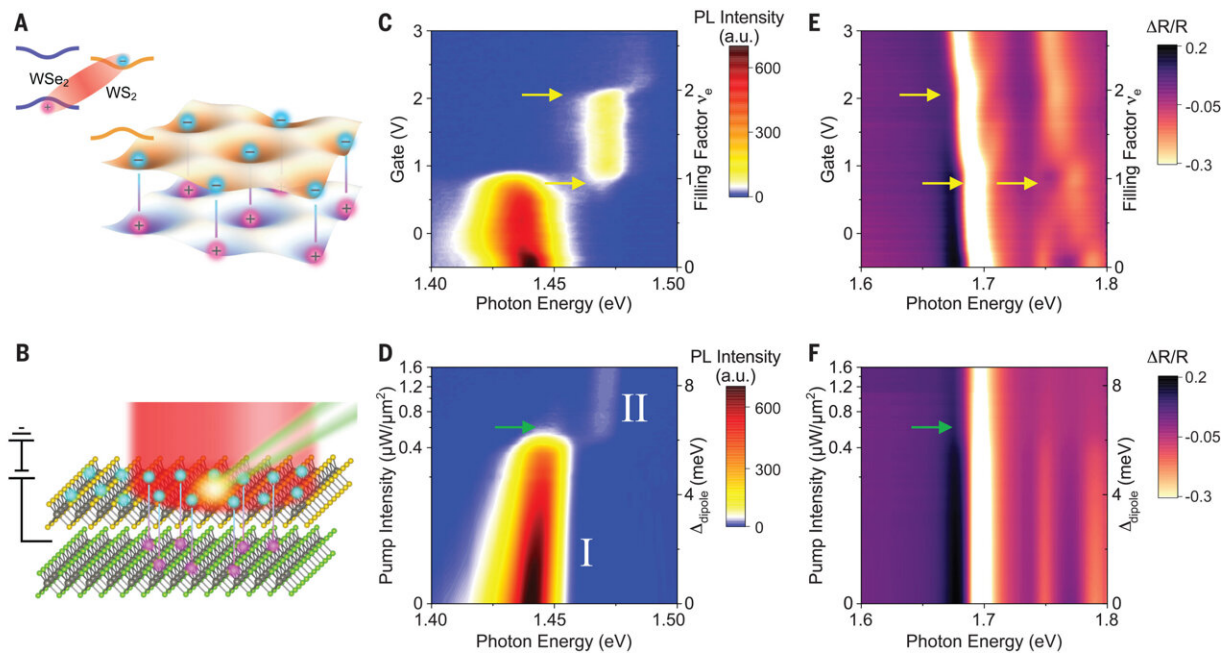


Physicists discover an exotic material made of bosons

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Bosonic correlated insulator. (A) Illustration of a bosonic correlated insulator consisting of interlayer excitons. Magenta spheres indicate holes and cyan spheres, electrons. (Inset) Type II band alignment of WSe₂/WS₂ heterostructure. (B) Schematics of continuous-wave pump-probe spectroscopy. The exciton and electron density are independently controlled by pump light and electrostatic gate. Red and green shading correspond to wide-field pump light and focused probe light, respectively. (C and E) Gate-dependent PL (C) and absorption (E) spectra of a 60°-aligned WSe₂/WS₂ moiré bilayer (device D1) at zero pump intensity. The PL peak shows a sudden blue shift at electron filling $\nu_e = 1$ and 2 (yellow arrows), where the absorption spectrum shows kinks and splitting. (D and F) Pump intensity-dependent PL (D) and absorption (F) spectra of device D1 at charge neutrality. Right axes show dipolar-interaction-induced interlayer

exciton energy shift Δ_{dipole} , which is approximately proportional to v_{ex} . The dominant PL peak in (D) at low and high pump intensity are labeled as peak I and II, respectively. All measurements are performed at a base temperature of 1.65 K. Credit: *Science* (2023). DOI: 10.1126/science.add5574

Take a lattice—a flat section of a grid of uniform cells, like a window screen or a honeycomb—and lay another, similar lattice above it. But instead of trying to line up the edges or the cells of both lattices, give the top grid a twist so that you can see portions of the lower one through it. This new, third pattern is a moiré, and it's between this type of overlapping arrangement of lattices of tungsten diselenide and tungsten disulfide where UC Santa Barbara physicists found some interesting material behaviors.

