Researchers guide a single ion through a Bose-Einstein condensate

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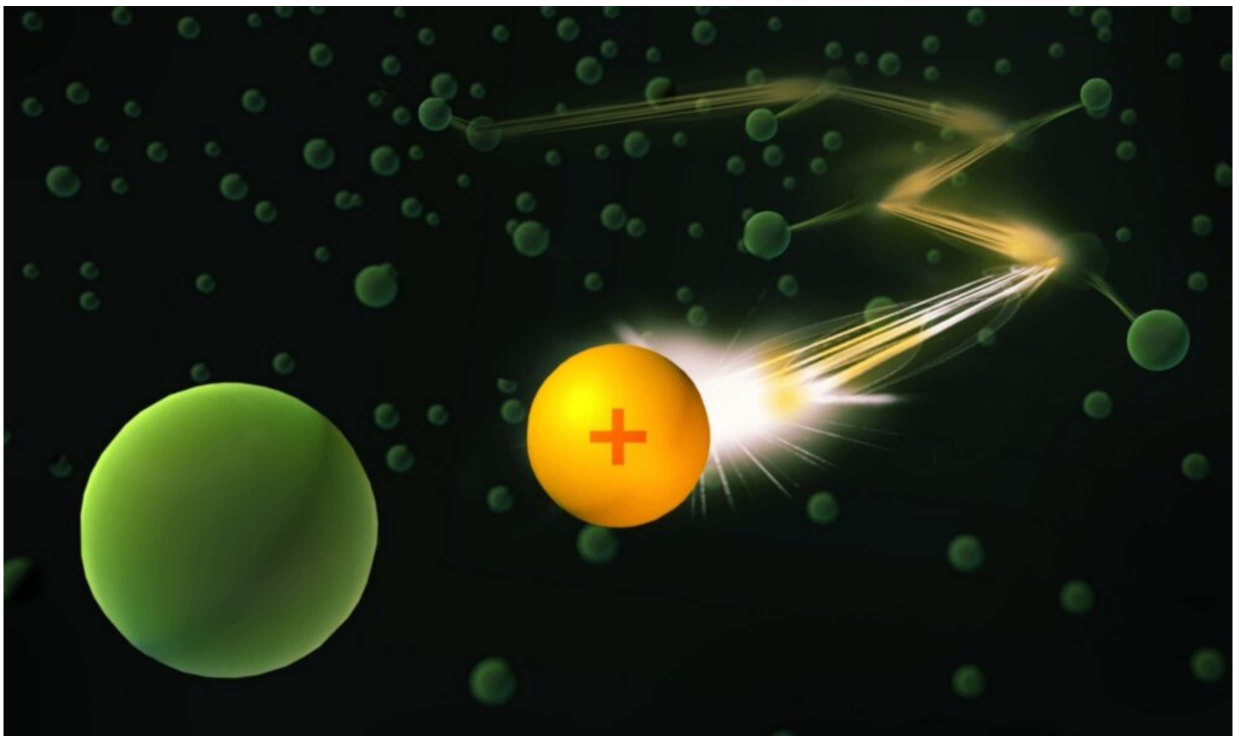

The path of the positively charged ion (yellow) through the BEC (green) can still only be depicted artistically. An ion microscope currently being developed at the Fifth Institute of Physics at the University of Stuttgart will make this path directly visible with a resolution of less than 200 nanometers. Credit: University of Stuttgart/PI5, Celina Brandes

Transport processes are ubiquitous in nature, but still raise many questions. The research team around Florian Meinert from the Fifth Institute of Physics at the University of Stuttgart has now developed a new method to observe a single charged particle on its path through a dense cloud of ultracold atoms. The results were published in *Physical Review Letters* and are further reported in a Viewpoint column in the journal *Physics*.

Meinert's team used a Bose-Einstein condensate (BEC) for their experiments. This exotic state of matter consists of a dense cloud of ultracold atoms. By means of sophisticated laser excitation, the researchers created a single Rydberg atom within the gas. In this giant atom, the electron is a thousand times further away from the nucleus than in the ground state and thus only very weakly bound to the core. With a specially designed sequence of electric field pulses, the researchers snatched the electron away from the atom. The formerly neutral atom turned into a positively charged ion that remained nearly at rest despite the process of detaching the electron.

In the next step, the researchers used precise electric fields to pull the ion in a controlled way through the dense cloud of atoms in the BEC. The ion picked up speed in the electric field, collided on its way with other atoms, slowed down and was accelerated again by the electric field. The interplay between acceleration and deceleration by collisions led to a constant motion of the ion through the BEC.

"This new approach allows us to measure the mobility of a single ion in a Bose-Einstein condensate for the very first time," says Thomas Dieterle, a Ph.D. student who participated in the experiment. The researchers' next goal is to observe collisions between a single ion and atoms at even lower temperatures, where quantum mechanics instead of classical mechanics dictates the processes. "In the future, our newly created model system—the transport of a single ion—will allow for a better understanding of more complex transport processes that are relevant in many-body systems, e.g., in certain solids or in superconductors," Meinert says. These measurements are also an important step on the way to investigate exotic quasi-particles, so-called polarons, which can arise through interaction between atoms and ions.

The neighboring lab at the institute is already working on an ion microscope that will allow researchers to observe collisions between atoms and ions directly. While an electron microscope uses negatively charged particles to create an image, this is what happens in an ion microscope with positively charged ions. Electrostatic lenses deflect ions similar to light rays in a classical optical microscope.

More information: T. Dieterle et al. Transport of a Single Cold Ion Immersed in a Bose-Einstein Condensate, *Physical Review Letters* (2021). DOI: 10.1103/PhysRevLett.126.033401

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