Zernike Colloquium

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16:00h
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Controlling and Protecting Quasiparticles in 2-D Quantum Materials

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In this presentation, we explore how new types of particle-like excitations, known as quasiparticles, can be controlled and stabilized within ultra-thin materials—so-called 2-D solids—by creating carefully designed atomic hetero structures. Quasiparticles are not fundamental particles like electrons or protons, but instead arise from the complex interactions between particles in a solid. They include phenomena such as excitons (bound states of electrons and holes), superconducting states, and polaritons (hybrids of light and matter), as well as more exotic systems like Tomonaga-Luttinger liquids. Each of these quasiparticles emerges due to the unique symmetries of the crystal structure.

By engineering precise atomic-scale patterns (heterostructures) within 2-D materials, we can not only create new types of quasiparticles but also protect and manipulate them for potential applications. For instance, heterostructures that confine matter in zero, one, or two dimensions allow us to control these emergent properties with unprecedented precision.

In the first part of my talk, I will focus on excitons—quasiparticles formed by electron-hole pairs. We have investigated excitons in stacks of the 2-D materials $MoSe_2$ and WS_2, which are promising candidates for next-generation quantum technologies. These stacks potentially host Bose-Einstein Condensates, a state where excitons behave like a collective whole. By coupling these excitons to nanoscale light traps (plasmonic cavities), we have been able to study how they emit light, particularly "dark excitons," which don't normally emit photons. Additionally, we provide evidence of excitons traveling coherently over distances when coupled to plasmons, forming a new hybrid quasiparticle called a plexciton.

In the second part of the talk, I will explore defects in 2-D materials that act as quantum emitters, which are critical for applications like quantum sensing. Using a high-precision technique called photo Scanning Tunneling Microscopy (photo-STM), we examine how tiny imperfections in the crystal structure of $MoSe_2$ and WS_2—such as missing atoms—create unique energy states within the material's band structure. These defects can emit single photons, which is a key requirement for quantum technologies. We have also shown how replacing individual atoms in the structure with elements like carbon or cobalt creates well-defined systems similar to color centers in diamonds, opening the door to new sensing and computational devices.

Finally, I will discuss how certain 1-D defects in 2-D materials—mirror twin boundaries—act as atomically thin conductors, which display a remarkable transition into a quantum liquid state at low temperatures. These systems give us new insights into highly correlated electron states, including superconductivity.

Coffee from 15:30h
Drinks & Snacks after

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