"We discovered a new state of matter—a bosonic correlated insulator," said Richen Xiong, a graduate student researcher in the group of UCSB condensed matter physicist Chenhao Jin, and the lead author of a paper that appears in the journal *Science*.

According to Xiong, Jin and collaborators from UCSB, Arizona State University and the National Institute for Materials Science in Japan, this is the first time such a material—a highly ordered crystal of bosonic particles called excitons—has been created in a "real" (as opposed to synthetic) matter system.

"Conventionally, people have spent most of their efforts to understand what happens when you put many fermions together," Jin said. "The main thrust of our work is that we basically made a new material out of interacting bosons."

Bosonic, correlated, insulator

Subatomic particles come in one of two broad types: fermions and bosons. One of the biggest distinctions is in their [behavior](#), Jin said.

"Bosons can occupy the same [energy level](#); fermions don't like to stay together," he said, "Together, these behaviors construct the universe as we know it."

Fermions, such as electrons, underlie the matter with which we are most familiar as they are stable and interact through the electrostatic force. Meanwhile bosons, such as photons (particles of light), tend to be more difficult to create or manipulate as they are either fleeting or do not interact with each other.

A clue to their distinct behaviors is in their different quantum mechanical characteristics, Xiong explained. Fermions have half-integer "spins" such as $1/2$ or $3/2$ et cetera, while bosons have whole integer spins (1, 2, etc.). An [exciton](#) is a state in which a negatively charged electron (a fermion) is bound to its positively charged opposite "hole" (another fermion), with the two half-integer spins together becoming a whole integer, creating a bosonic particle.

To create and identify excitons in their system, the researchers layered the two lattices and shone strong lights on them in a method they call "pump-probe spectroscopy." The combination of particles from each of the lattices (electrons from the [tungsten disulfide](#) and the holes from the tungsten diselenide) and the light created a favorable environment for the formation of and interactions between the excitons while allowing the researchers to probe these particles' behaviors.

"And when these excitons reached a certain density, they could not move anymore," Jin said. Thanks to [strong interactions](#), the collective behaviors of these particles at a certain density forced them into a crystalline state, and created an insulating effect due to their immobility.

"What happened here is that we discovered the correlation that drove the bosons into a highly ordered state," Xiong added. Generally, a loose collection of bosons under ultracold temperatures will form a condensate, but in this system, with both light and increased density and interaction at relatively higher temperatures, they organized themselves into a symmetric solid and charge-neutral insulator.

The creation of this exotic state of matter proves that the researchers' moiré platform and pump-probe spectroscopy could become an important means for creating and investigating bosonic materials.

"There are many-body phases with fermions that result in things like superconductivity," Xiong said. "There are also many-body counterparts with bosons that are also exotic phases. So what we've done is create a platform, because we did not really have a great way to study bosons in real materials." While excitons are well-studied, he added, there hadn't until this project been a way to coax them to interacting strongly with one another.

With their method, according to Jin, it could be possible to not only study well-known bosonic particles like excitons but also open more windows into the world of condensed matter with new bosonic materials.

"We know that some materials have very bizarre properties," he said. "And one goal of condensed [matter](#) physics is to understand why they have these rich properties and find ways to make these behaviors come out more reliably."

More information: Richen Xiong et al, Correlated insulator of excitons in WSe₂ /WS₂ moiré superlattices, *Science* (2023). [DOI: 10.1126/science.add5574](https://doi.org/10.1126/science.add5574)

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