Cool down fast to advance quantum nanotechnology

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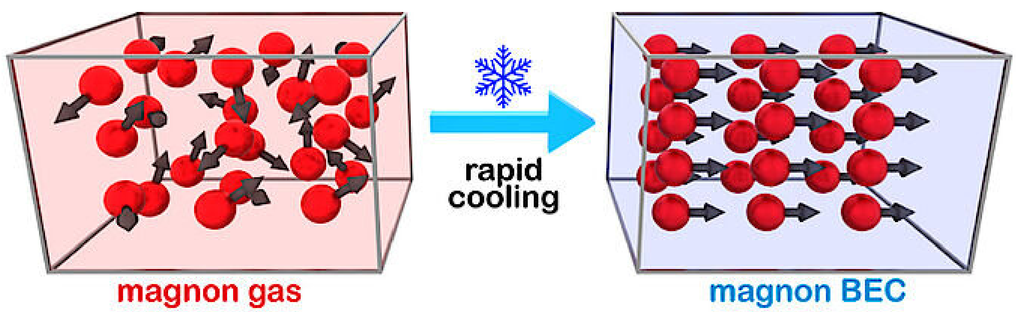

(From left to right) Magnon gas particles bounce around in many directions inside a magnetic nanostructure. When rapidly cooled, they all spontaneously jump into the same state, forming a Bose-Einstein condensate (BEC). This is a much simpler method to generate the condensate, which could have implications for quantum computing. Credit: Dr. Andrii Chumak, Technische Universität Kaiserslautern/Universität Wien

Rapidly cooling magnon particles proves a surprisingly effective way to create an elusive quantum state of matter, called a Bose-Einstein condensate. The discovery can help advance quantum physics research and is a step towards the long-term goal of quantum computing at room temperature.

An international team of scientists have found an easy way to trigger an unusual state of matter called a Bose-Einstein condensate. The new method, recently described in the journal *Nature Nanotechnology*, is expected to help advance the research and development of quantum computing at room temperature.

The team, led by physicists at the Technische Universität Kaiserslautern (TUK) in Germany and University of Vienna in Austria, generated the Bose-Einstein condensate (BEC) through a sudden change in temperature: first heating up quasi-particles slowly, then rapidly cooling them down back to room temperature. They demonstrated the method using quasi-particles called magnons, which represent the quanta of magnetic excitations of a solid body.

"Many researchers study different types of Bose-Einstein condensates," said Professor Burkard Hillebrands from TUK, one of the leading researchers in the field of BEC. "The new approach we developed should work for all systems."

Puzzling and spontaneous

Bose-Einstein condensates, named after Albert Einstein and Satyendra Nath Bose who first proposed they exist, are a puzzling type of matter. They are particles that spontaneously all behave the same way on the quantum level, essentially becoming one entity. Originally used to describe ideal gas particles, Bose-Einstein condensates have been established with atoms, as well as with quasi-particles such as bosons, phonons and magnons.

Creating Bose-Einstein condensates is tricky business because, by definition, they have to occur spontaneously. Setting up the right conditions to generate the condensates means not trying to introduce any kind of order or coherence to encourage the particles to behave the same way; the particles have to do that themselves.

Currently, Bose-Einstein condensates are formed by decreasing the temperature to near absolute zero, or by injecting a large number of particles at room temperature into a small space. However, the room temperature method, which was first reported by Hillebrands and collaborators in 2005, is technically complex and only a few research teams around the world have the equipment and know-how required.

The new method is much simpler. It requires a heating source, and a tiny magnetic nanostructure, measuring a hundred times smaller than the thickness of a human hair.

"Our recent progress in the miniaturization of magnonic structures to nanoscopic scale allowed us to address BEC from completely different perspective," said Professor Andrii Chumak from the University of Vienna.

The nanostructure is heated up slowly to 200°C to generate phonons, which in turn generate magnons of the same temperature. The heating source is turned off, and the nanostructure rapidly cools down to room temperature in about a nanosecond. When this happens, the phonons escape to the substrate, but the magnons are too slow to react, and remain inside the magnetic nanostructure.

Michael Schneider, lead paper author and a Ph.D. student in TUK'S Magnetism Research Group, explained why this happens: "When the phonons escape, the magnons want to reduce energy to stay in equilibrium. Since they cannot decrease the number of particles, they have to decrease energy in some other way. So, they all jump down to the same low energy level."

By spontaneously all occupying the same energy level, the magnons form a Bose-Einstein condensate.

"We never introduced coherence in the system," Chumak said, "so this is a very pure and clear way to create Bose-Einstein condensates."

Unexpected result

As is often the case in science, the team made the discovery quite by accident. They had set out to study a different aspect of nanocircuits when strange things began to happen.

"At first we thought something was really wrong with our experiment or data analysis," Schneider said.

After discussing the project with collaborators at TUK and in the U.S., they tweaked some experimental parameters to see if the strange thing was in fact a Bose-Einstein condensate. They verified its presence with spectroscopy techniques.

The finding will primarily interest other physicists studying this state of matter. "But revealing information about magnons and their behavior in a form of macroscopic quantum state at room temperature could have bearing on the quest to develop computers using magnons as data carriers," Hillebrands said.

More information: Michael Schneider et al. Bose–Einstein condensation of quasiparticles by rapid cooling, *Nature Nanotechnology* (2020). DOI: 10.1038/s41565-020-0671-z

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