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A New Quantum State of Matter Works at Room Temperature

Researchers from the University of Warsaw, the Military University of Technology (Poland), IBM Research Zurich, and the French National Centre for Scientific Research (CNRS) have observed a new quantum state of matter known as a supersolid in an exciton-polariton Bose-Einstein condensate. Remarkably, the phenomenon occurs not at temperatures close to absolute zero, but at room temperature. The results have been published in Science Advances.

How can a liquid also be a crystal?

At first glance, this seems impossible. A crystal is rigid and ordered, while a liquid flows. Yet quantum mechanics allows a state that combines both properties. The story begins with superfluidity – an extraordinary state of matter in which viscosity completely disappears. A superfluid can flow through the narrowest channels without resistance. If you dipped an oar into such a liquid, you would feel almost no drag until a critical velocity was exceeded, at which point quantum vortices would suddenly appear.

As early as the 1960s, physicists predicted that a superfluid could simultaneously develop a periodic crystal-like structure. The resulting phase, called a supersolid, retains the frictionless flow of a superfluid while exhibiting the spatial order of a crystal. For more than half a century, this remained a theoretical prediction. It was not until 2017 that supersolidity was experimentally observed in ultracold atomic Bose-Einstein condensates.

Light instead of atoms

The TopoLight consortium chose a completely different route. Rather than using ultracold atoms, the researchers studied exciton polaritons – hybrid quasiparticles formed by the strong coupling between light and matter inside an optical microcavity. Although they exist for only a few picoseconds, this is sufficient for them to form a Bose–Einstein condensate and behave as a quantum superfluid.

The optical microcavity was filled with a specially designed liquid crystal and coated with an organic semiconductor. This unique combination enabled strong light-matter coupling at room temperature.

“Our liquid-crystal microcavities can operate even at temperatures approaching 60°C,” says Professor Wiktor Piecek from the Military University of Technology, whose group developed the liquid-crystal structures.

How do you recognize a supersolid?

The transition into the supersolid phase is revealed by the appearance of regularly spaced bright fringes in the light emitted from the sample. These fringes indicate that the condensate has spontaneously formed a periodic density modulation – a hallmark of crystallization.

But the experiment revealed something even more remarkable.

With every laser pulse exciting the sample, the fringes appeared at a different position. Each time, the quantum system independently selected one of many equivalent configurations.
“This is a textbook example of spontaneous symmetry breaking,” explains Professor Guillaume Malpuech from Institut Pascal (CNRS). “Theory predicted that the supersolid could choose among several equivalent states, and that is exactly what we observed.”
At the same time, the condensate also exhibited a persistent spin helix – a periodic modulation of the polarization of the emitted light. As a result, the researchers observed two distinct forms of order simultaneously: one in the polarization and another in the light intensity.

A race against time
Performing the experiment proved far more challenging than anticipated.
The organic semiconductor gradually reacted with the liquid crystal, meaning that all measurements had to be completed within only a few hours after the sample was assembled.
“We had to plan the entire sequence of experiments in advance,” recalls Dr. Marcin Muszyński, the paper’s first author, now a postdoctoral researcher at The City College of New York. “Repeating a measurement meant fabricating an entirely new sample.”
The most important measurements were carried out at IBM Research Zurich, where thin films of the organic semiconductor were deposited onto photonic structures fabricated at the Military University of Technology.
“We have studied the organic semiconductor MeLPPP (methyl-substituted ladder-type poly(paraphenylene) for many years and previously observed Bose-Einstein condensation in this material,” says Thilo Stöferle from IBM Research. “This was the first time we combined it with a liquid-crystal microcavity.”

Why does it matter?
Until now, most studies of exotic quantum phases required expensive cryogenic systems operating close to absolute zero. The new results demonstrate that similar quantum phenomena can be explored in photonic systems functioning at room temperature.
This opens exciting opportunities for future quantum technologies based on light – from ultrafast photonic devices and neuromorphic computing accelerators to highly sensitive optical sensors exploiting the extraordinary polarization sensitivity of the supersolid phase.
Perhaps even more importantly, liquid-crystal microcavities provide the first electrically tunable platform for investigating supersolid exciton-polariton condensates. Unlike previous systems, their optical properties can be dynamically controlled with an external voltage, offering unprecedented flexibility for studying quantum phases of light and matter and paving the way toward practical quantum photonic devices.

Faculty of Physics at the University of Warsaw

Physics and astronomy at the University of Warsaw appeared in 1816 as part of the then Faculty of Philosophy. In 1825, the Astronomical Observatory was established. Currently, the Faculty of Physics at the University of Warsaw consists of the following institutes: Experimental Physics, Theoretical Physics, Geophysics and the Department of Mathematical Methods in Physics. The research covers almost all areas of modern physics on scales from quantum to cosmological. The Faculty's research and teaching staff consists of over 250 academic teachers. About 1350 students and over 150 doctoral students study at the Faculty of Physics UW. The University of Warsaw is among the 150 best universities in the world, educating in the field of physics according to Shanghai's Global Ranking of Academic Subjects.

SCIENTIFIC PUBLICATION:

Marcin Muszyński, Pavel Kokhanchik, Rafał Mirek, Darius Urbonas, Pietro Tassan, Piotr Kapuściński, Przemysław Oliwa, Ioannis Georgakilas, Thilo Stöferle, Rainer F. Mahrt, Michael Forster, Ullrich Scherf, Dmitriy Dovzhenko, Rafał Mazur, Przemysław Morawiak, Wiktor Piecek, Przemysław Kula, Barbara Piętka, Dmitry Solnyshkov, Guillaume Malpuech, Jacek Szczytko, *Observation of a supersolid phase in a spin-orbit coupled exciton-polariton Bose-Einstein condensate,* Science Advances **12**, eaee4875 (2026)
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A supersolid is an extraordinary state of matter that combines superfluidity with the spontaneous formation of a periodic, crystal-like structure. (Visualisation: Marcin Muszyński, Faculty of Physics University of Warsaw)

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