Controlling chemical reactions near absolute zero

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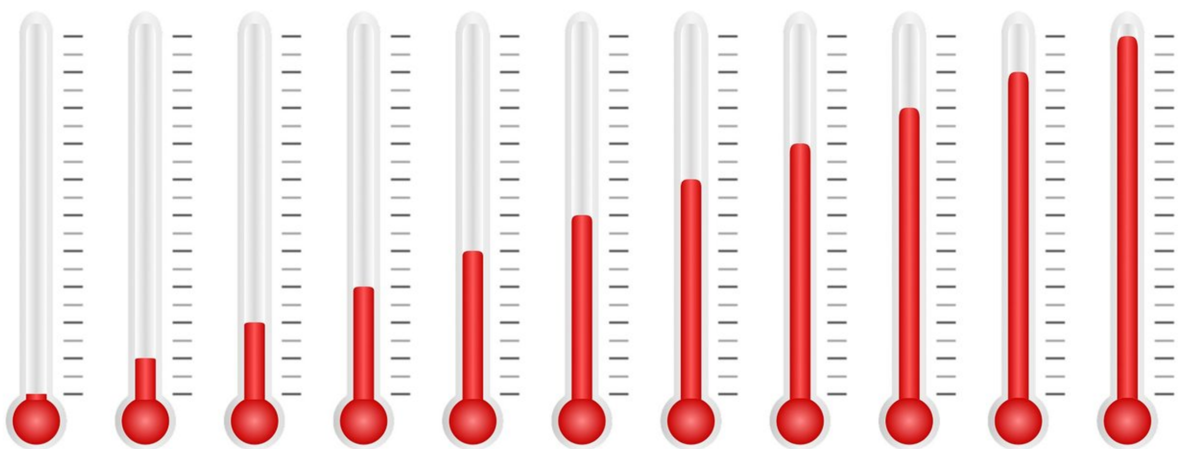

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It is an understatement to say that chemical reactions take place everywhere, constantly. In both nature and the lab, chemistry is ubiquitous. But despite advances, it remains a fundamental challenge to gain a complete understanding and control over all aspects of a chemical reaction, such as temperature and the orientation of reacting molecules and atoms.

This requires sophisticated experiments where all the variables that define how two reactants approach, and ultimately react with, each other can be freely chosen. By controlling things like the speed and the orientation of the reactants, chemists can study the finest details of a particular reaction mechanism.

In a new study, a team led by Andreas Osterwalder at EPFL's Institute of Chemical Sciences and Engineering, working with theorists from the University of Toronto, have built an apparatus that allows them to control the orientation and energies of reacting atoms, down to nearly absolute zero. "It's the coldest formation of a chemical bond ever observed in molecular beams," says Osterwalder. A molecular beam is a jet of gas inside a vacuum chamber, frequently used in spectroscopy and studies in fundamental chemistry.

The scientists have used two such beams that merge into a single beam to study chemi-ionization, a fundamental energy-transfer process that is used in several applications, e.g. in mass spectrometry. During chemi-ionization, an atom or molecule in the gas phase reacts with another atom or molecule in an excited state and creates an ion. The identity of the resulting ion depends on the reaction, a new bond can be formed during the collision, resulting in a molecular ion, or else an atomic ion can be formed

The researchers studied the reaction between two gases: an excited neon atom and an atom of argon. Their apparatus contains a pair of solenoid magnets that is used to precisely tune the direction of a magnetic field wherein the reaction takes place, which allowed the researchers to control the actual orientation of the two atoms relative to each other. "Even though atoms often are represented as tiny balls, they are not normally spherical objects," says Osterwalder. "Exactly because they are not, they have specific orientations, and this can affect their reactivity."

But even though the experiment could control the orientation which in turn controlled the amount of atomic vs molecular ions formed from the chemi-ionization, the researchers found that below a temperature of around 20 Kelvin (- 253.15 °C), the inter-atomic forces took over and the atoms re-oriented themselves irrespective of the applied field.

"This is the first time anyone has done this at such a low temperature," says Osterwalder. "With this level of control, we can study some of the most fundamental models at the core of chemistry, such as the relationship between orientation and reactivity."

More information: Sean D. S. Gordon et al, Quantum-state-controlled channel branching in cold Ne($^3P_{2)}$+Ar chemi-ionization, *Nature Chemistry* (2018). DOI: 10.1038/s41557-018-0152-2

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