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Researchers raise the temperature for exciton condensation

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New Cornell-led research is pointing the way toward an elusive goal of physicists—high-temperature superfluidity—by exploring excitons in atomically thin semiconductors.

An exciton, which consists of a bound electron-hole pair, is a mobile bundle of energy that is able to exist in insulators and semiconductors. By using excitons with large binding energy, the researchers were able to increase the condensation temperature a hundredfold, from about 1 kelvin (-457.87 F) to about 100 kelvins (-279.67 F). Room temperature is around 295 kelvins.

While high-temperature superfluidity remains to be demonstrated, this robust Bose-Einstein condensate could result in brighter, more efficient lighting systems that outshine conventional LEDs.

The research team's paper, "Evidence of High-Temperature Exciton Condensation in 2-D Atomic Double Layers," was published Oct. 2 in *Nature*.

"The realization of an exciton condensate at much higher temperature than earlier studies provides an exciting opportunity to explore this quantum phase of matter at significantly less stringent experimental conditions," said postdoctoral researcher Zefang Wang, Ph.D. '18, the paper's lead author.

Quantum particles fall into two fundamental classes—bosons and fermions—that are differentiated by their spin. Bosons are the socializers, happy to be clustered together; fermions are like passengers on a bus who don't want to sit near each other. One type of boson is the exciton, which is comprised of two fermions—an electron paired with an electron hole, which is the absence of an electron in the system—that manage to overcome their antisocial tendencies and cling happily to other particles.

Excitons in 2-D atomic double layers are also light in mass and tiny in size, so they can be packed densely together—much more so than atoms and excitons in conventional materials—and behave collectively, which could allow flow without viscosity or resistance. These are ideal conditions for achieving condensation and superfluidity at higher temperatures.

"Quantum states of matter are usually pretty fragile. That's why you have to cool them down to very, very low temperature in a lab, to protect them and isolate them from the environment," said Kin Fai Mak, associate professor of physics in the College of Arts and Sciences, the paper's co-senior author along with Jie Shan, professor of applied and engineering physics in the College of Engineering.

"But," Mak said, "if you can create a more robust quantum state of matter that lives happily at a high temperature, or even at ambient condition, then there are lots of things you can do with it."

One of those potential applications is optoelectronics. In conventional LEDs, excitons behave independently, rather than cooperatively, because they are not in a condensed state. But once condensed, the particles can collectively recombine and produce photons much more effectively.

"You can actually create much brighter, more energy-efficient light sources than conventional LEDs," Mak said.

The team took a decidedly "low-tech" approach to assembling their condensation layers: They used clear tape to peel off monolayers of atoms from crystals and restack them with the electrons and holes—separated by about 1 nanometer and aligned to maximize their attraction—forming social-loving bosons.

"One outstanding property of the condensate is that the bosons can flow without resistance," Mak said. "What it means is each layer by itself is a superconductor. So another route to creating a high-temperature superconductor is basically making this type of structure and measuring separately the resistance on the individual layer to see whether it has zero resistance. And we're working on this type of experiment."

More information: Zefang Wang et al. Evidence of high-temperature exciton condensation in two-dimensional atomic double layers, *Nature* (2019). DOI: 10.1038/s41586-019-1591-7

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