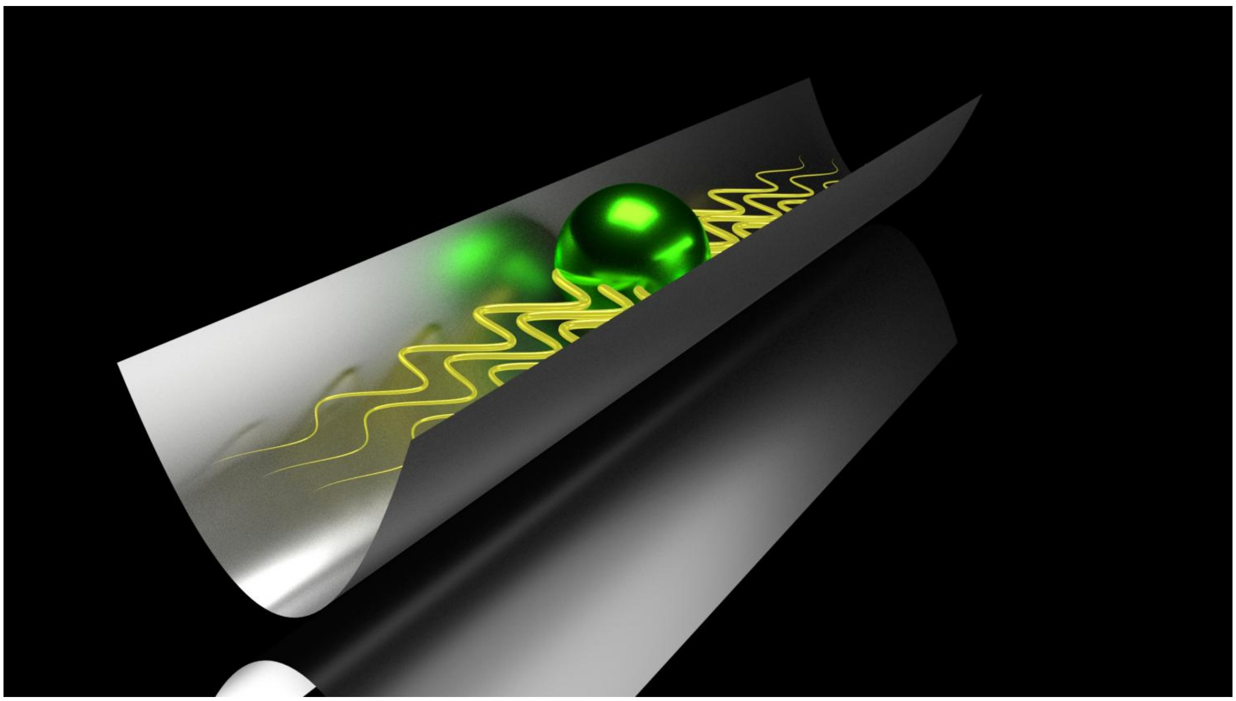
Breaking Newton's Law: Intriguing oscillatory back-and-forth motion of a quantum particle

June 1 2017



Innsbruck physicists have observed an intriguing oscillatory back-and-forth motion of a quantum particle in a one-dimensional atomic gas. Credit: Florian Meinert

A ripe apple falling from a tree has inspired Sir Isaac Newton to formulate a theory that describes the motion of objects subject to a force. Newton's equations of motion tell us that a moving body keeps on moving on a straight line unless any disturbing force may change its path. The impact of Newton's laws is ubiquitous in our everyday experience, ranging from a skydiver falling in the earth's gravitational field, over the inertia one feels in an accelerating airplane, to the earth orbiting around the sun.

In the quantum world, however, our intuition for the motion of objects is strongly challenged and may sometimes even completely fail. What about imagining a marble falling through water oscillating up and down rather than just moving straight downwards? Sounds strange. Yet, that's what experimental physicist from Innsbruck in collaboration with theorists from Munich, Paris and Cambridge have discovered for a quantum particle. At the heart of this surprising behavior is what physicists call 'quantum interference', the fact that quantum mechanics allows particles to behave like waves, which can add up or cancel each other.

Approaching absolute zero temperature

To observe the quantum particle oscillating back and forth the team had to cool a gas of Cesium atoms just above absolute zero temperature and to confine it to an arrangement of very thin tubes realized by high-power laser beams. By means of a special trick, the atoms were made to interact strongly with each other. At such extreme conditions the atoms form a quantum fluid whose motion is restricted to the direction of the tubes. The physicists then accelerated an impurity atom, which is an atom in a different spin state, through the gas. As this quantum particle moved, it was observed to scatter off the gas particles and to reflect backwards. This led to an oscillatory motion, in contrast to what a marble would do when falling in water. The experiment demonstrates that Newton's laws cannot be used in the quantum realm.

Quantum fluids sometimes act like crystals

The fact that a quantum-wave may get reflected into certain directions has been known since the early days of the development of the theory of quantum mechanics. For example, electrons reflect at the regular pattern of solid crystals, such as a piece of metal. This effect is termed 'Bragg-scattering'. However, the surprise in the experiment performed in Innsbruck was that no such crystal was present for the impurity to reflect off. Instead, it was the gas of atoms itself that provided a type of hidden order in its arrangement, a property that physicist dub 'correlations'. The Innsbruck work has demonstrated how these correlations in combination with the wave-nature of matter determine the motion of particles in the quantum world and lead to novel and exciting phenomena that counteract the experiences from our daily life.

Understanding the oddity of quantum mechanics may also be relevant in a broader scope, and help to understand and optimize fundamental processes in electronics components, or even transport processes in complex biological systems.

The study is published in the journal *Science*.

More information: "Bloch oscillations in the absence of a lattice" *Science* (2017). science.sciencemag.org/cgi/doi … 1126/science.aah6616

Provided by University of Innsbruck