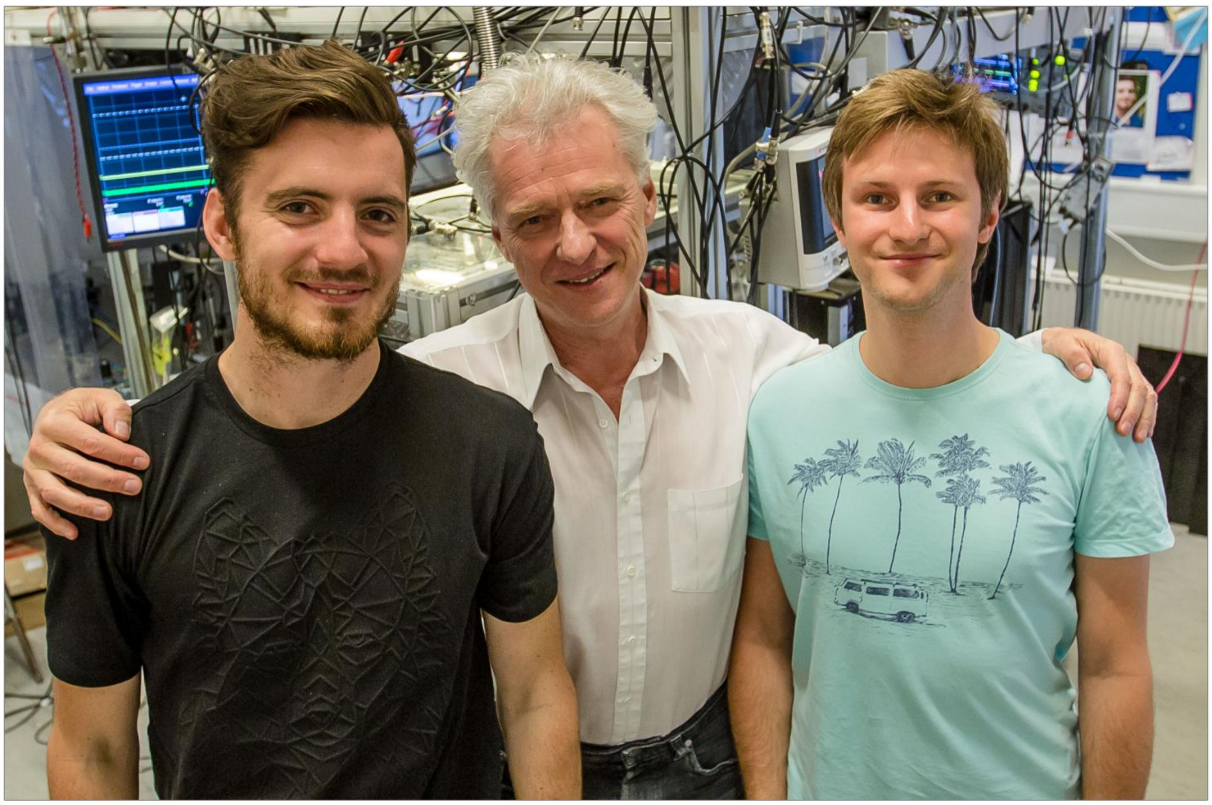

The atomic part of the hybrid experiment is shown. The atoms are contained in a micro-cell inside the magnetic shield seen in the middle. Credit: Ola J. Joensen

Scientists at the University of Copenhagen have developed a hands-on answer to a challenge linked to Heisenberg's Uncertainty Principle. The researchers used laser light to link caesium atoms and a vibrating membrane. The research, the first of its kind, points to sensors capable of measuring movement with unseen precision.

When measuring atom structures or light emissions at the quantum level by means of advanced microscopes or other forms of special equipment, things are complicated due to a problem which, during the 1920s, had the full attention of Niels Bohr and Werner Heisenberg. And this problem, dealing with inaccuracies that taint certain measurements conducted at quantum level, is described in Heisenberg's Uncertainty Principle, which states that complementary variables of a particle, such as velocity and position, can never be simultaneously known.

In a scientific report published in this week's issue of *Nature*, NBI researchers demonstrate that Heisenberg's Uncertainty Principle can be neutralized to some degree. This has never been shown before, and the results may spark development of new measuring equipment, and new and better sensors.

Professor Eugene Polzik, head of the Quantum Optics (QUANTOP) at the Niels Bohr Institute, led the research, which involved the construction of a vibrating membrane and an advanced atomic cloud locked up in a minute glass cage.

Light 'kicks' object

The Uncertainty Principle emerges in observations conducted via a microscope operating with laser light, which inevitably will lead to the object being kicked by photons. As a result of those kicks, the object begins to move in a random way. This phenomenon is known as quantum back action (QBA), and these random movements put a limit to the accuracy with which measurements can be carried out at quantum level. To conduct the experiments at NBI, professor Polzik and his collaborators used a tailor-made membrane as the object observed at quantum level.

In recent decades, scientists have tried to find ways of 'fooling' Heisenberg's Uncertainty Principle. Eugene Polzik and his colleagues came up with the idea of implementing the advanced atomic cloud a few years ago. It consists of 100 million caesium atoms locked in a hermetically closed glass cell, explains the professor:

"The cell is just one centimeter long, 1/3 of a millimeter high and 1/3 of a millimeter wide, and in order to make the atoms work as intended, the inner cell walls have been coated with paraffin. The membrane, whose movements we observed at quantum level, measures 0.5 millimeters, which actually is a considerable size from a quantum perspective."

The idea behind the glass cell is to deliberately send the laser light used to study the membrane movements through the encapsulated atomic cloud before the light reaches the membrane, explains Eugene Polzik: "This results in the laser light-photons 'kicking' the object—i.e. the membrane—as well as the atomic cloud, and these 'kicks,' so to speak, cancel out. This means that there is no longer any quantum back action—and therefore no limitations as to how accurately measurements can be carried out at quantum level."

How can this be utilized?

"For instance, when developing new and much more advanced types of sensors for analyses of movements,", says professor Eugene Polzik. "Generally speaking, sensors operating at quantum level are receiving a lot of attention these days. One example is the Quantum Technologies Flagship, an extensive EU program which also supports this type of research."

The fact that it is, indeed, possible to 'fool' Heisenberg's Uncertainty Principle may also prove significant in relation to better understanding gravitational waves—waves in space moving at the speed of light. In September of 2015, the American LIGO experiment published the first direct registrations and measurements of gravitational waves stemming from a collision between two very large black holes. However, the equipment used by LIGO is influenced by quantum back action, and the new research from NBI may prove capable of eliminating that problem, says Polzik.

More information: Quantum back-action-evading measurement of motion in a negative mass reference frame, *Nature* (2017). nature.com/articles/doi:10.1038/nature22980

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