# Researchers use webs of lasers to remove entropy from a system causing quantum gases to cool

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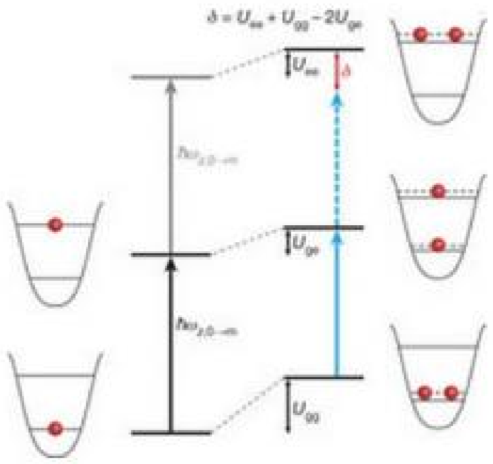

Orbital excitation blockade mechanism in an optical lattice. Image (c) NPG, doi:10.1038/nature10668

(PhysOrg.com) -- Many physicists around the world are hard at work trying to figure out new and exciting ways to create ultra-cold objects, the reason being is that if a system could be created that operates at or at least very near absolute zero, superconductors could be devised that might help create quantum computers, which would of course run at speeds that would make the current generation look quaint. Plus, theory suggests new states of matter might be discovered.

Now, new work by a group of physicists from Harvard appears to be coming closer than ever. They've figured out a way to remove entropy from a specialized system leaving much colder atoms behind. In their paper, published in *Nature*, they discuss how they've come up with something called an orbital excitation blockade, a form of interaction blockade, to reach temperatures tens to hundreds of times colder than current methods.

The team did their research in a three step process. In the first they shot atoms that make up rubidium with a laser, forcing them to glow in a way that made them give off more energy then they absorbed, making them cooler of course. By doing so they also created a system whereby they were able to control the atoms due to the pressure created by the laser. Thus they could hold them still, move them around, or even cause them to run into each other.

Next, the team caused the atoms to grow even colder by allowing evaporative cooling to due its work.

After that, the real work began. Here the team used meshes of lasers, called optical lattices to remove entropy from the system. The already cooled atoms were made to knock into one another using lasers ala the method used to start the whole process; this time in the optical lattices. In so doing, the excited activity of atom one dampened the excited activity of the other, a process the team calls an orbital excitation blockade. The team then removed the excited atoms from the system, leaving the unexcited, cold atoms behind, in effect, removing entropy from the system.

In actual experiments done thus, far, the team has demonstrated an ability to actually remove heat from a system using their excitation blockade, but only to a certain point. They believe more research will allow them to reach temperatures tens or even hundreds of a billionth of a degree above absolute zero, which would take them into truly unknown territory.

**More information:** Orbital excitation blockade and algorithmic cooling in quantum gases, *Nature*, 480, 500–503 (22 December 2011) doi:10.1038/nature10668

## Abstract

Interaction blockade occurs when strong interactions in a confined, few-body system prevent a particle from occupying an otherwise accessible quantum state. Blockade phenomena reveal the underlying granular nature of quantum systems and allow for the detection and manipulation of the constituent particles, be they electrons, spins, atoms or photons. Applications include single-electron transistors based on electronic Coulomb blockade7 and quantum logic gates in Rydberg atoms. Here we report a form of interaction blockade that occurs when transferring ultracold atoms between orbitals in an optical lattice. We call this orbital excitation blockade (OEB). In this system, atoms at the same lattice site undergo coherent collisions described by a contact interaction whose strength depends strongly on the orbital wavefunctions of the atoms. We induce coherent orbital excitations by modulating the lattice depth, and observe staircase-like excitation behaviour as we cross the interaction-split resonances by tuning the modulation frequency. As an application of OEB, we demonstrate algorithmic cooling of quantum gases: a sequence of reversible OEB-based quantum operations isolates the entropy in one part of the system and then an irreversible step removes the entropy from the gas. This technique may make it possible to cool quantum gases to have the ultralow entropies required for quantum simulation of strongly correlated electron systems. In addition, the close analogy between OEB and dipole blockade in Rydberg atoms provides a plan for the implementation of two-quantum-bit gates in a quantum computing architecture with natural scalability.

# A Harvard University press release can be found below:

*Physicists at Harvard University have realized a new way to cool synthetic materials by employing a quantum algorithm to remove excess energy. The research, published this week in the journal Nature, is the first application of such an "algorithmic cooling" technique to ultra-cold atomic gases, opening new possibilities from materials science to quantum computation.*

"Ultracold atoms are the coldest objects in the known universe," explains senior author Markus Greiner, associate professor of Physics at Harvard. "Their temperature is only a billionth of a degree above absolute zero temperature, but we will need to make them even colder if we are to harness their unique properties to learn about quantum mechanics."

Greiner and his colleagues study quantum many-body physics, the exotic and complex behaviors that result when simple quantum particles interact. It is these behaviors which give rise to high-temperature superconductivity and quantum magnetism, and that many physicists hope to employ in quantum computers.

"We simulate real-world materials by building synthetic counterparts composed of ultra-cold atoms trapped in laser lattices," says co-author Waseem Bakr, a graduate student in physics at Harvard. "This approach enables us to image and manipulate the individual particles in a way that has not been possible in real materials."

The catch is that observing the quantum mechanical effects that Greiner, Bakr and colleagues seek requires extreme temperatures.

"One typically thinks of the quantum world as being small," says Bakr, " but the truth is that many bizarre features of quantum mechanics, like entanglement, are equally dependent upon extreme cold."

The hotter an object is, the more its constituent particles move around, obscuring the quantum world much as a shaken camera blurs a photograph.

The push to ever-lower temperatures is driven by techniques like "laser cooling" and "evaporative cooling," which are approaching their limits at nanoKelvin temperatures. In a proof-of-principle experiment, the Harvard team has demonstrated that they can actively remove the fluctuations which constitute temperature, rather than merely waiting for hot particles to leave as in evaporative cooling.

Akin to preparing precisely one egg per dimple in a carton, this "orbital excitation blockade" process removes excess atoms from a crystal until there is precisely one atom per site.

"The collective behaviors of atoms at these temperatures remain an important open question, and the breathtaking control we now exert over individual atoms will be a powerful tool for answering it," said Greiner. "We are glimpsing a mysterious and wonderful world that has never been seen in this way before."

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