Physicists Report Bose-Einstein Condensation of Cold Excitons

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Bose-Einstein condensates are enigmatic states of matter in which huge numbers of particles occupy the same quantum state and, for all intents and purposes, lose their individual identity. Predicted long ago by Albert Einstein and Satyendranath Bose, these bizarre condensates have recently become one of the hottest topics in physics research worldwide. Now, physicists at the California Institute of Technology and the University of Texas at Austin have created a sustained Bose-Einstein condensate of excitons, unusual particles that inhabit solid semiconductor materials.

By contrast, most recent work on the phenomenon has focused on supercooled dilute gases, in which the freely circulating atoms of the gas are reduced to a temperature where they all fall into the lowest-energy quantum state. The new Caltech-UT Austin results are being published this week in the journal Nature.

According to Jim Eisenstein, who is the Roshek Professor of Physics at Caltech and co-lead author of the paper, exciton condensation was first predicted over 40 years ago but has remained undiscovered until now because the excitons usually decay in about a billionth of a second. In this new work, the researchers created stable excitons, which consist of an electron in one layer of a sandwich-like semiconductor structure bound to a positively charged "hole" in an adjacent layer. A hole is the vacancy created when an electron is removed from a material.

Bound together, the electron and hole form a "boson," a type of particle that does not mind crowding together with other similar bosons into the same quantum state. The other type of particle in the universe, "fermions," include individual protons and electrons and neutrons. Only one fermion is allowed to occupy a given quantum state.

The picture is complex, but if one imagines two layers of material, one containing some electrons, the other completely empty, the results are somewhat easier to visualize. Begin by transferring half of the electrons from the full layer to the empty one. The resulting situation is equivalent to a layer of electrons in parallel with a layer of holes. And because the electron has a negative charge, the taking away of an electron means that the hole in which it once existed has a positive charge.

The difficult thing about the procedure is that the layers have to be positioned just right and a large magnetic field has to be applied just right in order to avoid swamping the subtle binding of the electron and hole by other forces in the system. The magnetic field is also essential for stabilizing the excitons and preventing their decay.

Eisenstein says that the simplest experiment consists of sending electrical currents through the two layers in opposite directions. The "smoking gun" for exciton condensation is the absence of the ubiquitous sideways force experienced by charged particles moving in magnetic fields. Excitons, which have no net charge, should not feel such a force.

One mystery that remains is the tendency of the excitons to dump a small amount of energy when they move. "We find that, as we go toward lower temperatures, energy dissipation does become smaller and smaller," Eisenstein says. "But we expected no energy dissipation at all.

"Therefore, this is not really an ideal superfluid--so far it is at best a bad one."

The other author of the paper is Allan MacDonald, who holds the Sid W. Richardson Foundation Regents Chair in physics at UT Austin and is a specialist in theoretical condensed matter physics.

Source: California Institute of Technology