Ultra-cold temperature physics opens way to understanding and applications

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Nearly 80 years ago, Albert Einstein and Satyendra Nath Bose predicted that gases of atoms cooled down very close to absolute zero would behave in unison. In 1995, three laboratories produced such Bose-Einstein condensates and opened the door for investigation of physical properties of atoms on a very cold scale.

David S. Weiss, associate professor of physics, Penn State, described recent research in one-dimensional quantum systems at the annual meeting of the American Association for the Advancement of Science today (Feb. 20) in Washington, D.C.

"These ultra-cold atoms can act as model systems to help us understand other quantum systems," says Weiss. "Their interactions can be calculated and controlled very accurately."

In a Bose-Einstein condensate, alkali metal atoms are cooled using lasers and a form of evaporation until they are a hair above absolute zero. Bosons, a class of particles that prefer to share the same energy state, when cooled this cold, begin to act in unison. The atoms' wave functions -- the description of each atom's position and momentum – all become identical. Initially, Bose-Einstein condensates were confined in featureless magnetic traps, but researchers have taken the experiments further.

"By putting Bose-condensed atoms into versatile light traps, we can make atomic wave functions exhibit remarkable behavior," says Weiss. "Most known quantum phenomena can be studied clearly with ultra-cold atoms, and as yet unknown phenomena can be conceived and observed."

The traps Weiss refers to are light traps created by lasers. By reflecting laser light back on itself, researchers create unmoving standing waves that, if created in a three-dimensional grid, can trap atoms. When this type of grid is superimposed over a Bose-Einstein condensate, the atoms segregate into individual traps, creating a matrix of tiny cells with ultra-cold atoms inside. Turning the lattice on and off can switch the system from a superfluid to something called a Mott insulator and back to a superfluid. Superfluids and Mott insulators have different quantum characteristics.

Weiss, who is using rubidium 87, takes the grid one step further and creates a one-dimensional Tonks-Girardeau gas. By constraining the grid in two directions so that movement is only possible in one dimension, as if the atom were on a wire, Weiss creates a system where the bosons – rubidium 87 atoms – act like fermions.

Fermions, unlike bosons, do not like to share energy states. Even near zero temperature, they avoid each other. In superconductivity, fermions act like bosons. In a Tonks-Girardeau gas, strongly interacting bosons act

as non-interacting fermions. "A one-dimensional Tonks-Girardeau gas is one of very few many-particle systems that can be exactly solved mathematically," says Weiss. "This was done in the '60s, but there had been no experimental system."

Now, Weiss can experimentally verify the mathematical calculations. Using these techniques, researchers may be able to understand superconductivity better, form quantum molecules and perhaps eventually create quantum computers.

Along with rubidium, some other potential elements for Bose-Einstein condensates and ultra-cold quantum physics are sodium, cesium, lithium and ytterbium.

Weiss considers quantum computing a promising way to use ultra cold atoms. The atoms can act as quantum bits, or qubits, with internal sub-states functioning as the ubiquitous 0 and 1s of computing.

"However, quantum computers can only do a certain class of calculations, factoring large numbers for example," says Weiss. "They might also be used to simulate other quantum mechanical systems, answering questions that are simply not answerable with any conceivable classic computer."

Superfluid clouds of atoms and grid-constrained super cold atoms are not the only possibilities researchers are exploring in ultra cold quantum physics. Other related areas of research include lattices of atomic vortices, coherent quantum chemistry and atomic interferometry.

Source: The Pennsylvania State University