Physicists control transitions between different states of matter

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An international group of physicists managed for the first time to experimentally observe the transition between two states of matter, propagating polariton-solitons and a Bose-Einstein condensate. Furthermore, physicists developed a theoretical model to explain such transitions and found a way to switch between the states by changing the laser pumping power in the polariton formation process. The results are published in *Physical Review Letters*.

Nonlinear systems are extensively studied in a wide range of physical systems, notably in photonics. In such systems, interactions between particles lead to a whole range of novel effects such as nonlinear transitions between different basic states of matter including polaritons, solitons and Bose-Einstein condensates.

"Polaritons are quasiparticles formed due to the hybridisation between matter and light. Once they are supplied with additional energy and densities, they form collective excitations, solitons. A soliton has the ability to propagate in space, preserving its shape. In other words, despite being a collective state consisting of many particles, a soliton behaves like a single particle. At the same time, a Bose-Einstein condensate is a quantum state of matter where all particles, in our case polaritons, populate the ground state of the system with minimal energy. Usually, the ground state is extended through all the area of the system under study. The soliton and Bose-Einstein condensate are two widely different regimes, and we managed to observe the transition between them," explains Ivan Shelykh, head of the International Laboratory of

Photoprocesses in Mesoscopic Systems at ITMO University in St Petersburg.

The group composed of Professor Maurice Skolnick, Dr. Dmitry Krizhanovskii and Dr. Maksym Sich from the University of Sheffield obtained the experimental data, while the theoretical group lead by Ivan Shelykh developed a theoretical model for quantitative description of the experiment. "First we had to create polaritons," says Maurice Skolnick. "This required fabrication of initial semiconductor structures with precisely defined features. Next we shone a laser on the structure at temperatures as low as 4 degrees Kelvin, created polaritons and detected the light that they emit."

The researchers observed that an increase in the laser pumping power triggered nonlinear effects in the system. "Increasing the laser power, we create more and more particles, which start to interact with each other. Therefore, the whole system goes into a nonlinear regime. Separate polaritons form solitons, which then transfer into a Bose-Einstein condensate. Although it was clear we had obtained some interesting results, without a good theory we would have never understood what they actually meant," Skolnick continues.

The theoretical model explaining the experimental data was developed by Ivan Shelykh's group. This collaborative work was carried out with the support of a Megagrant of the Ministry of Education and Science of the Russian Federation on the study of hybrid light states. "The Megagrant gave us the ability to initiate a productive collaboration with leading experimenters from Sheffield. During a year of our collaborative work we published two major papers, combining experiments with theory," Shelykh notes.

Further research plans include decreasing size of nonlinear transitions systems to the subwavelength scale. Maurice Skolnick described perspectives of the study: "Now this work has mainly fundamental significance as we described completely new physics. Yet once we make miniature devices, it will be possible to use nonlinear transitions between different states of matter for telecommunications or, for example, for the creation of new lasers."

More information: M. Sich et al, Transition from Propagating Polariton Solitons to a Standing Wave Condensate Induced by Interactions, *Physical Review Letters* (2018). DOI: 10.1103/PhysRevLett.120.167402

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