A new technique to detect collisions between single atom-ion pairs

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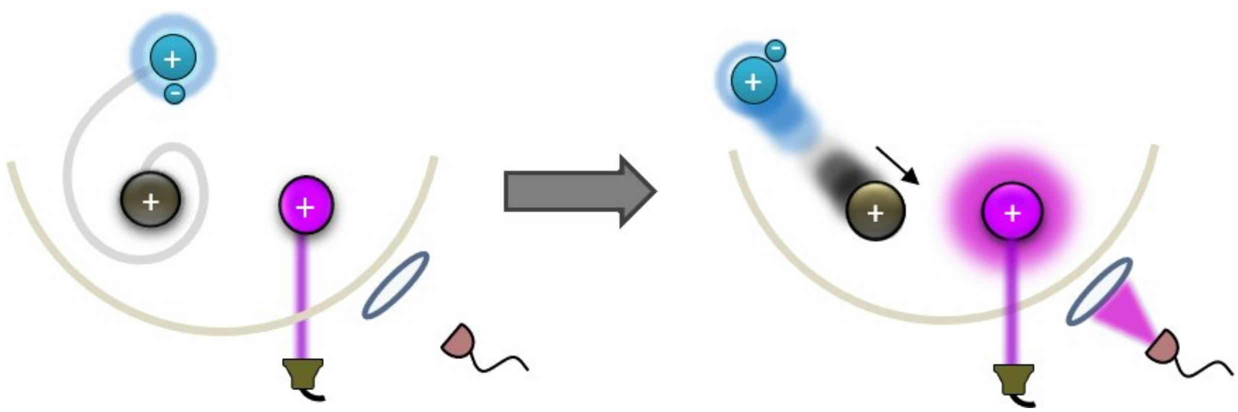

Credit: Katz et al.

Quantum chemistry is the branch of chemistry that explores the applications of quantum mechanics to chemical systems. Studies in this field can help to better understand the behavior of pairs or groups of atoms in a quantum state as well as the chemical reactions resulting from their interactions.

Many quantum chemistry studies specifically explored the interactions between pairs of atoms in a quantum state. While some of these works gathered interesting insight, they were often limited by the lack of available techniques for observing and controlling the outcomes of individual atom collisions.

Researchers at the Weizmann Institute of Science have been trying to devise new and more advanced tools to study the basic interactions between a single pair of atoms. In a paper recently published in *Nature Physics*, they introduced a new technique based on quantum logic that can be used to study interactions between an ultracold neutral atom and a cold ion.

"When atoms are brought up at short distances, they can experience several processes such as energy release or a chemical reaction, which are governed by quantum mechanics," Or Katz, one of the researchers who carried out the study, who is now at Duke University, told Phys.org. "Previously devised methods can be used to study these processes, but they require optical access and control of at least one of the atoms, which in turn severely limits the atomic species as well as the set of interactions that can be studied practice. Our work alleviates this requirement and allows us to study the interaction between many pairs of atoms using just a single additional atom, which acts as a probe."

Essentially, the researchers laser cooled and then trapped a pair of ions and a cloud of neutral atoms. The ions were trapped in a Paul trap, using electromagnetic fields. The neutral atoms, on the other hand, were trapped in an optical lattice, which they could bring in and out of the Paul trap at will.

"We study the interaction of a single 'chemistry ion' with one neutral atom by measuring the imprint on the second 'logic ion' in the trap that acts as a probe," Katz explained. "Specifically, when the chemistry ion gains energy by its interaction with an atom in an exothermic (energy releasing) process, it pushes the "logic ion," which in our experimental configuration, consequent with fluorescence of light. Detection of this fluorescence light from the logic ion reveals information about the process the other ion and atom have experienced."

The recent work by Katz and his colleagues opens new possibilities for the study of processes that were previously difficult or impossible to probe experimentally. For instance, the technique they introduced in their paper could be used to measure new effects in which the motion of atom and ion features is characterized by quantum interference. Using previously developed tools, these effects would be very difficult to observe and examine.

"One hint for such effect is already seen in this work, reflected in the difference of cross-sections that is measured for the interaction of different isotopes of Sr+ with 87Rb, but the technique is not limited to this example and can be applied to study quantum effects in many other pairs," Katz added. "We plan to apply the same technique to study additional processes, such as exchange of spin as well as chemical reactions."

In addition to using their technique to study other processes, Katz and his colleagues plan to gather more evidence of quantum interference effects. This will allow them to further assess the potential of quantum mechanics-based tools for the study of fundamental interactions between atoms.

More information: Or Katz et al, Quantum logic detection of collisions between single atom–ion pairs, *Nature Physics* (2022). DOI: 10.1038/s41567-022-01517-y

Lothar Ratschbacher et al, Controlling chemical reactions of a single particle, *Nature Physics* (2012). DOI: 10.1038/nphys2373

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