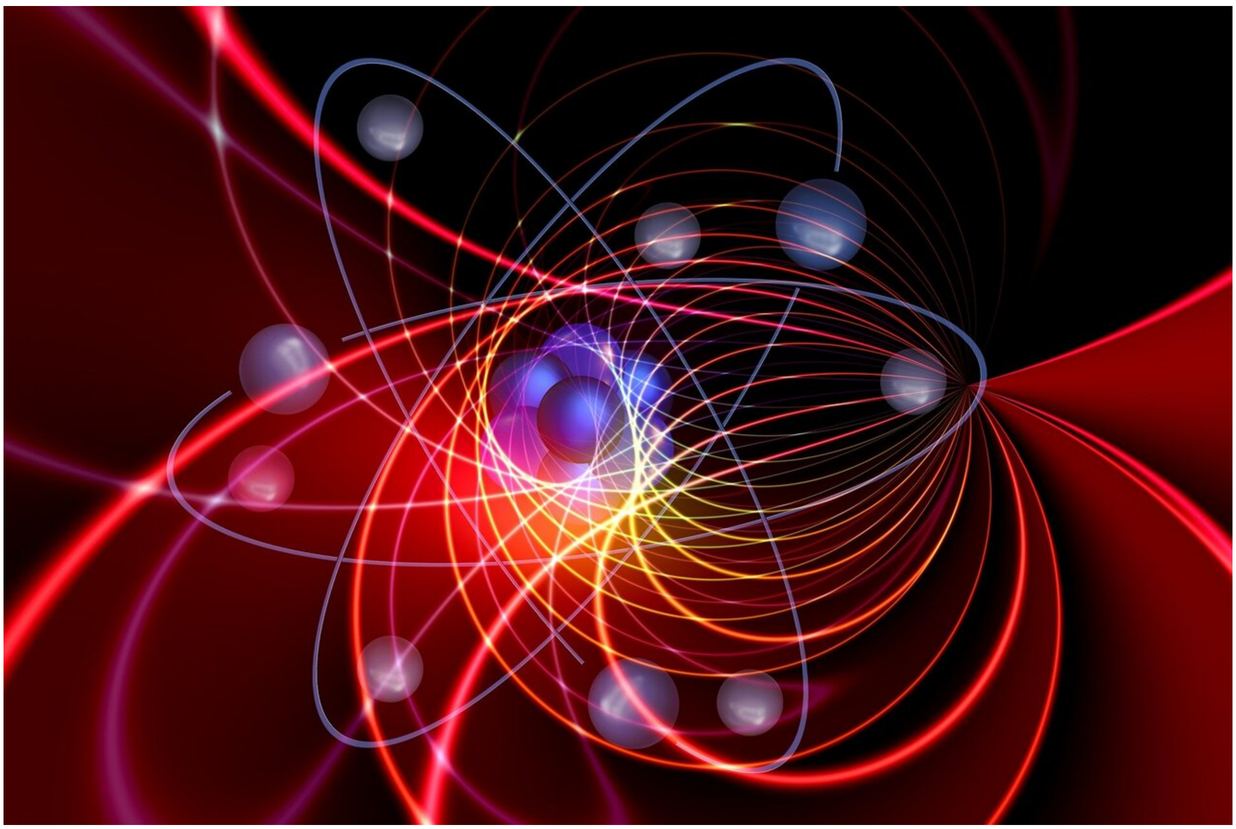
Cooling of a trapped ion to the quantum regime

February 25 2020, by Ingrid Fadelli



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Neutral atoms and charged ions can be cooled down to extremely low temperatures (i.e., to microkelvins, 1 millionth of a degree above absolute zero) using laser techniques. At these low temperatures, the particles have often been found to behave in accordance with the laws of quantum mechanics.

Researchers have been conducting laser cooling experiments on atoms and ions for decades now. So far, however, no study had observed mixtures of both atoms and ions at extremely low temperatures.

Researchers at the University of Amsterdam were the first to achieve this by placing an ion inside a cloud of lithium atoms pre-cooled to a few millionths of a kelvin. Their observations, published in *Nature Physics*, unveiled numerous effects that could have interesting implications for the development of new quantum technologies.

"Cold atoms and ions find applications in studies aimed at understanding quantum many-body phenomena and could be used in atomic clocks or possibly even quantum computers," Dr. Rene Gerritsma, one of the researchers who carried out the study, told Phys.org. "So far, however, nobody had ever made a mixture of both atoms and ions at these ultracold temperatures. The objective behind our study was to achieve this for the first time."

In their experiments, Gerritsma and his colleagues started off by cooling a single ion using laser cooling techniques. Separately, they also prepared a cloud of approximately 10,000 lithium atoms and cooled it down to a few microkelvin.

Subsequently, the researchers overlapped the ion with the cloud of atoms and monitored the ion's energy levels, using a set of tools typically employed for research into trapped ion quantum computers. This ultimately allowed them to determine the energy arising from the collision between the ion and the cloud of atoms.

"The main challenge in our experiment was keeping the ion trapped in the gas," Dr. Gerritsma explained. "To achieve this, we use electric fields, but these have a negative effect on the atom-ion collisions, causing heating."

A few years ago, while conducting similar experiments, a research group at MIT predicted that the heating effects arising from the use of electric fields could be mitigated using a very heavy ion and a light atom species. This prediction ultimately inspired Gerritsma and his colleagues to conduct their experiments using an ytterbium ion and a cloud of lithium atoms.

"For the very first time, we have observed that an ion in a neutral gas of atoms cools to a regime where quantum effects become important," Dr. Gerritsma said. "The system can be used to study quantum chemistry on the single particle level, or the quantum many-body physics of interacting atoms and ions or perhaps even to buffer gas cool the trapped ion quantum computer."

By measuring the kinetic energy of the atoms and ion in all directions of motion, Gerritsma and his colleagues were able to gather a number of interesting observations. For instance, the collision energy between the ytterbium ion and lithium atoms was found to reach what is known as the s-wave limit, which suggests that quantum theory can help to better understand the collision.

The research team found evidence pointing to the occurrence of quantum phenomena in collisions between the ion and atoms. These new observations could have implications for future research, for instance, paving the way for in-depth investigations of short-lived atom-ion configurations known as magneto-molecular resonances. In their next studies, Gerritsma and his colleagues plan to use a method similar to the one employed in their recent study to search for so-called Feshbach resonances between atoms and ions.

"In these resonances, the atom and ion can form a molecule and they can be used to boost the interaction strength between the atoms and ions," Dr. Gerritsma said. "Feshbach resonances have been observed between neutral atoms, and they have been predicted to exist between atoms and ions as well. However, they have never been observed because the required ultracold temperatures had not been reached up until now."

More information: T. Feldker et al. Buffer gas cooling of a trapped ion to the quantum regime, *Nature Physics* (2020). DOI: 10.1038/s41567-019-0772-5

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