Physicists discover important step for making light crystals (w/Videos)

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Ohio State University researchers have developed a new strategy to overcome one of the major obstacles to a grand challenge in physics.

What they've discovered could eventually aid high-temperature superconductivity, as well as the development of new high-tech materials.

In 2008, the Defense Advanced Research Projects Agency (DARPA) chose three multi-university teams to tackle an ambitious problem: trap atoms inside a light crystal -- also called an "optical lattice" -- that can simulate exotic materials and answer fundamental questions in physics.

The deadline for the first phase of the challenge -- June 2009 -- is fast approaching, and the teams have been unable to make the atoms cold enough for their experiments to work.

In this week's online edition of the Proceedings of the National Academy of Sciences, Ohio State university physicist Tin-Lun Ho and doctoral student Qi Zhou present a potential solution.

Their calculations suggest that it's possible to compress the atoms in an optical lattice until the heat is squeezed out of them -- and into a surrounding pool of ultra-cold Bose-Einstein condensate (BEC), which will absorb the heat and evaporate it away.

"It is absolutely essential to achieve very low temperatures for this program to succeed. All three teams have made much progress, but until now, temperature has been a bottleneck for the whole enterprise," said Ho, Distinguished Professor of Mathematical and Physical Sciences at Ohio State.

"Ours is the first proposal to show how the temperature can be lowered dramatically. In fact, we believe it can be made much lower that what is considered achievable today."

A Bose-Einstein Condensate is a collection of atoms cooled with laser light to a temperature just above absolute zero (0 Kelvin, −273 degrees Celsius, or −460 degrees Fahrenheit). The first BEC ever produced was 170 nanokelvin, or 170 billionths of a Kelvin. Researchers have since produced condensates as cold as 500 picokelvin, or 500 trillionths of a Kelvin.

Ho pioneered theoretical studies of BEC. He has made a wide range of contributions in the field, for which he was awarded the 2008 Lars Onsager Prize of the American Physical Society. Recently, he has worked on the physics of cold atoms in optical lattices, and has pointed out the amount of cooling needed to meet the DARPA challenge.

The new method cools the atoms in an optical lattice by literally squeezing the heat out of them and into a surrounding BEC, which acts as a heat sink.

Ho has already shared the cooling method with the three teams in recent DARPA Meetings. The teams are led by the Massachusetts Institute of Technology, Rice University, and the University of Maryland. Each team is approaching the problem a little differently, and Ho is a member of two of the teams: Rice and Maryland.

All are working to create an optical lattice -- a three-dimensional cubic structure made of laser light which contains many smaller cubes, or "cells," inside it. Each cell in the lattice is supposed to contain one atom.

If the researchers succeed, they will have made an adjustable crystal out of laser light, and will be able to emulate different solid materials.

Physicists think of heat in terms of entropy, or disorder, Ho explained. His cooling method involves boosting the laser intensity to force the atoms into a very orderly arrangement.

The researchers are trying to trap atomic particles called fermions, which have an internal angular momentum called spin. When fermions are hot, they spin chaotically. The hotter the atoms, the more disordered these spins become.

Ho and Zhou discovered that by raising the laser intensity, researchers could compress the fermions into a so-called "band insulator," where each cell in the lattice contains two fermions instead of one. Each fermion will naturally pair up with one that is spinning in the opposite direction, so that the two spins cancel each other out. This two-fermion state would have no entropy, or heat.

But according to the laws of thermodynamics, the heat has to go somewhere. Ho calculates that it would be pressed outward to the surface of the lattice, where a Bose-Einstein Condensate could absorb it.

After the BEC evaporated away, the researchers could turn down the intensity of the laser, so that the lattice could expand and the atoms could return to their original locations, with one per cell. Only this time, the whole lattice would be much colder than before.

"Effectively, this is a two-part solution -- divide and conquer," Ho said. "The 'divide' part is to push the entropy out of the interior of the system.

The 'conquer' part is to get rid of the entropy by evaporating away the BEC. Next, we'd like to reduce it to a one-step process, and eliminate the need for the BEC entirely." Recently, Ho and Zhou have come up with another method which they believe may be even simpler.

Physicists hope that the light crystal will be able to simulate new materials, and perhaps even reveal the key to high-temperature superconductivity. Ho is optimistic that such applications will be achievable in the next decade.

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