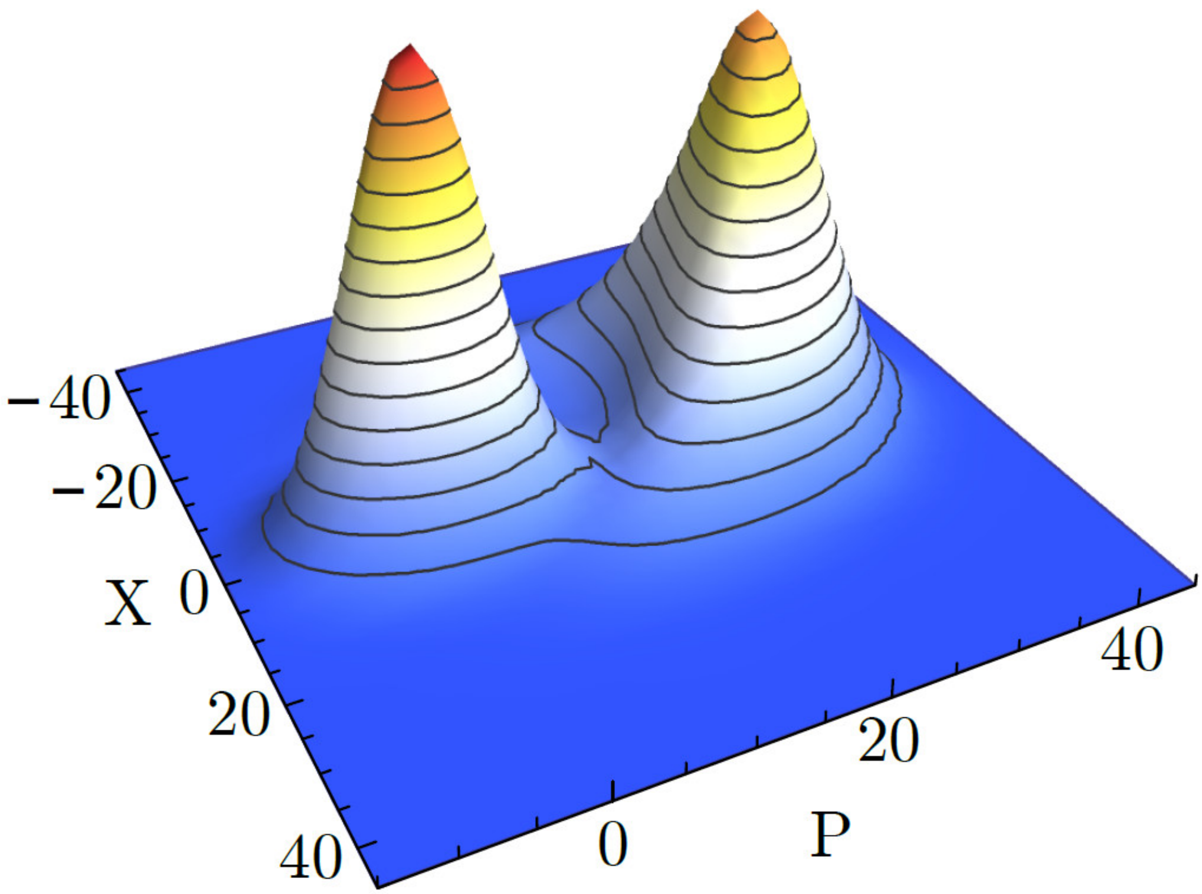
Quantum phase transition observed for the first time

February 2 2017



Probability distribution showing the equal likelihood for the cavity being transparent and opaque at the critical point. Credit: J. Fink

A group of scientists led by Johannes Fink from the Institute of Science and Technology Austria (IST Austria) reported the first experimental observation of a first-order phase transition in a dissipative quantum system. Phase transitions include such phenomena as the freezing of water at the critical temperature of 0 degrees Celsius. However, phase transitions also occur at the quantum mechanical level, where they are still relatively unexplored by researchers.

One example of a phase transition at the quantum level is the photon-blockade breakdown, which was only discovered two years ago. During photon blockade, a photon fills a cavity in an optical system and prevents other photons from entering the same cavity until it leaves, hence blocking the flow of photons. But if the photon flux increases to a critical level, a quantum phase transition is predicted: The photon blockade breaks down, and the state of the system changes from opaque to transparent. This specific phase transition has now been experimentally observed by researchers who, for the first time, met the very specific conditions necessary to study this effect.

During a phase transition, the continuous tuning of an external parameter, for example temperature, leads to a transition between two robust steady states with different attributes. First-order phase transitions are characterized by a coexistence of the two stable phases when the control parameter is within a certain range close to the critical value. The two phases form a mixed phase in which some parts have completed the transition and others have not, as in a glass containing ice water. The experimental results that Fink and his collaborators will publish in the journal *Physical Review X* give insight into the quantum mechanical basis of this effect in a microscopic, zero-dimensional system.

Their setup consisted of a microchip with a superconducting microwave resonator acting as the cavity and a few superconducting qubits acting as the atoms. The chip was cooled to a temperature astoundingly close to absolute zero—0.01 Kelvin—so that thermal fluctuations did not play a role. To produce a flux of photons, the researchers then sent a continuous microwave tone to the input of the resonator on the chip. On the output side, they amplified and measured the transmitted microwave flux. For certain input powers, they detected a signal flipping stochastically between zero transmission and full transmission, proving the expected coexistence of both phases had occurred. "We have observed this random switching between opaque and transparent for the first time and in agreement with theoretical predictions," says lead author Johannes Fink from IST Austria.

Potential future applications include memory storage elements and processors for quantum simulation. "Our experiment took exactly 1.6 milliseconds to complete for any given input power. The corresponding numerical simulation took a couple of days on a national supercomputer cluster. This gives an idea why these systems could be useful for quantum simulations," Fink explains.

Johannes Fink came to IST Austria in 2016 to start his working group on Quantum Integrated Devices. The main objective of his group is to advance and integrate quantum technology for chip-based computation, communication, and sensing.

More information: J. M. Fink et al, Observation of the Photon-Blockade Breakdown Phase Transition, *Physical Review X* (2017). DOI: 10.1103/PhysRevX.7.011012

Provided by Institute of Science and Technology Austria