An ultradilute quantum liquid made from ultra-cold atoms

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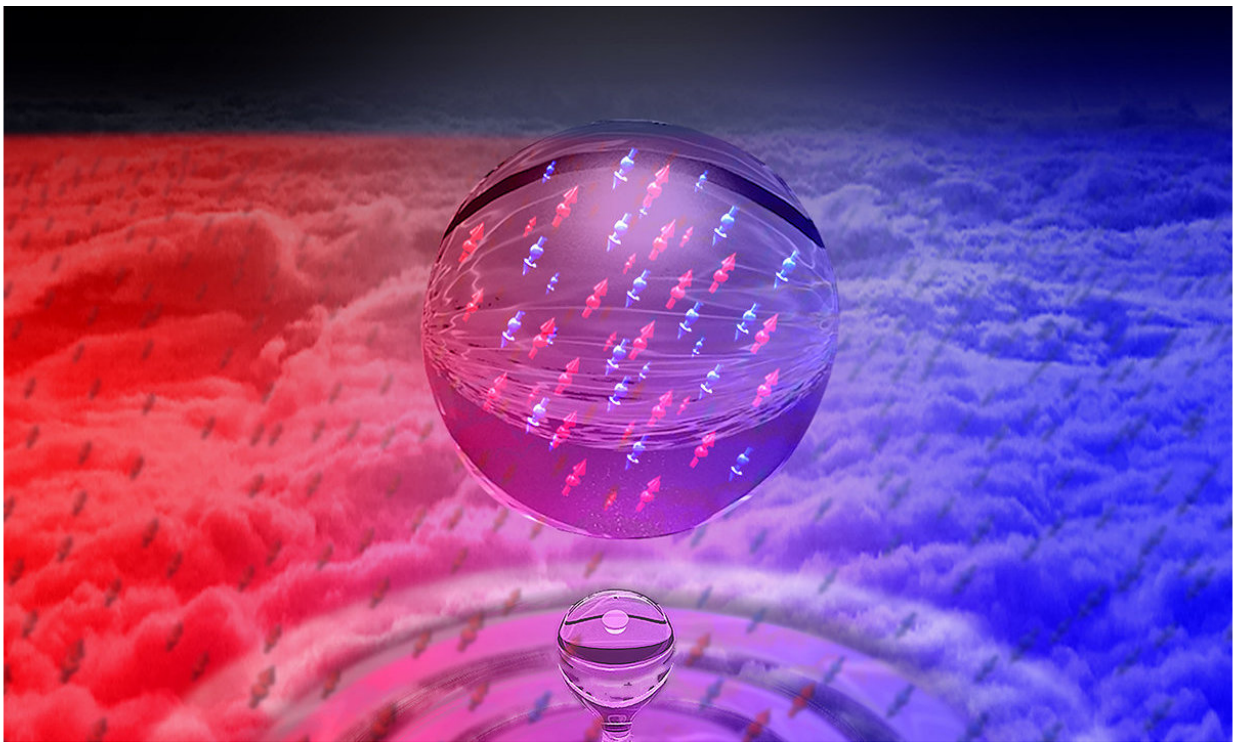


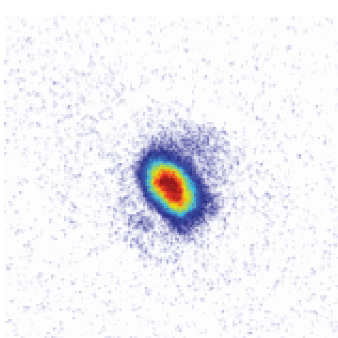
Artistic view of a quantum liquid droplet formed by mixing two gases of ultracold potassium atoms. Credit: ICFO/ Povarchik Studios Barcelona

ICFO researchers created a novel type of liquid 100 million times more dilute than water and 1 million times thinner than air. The experiments, published in *Science*, exploit a fascinating quantum effect to produce droplets of this exotic phase of matter.

Liquids and gases are two different phases of matter. While gases are dilute, compressible and take the size of their container, liquids are dense, have a fixed volume and, in small quantities, form droplets. These are ensembles of particles that remain bound by themselves, and have a free surface that separates them from the environment. By increasing the temperature, it is possible to induce a phase transition between liquid and gas. This is what happens when boiling water in a pan.

But are gases always dilute and liquids always dense? Although in normal conditions the answer to this question is yes, things can become very different at ultra-low temperatures. In a recent study published in *Science*, ICFO researchers created a liquid 100 million times more dilute than water and 1 million times thinner than air.

The team cooled down a gas of potassium atoms to -273.15 degrees Celsius, very close to absolute zero. Although at these temperatures, the atoms behave as waves and follow the rules of quantum mechanics, they still conserve an intrinsic property of a gas: They expand in the absence of containment. In contrast, when two such gases are mixed together and attract each other, the atoms instead form liquid droplets. Cesar Cabrera, first author of the study, says, "In many respects, our potassium droplets are very similar to those of water: They have their own size and shape, regardless of where we put them, but they are much colder and their properties are quantum."



A mixture of two ultracold gases that attract each other can form an ultra-dilute liquid, which remains self-bound in a droplet even in the absence of any confinement. Credit: ICFO

Indeed, the existence of these liquid droplets is entirely due to quantum fluctuations, a fascinating intrinsic quantum effect. Furthermore, due to quantum mechanics, the atoms forming a droplet cannot stay completely at rest inside it. This is forbidden by Heisenberg's uncertainty principle. They thus remain in perpetual motion, leading to a quantum pressure that makes very small droplets unstable and evaporates them into an expanding gas. Prof. Leticia Tarruell says, "These droplets are fascinating macroscopic objects: even if they are made up of thousands of particles, their behavior is still fully determined by quantum fluctuations and correlations. By observing the phase transition between liquid and gas, we measure very precisely these surprising quantum effects."

The unique combination of diluteness and "quantumness" makes quantum liquid droplets an ideal testbed to better understand quantum systems made of many interacting particles, and comprehend features they share with liquid Helium, neutron stars or other complex materials.

More information: Quantum liquid droplets in a mixture of Bose-Einstein condensates, C. R. Cabrera, L. Tanzi, J. Sanz, B. Naylor, P. Thomas, P. Cheiney and L. Tarruell, *Science*, 14 December 2017.

Provided by ICFO