'Ultracold' molecules promising for quantum computing, simulation

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(Phys.org) —Researchers have created a new type of "ultracold" molecule, using lasers to cool atoms nearly to absolute zero and then gluing them together, a technology that might be applied to quantum computing, precise sensors and advanced simulations.

"It sounds counterintuitive, but you can use lasers to take away the kinetic energy, resulting in radical cooling," said Yong P. Chen, an associate professor of physics and electrical and computer engineering at Purdue University.

Physicists are using lasers to achieve such extreme cooling, reducing the temperature to nearly absolute zero, or minus 273 degrees Celsius (minus 459 degrees Fahrenheit) - the lowest temperature possible in the universe.

At these temperatures atoms are brought to a near standstill, making possible new kinds of chemical interactions that are predominantly quantum mechanical in nature. The process is performed inside of an apparatus called a magneto-optical trap, a system that uses a vacuum chamber, magnetic coils and a series of lasers to cool and trap the atoms.

"This is our test tube," said Daniel S. Elliott, a professor of electrical and computer engineering and physics. "In ultracold chemistry, molecules are really moving slowly so they have a long time to interact with each other."

Other researchers have used the method to create cold molecules out of atoms of other alkali metals, which are relatively easy to turn into ultracold molecules. The Purdue researchers are the first to achieve the milestone with the alkali metals lithium and rubidium, in work led by Chen and Elliott.

Findings are detailed in a research paper that appeared as a "Rapid Communication" in the February issue of the journal *Physical Review A*, a publication of the American Physical Society. The paper was authored by former Purdue physics doctoral student Sourav Dutta, who has graduated; graduate students John Lorenz and Adeel Altaf; Elliott and Chen. The paper is available online at http://pra.aps.org/abstract/PRA/v89/i2/e020702

The method is called photoassociation: two atoms are merged using lasers to induce a chemical bond between them, forming a molecule. These molecules may contain two of the same types of atoms - making them homonuclear - or they can contain two different types of atoms, heteronuclear, such as the case with the lithium-rubidium molecules created by the team.

If the molecules are heteronuclear there is a difference in electric charge between these two atoms and the molecule is said to be polar. This difference in charge is called a dipole moment, which enables interaction between molecules. The greater the dipole moment, the stronger the interaction.

The lithium-rubidium molecule is potentially ideal for various applications, including quantum computing, because it has a significant dipole moment, which can enable these molecules to be used as "quantum bits."

Quantum computers would take advantage of a phenomenon described by quantum theory called "entanglement." Instead of only the states of one and zero used in conventional computer processing, there are many possible "entangled quantum states" in between one and zero, dramatically increasing the capacity to process information.

"In quantum computing the larger the dipole moment the stronger the interaction would be between molecules, and you need that interaction," Elliott said. "They need to interact with each other in order to affect each other, the key to entanglement."

Another potential advantage for the lithium-rubidium molecule is that it can be produced in large quantities.

"The rate of production is much greater for lithium-rubidium than for other bi-alkali-metal molecules," Chen said. "That was a pleasant surprise. It was already known that it has the third- largest dipole moment among bi-alkali-metal molecules, but nobody expected it would be made so efficiently."

Ultracold means temperatures less than about one thousandth of degree above absolute zero. Achieving such frigid extremes requires reducing the kinetic energy of molecules as well as their "internal excitation energies," which are stored in three ways: the rotation of the molecule itself, the vibrations of the atomic nuclei, and the movement of electrons in "shells" surrounding the nuclei. The combined energy of the trio is called rovibronic, a shortened version of rotational, vibrational and electronic.

"We are reporting a highly efficient production of ultracold lithium-rubidium molecules by photoassociation," Dutta said. "This provides the first step towards the production of such ultracold lithium-rubidium molecules in their ground, polar state."

Molecules in their "ground state" have the lowest possible rovibronic energy, which would make them more stable and easier to control.

A related research paper was also published by the team in January in the journal *Europhysics Letters*, a publication of the European Physical Society. That paper is available online at http://iopscience.iop.org/0295-5075/104/6/63001/article

"Lithium rubidium is one of the last bi-alkali molecules to be made cold, and we are the first to do this," Chen said. "People knew virtually nothing about these molecules."

Ultimately, researchers are seeking more efficient methods for the production of ultracold molecules.

The research has been funded by Purdue's Bilsland Dissertation Fellowship, the National Science Foundation, Army Research Office, and more recently by a research incentive grant from Purdue's Office of Vice President for Research.

The research falls within a field called AMO, for atomic, molecular, and optical physics, an area under expansion at Purdue.

"AMO physics is an exciting area in the landscape of experimental and theoretical physics," Elliott said. "Seven years ago we had one person working in this area."

Since then, the department has added three faculty members working in AMO and is in the process of adding more.

"Purdue is positioned to become a leader in AMO physics," Chen said.

Provided by Purdue University