All for one, one for all: Atoms behave like Three Musketeers

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An international team of physicists has converted three normal atoms into a special new state of matter whose existence was proposed by Russian scientist Vitaly Efimov in 1970.

In this new state of matter, any two of the three atoms--in this case cesium atoms-- repel one another in close proximity. "But when you put three of them together, it turns out that they attract and form a new state," said Cheng Chin, an Assistant Professor in Physics at the University of Chicago.

Chin, along with 10 scientists led by Rudolf Grimm at the University of Innsbruck in Austria, report this development in the March 16 issue of the journal *Nature*. The paper describes the experiment in Grimm's laboratory where for the first time physicists were able to observe the Efimov state in a vacuum chamber at the ultracold temperature of a billionth of a degree above absolute zero (minus 459.6 degrees Fahrenheit).

This new state behaves like the Borromean ring, a symbol of three interlocking circles that has historical significance in Italy. The Borromean concept also exists in physics, chemistry and mathematics.

"This ring means that three objects are entangled. If you pick up any one of them, the other two will follow. However, if you cut one of them off, the other two will fall apart," Chin said. "There is something magic about this number of three."

The Innsbruck experiment involved three cesium atoms, a soft metal used in atomic clocks, formed into a molecule that manifested the Efimov state. But in theory the Efimov state should apply universally to other sets of three particles at ultracold temperatures. "If you can create this kind of state out of any other type of particle, it'll have exactly the same behavior," Chin said.

The finding may lead to the establishment of a new research specialty devoted to understanding the quantum mechanical behavior of just a few interacting particles, Grimm said. Quantum mechanics governs the interactions of atoms and subatomic particles, but is best understood when applied to systems consisting of two particles or of many particles.

A good understanding of systems that contain just a handful of particles still eludes scientists. That may change as scientists begin to produce laboratory experiments that simulate systems made of just three or four particles, like those found in the nucleus of an atom.

Now that the Efimov state has been achieved, scientists can aspire to engineer the very properties of matter, Chin said. The Innsbruck-Chicago team exerted total control over the atoms in the experiment, converting them into the Efimov state and back into normal atoms at will.

"This so-called quantum control over the fundamental properties of matter now seems feasible. We're not limited to the properties of, say, aluminum, or the properties of the copper of these particles. We are really creating a new state in which we can control their properties."

Today, nanotechnology researchers can combine atoms in novel ways to form materials with interesting new properties, "but you are not changing the fundamental interactions of these atoms," Chin said. That can only be done at temperatures near absolute zero. "At the moment, I don't see how this can be done at much higher temperatures," he said.

Chin began working with Grimm's group as a visiting scientist at the University of Innsbruck from 2003 until 2005. He continued the collaboration after joining the University of Chicago faculty last year.

"Cheng was very excited about the prospects of observing Efimov physics in cesium already as a Ph.D. student at Stanford," Grimm said. The 1999 Stanford experiment, led by physicists Vladan Vuletic and Steven Chu, was conducted at one millionth of a degree above absolute zero. "Now we know that their sample was too hot" to observe the Efimov state, Grimm said.

Added Chin: "After working on cesium for many years, this is a dream come true for me."

Source: University of Chicago

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