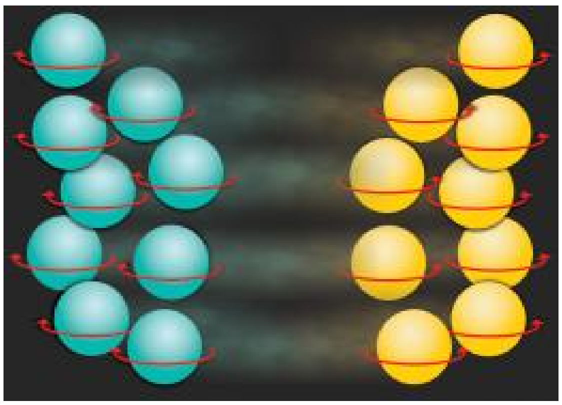
A one-way street for spinning atoms

August 30 2012



Elementary particles have a fundamental property called 'spin' that determines how they align in a magnetic field. MIT researchers have created a new physical system in which atoms with clockwise spin move in only one direction, while atoms with counterclockwise spin move in the opposite direction. Graphic: Christine Daniloff

Elementary particles have a property called "spin" that can be thought of as rotation around their axes. In work reported this week in the journal *Physical Review Letters*, MIT physicists have imposed a stringent set of traffic rules on atomic particles in a gas: Those spinning clockwise can move in only one direction, while those spinning counterclockwise can move only in the other direction.

Physical materials with this distinctive property could be used in "spintronic" circuit devices that rely on spin rather than electrical current for transferring information. The correlation between spin and direction of motion is crucial to creating a so-called topological superfluid, a key ingredient of some quantum-computing proposals.

The MIT team, led by Martin Zwierlein, an associate professor of physics and a principal investigator in the Research Laboratory of Electronics (RLE), produced this spin-velocity correlation in an ultracold, dilute gas of atoms. Just like electrons, the atoms in the gas are fermions, particles that cannot share the same quantum state; as a consequence, each atom has to have a different combination of spin and velocity.

In the process of sorting themselves into separate quantum states, the atoms moving very fast to the left end up spinning one way, while those moving very fast to the right end up spinning the other way. "What about the atoms moving with a velocity in between these extremes?" Zwierlein asks. "Quantum mechanics provides a surprising answer: They can simultaneously spin both ways."

Physical systems that correlate spin and velocity could open the door to a novel approach to quantum computers, largely hypothetical devices that would perform some types of computations exponentially faster than conventional computers. They derive this speed advantage by taking advantage of superposition, the ability of tiny particles—such as the atoms spinning in both directions at once—to inhabit more than one physical state at a time.

The chief obstacle in building quantum computers is that superposition is very difficult to maintain. In theory, topological superfluids should give rise to particles called Majorana fermions, which are much harder to knock out of superposition than other particles.

In previous experiments, the RLE researchers created a superfluid—a completely frictionless gas—of lithium atoms. In their new experiment, the researchers used laser beams to trap a cloud of lithium atoms about 50 micrometers in diameter. The atoms were cooled to just a few billionths of a degree above absolute zero. At such low temperatures, quantum mechanics describes the behavior of the gas.

The researchers illuminated the gas with a pair of laser beams, sorting the atoms into two lanes, each of which consists of atoms with the same spin moving in the same direction. For the first time in an atomic system, this correlation of atoms' spins with their velocities was directly measured.

"The combined system of ultracold atoms and the light we shine on them forms a material with unique properties," says Lawrence Cheuk, lead author of the paper and a graduate student in MIT's physics department. "The gas acts as a quantum diode, a device that regulates the flow of spin currents."

Zwierlein's research team, in addition to Cheuk, included MIT graduate student Ariel Sommer and postdocs Tarik Yefsah and Waseem Bakr—all members of MIT's Center for Ultracold Atoms—as well as visiting professor Zoran Hadzibabic of the University of Cambridge.

Topological superfluids are an exotic state of matter that can be distinguished by their topology, which is a very general description of their geometry. For instance, any object with a hole in it, such as a donut, is topologically identical to any other object with a hole in it, no matter how distorted they get—but an object with one hole in it is topologically distinct from an object with no hole, or with two. "The topological properties of the quantum states reduce their susceptibility to noise from the environment, which should make them an invaluable resource for quantum memories and information processors," Zwierlein says.

Ian Spielman, a physicist at the National Institute of Standards and Technology and the University of Maryland's Joint Quantum Institute, had previously demonstrated the correlation of spin and velocity in Bose gases, or gases of bosons. (All basic particles of matter are either bosons or fermions.) "Bose gases are wonderful, but there's not a topological superfluid in sight for them," Spielman says. "You need fermions."

In their new experiments, the MIT researchers "demonstrated a neat new measurement technique, which is the inverse of something that you can do in conventional condensed-matter systems," Spielman says. In the conventional measurement scheme, "you use light to kick electrons out and measure the energy and momentum of the electron you kicked out," Spielman says. "What Martin did, which was actually quite sneaky, was the reverse—where they got atoms and stuffed them into the interesting state, and said, 'What is the energy and momentum of the atom we stuffed in?'"

Other researchers are trying to produce topological systems in physical materials, such as superconducting wires, rather than gases. But the MIT researchers' measurement technique wouldn't work with materials, Spielman says. Moreover, "what we're really wanting to do is create extended regions of topological superfluid," Spielman says. "In a material system that's highly disordered, you don't just have a big blob of topological superfluid; you have a whole bunch of puddles. And probably, at the end of each of these puddles, you would find little Majorana fermions—which is neat, but it's an extremely complicated, disordered setup. And this is something that cold atoms are not bothered by."

More information: prl.aps.org/abstract/PRL/v109/i9/e095302

This story is republished courtesy of MIT News *(web.mit.edu/newsoffice/), a popular site that covers news about MIT research, innovation and teaching.*

Provided by Massachusetts Institute of Technology

Citation: A one-way street for spinning atoms (2012, August 30) retrieved 25 April 2024 from https://phys.org/news/2012-08-one-way-street-atoms.html

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.