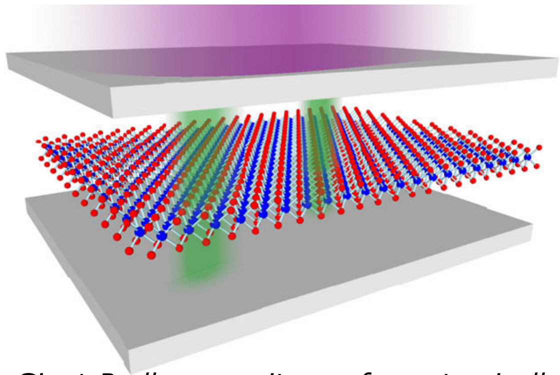
Research highlight

Research in the Niels Bohr Professorship for Many-Body Quantum Optics at Aarhus University describes interactions between giant quantum states of electrons in semiconductors.

The theory of electromagnetism, as dating back to the mid 19th century, explains the physics of light in vacuum and nearly as well in air. It is relatively simple because it does not dependent on how much light there is. In other words, photons, the elementary quanta of light, propagate independently from each other.



Giant Rydberg excitons of an atomically thin semiconductor can generate effective interactions between photons (green) in a planar optical cavity.

A new situation can arise when a beam of light falls onto a semiconductor. While such a material typically contains electrons that do not contribute the its electrical conductivity, incident light can kick some of these electrons and promote them to mobile states of higher energy — a process which is vital to the vast array of our modern semiconductor technology. Each of these excited electrons leaves behind a positively charged hole to which it remains attracted and may form a so-called exciton. Excitons can be considered as solid-state analogs of hydrogen atoms, and just like their atomic counterparts experience mutual interactions. This opens up a way to affect the behavior of photons. When a photon moves through a semiconductor, it can be absorbed to create an exciton, which re-emits light when it decays. The emitted photon in turn can create another exciton, and so on. Now imagine that two photons in a semiconductor both get converted into excitons, which, when they interact, change their state and are finally converted back into photons. The resulting change of the two-photon quantum state can be seen as an effective photon-photon interaction. In most cases, however, this effect is very weak and effective only at close distances, because excitons are extremely small and very many of them are needed to make their interactions noticeable.

A few years ago, spectroscopic measurements on a special type of semiconductor revealed the existence of a different type of exciton with gigantic dimensions. In these so-called Rydberg excitons, the electron and hole orbit each other at an astonishing radius which is about a billion times larger than that of the atoms in the material. With such an enormous extent, the realised excitons are very sensitive to perturbations, which lets them interact very strongly even at large distances well beyond their actual size.

The presence of such gigantic excitons dramatically changes the way how light propagates in a semiconductor. The theoretical results by the Aarhus group show that Rydberg excitons could indeed be used to generate effective photonic interactions, much larger than those in conventional semiconductors. This exaggerated optical response provides a promising outlook for nonlinear optics and is expected to make light behave as a fluid or molasses. Besides offering a platform for such exotic phenomena, the strength and long range of the optical nonlinearities suggest viable applications to low-energy optical switching, and even to manipulating light at the level of single quanta.

Giant optical nonlinearities from Rydberg excitons in semiconductor microcavities, V. Walther, R. Johne and T. Pohl, Nature Comm. **9**, 1309 (2018)