



PRESS RELEASE

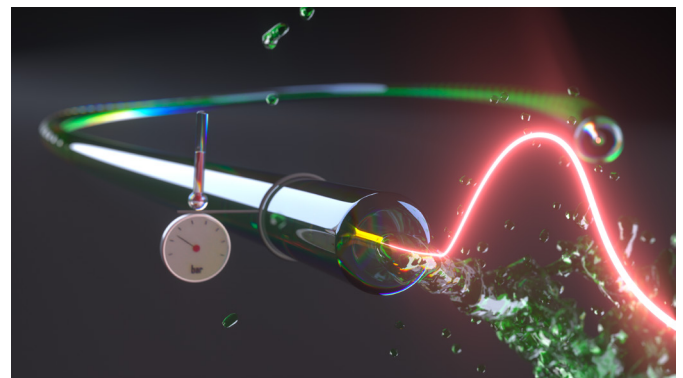
Light and sound waves reveal negative pressure

ERLANGEN, 25 SEPTEMBER 2023

Negative pressure is a rare and challenging-to-detect phenomenon in physics. Using liquid-filled optical fibers and sound waves, researchers at the Max Planck Institute for the Science of Light (MPL) in Erlangen have now discovered a new method to measure it. In collaboration with the Leibniz Institute of Photonic Technologies in Jena (IPHT), the scientists in the Quantum Optoacoustics research group, led by Birgit Stiller, can gain important insights into thermodynamic states.

As a physical quantity pressure is encountered in various fields: atmospheric pressure in meteorology, blood pressure in medicine, or even in everyday life with pressure cookers and vacuum-sealed foods. Pressure is defined as a force per unit area acting perpendicular to a surface of a solid, liquid, or gas. Depending on the direction in which the force acts within a closed system, very high pressure can lead to explosive reactions in extrem cases, while very low pressure in a closed system can cause the implosion of the system itself. Overpressure always means that the gas or liquid pushes against the walls of its container from the inside, like a balloon expanding when more air is added. Regardless of whether it's high or low pressure, the numerical value of pressure is always positive under normal circumstances.

However, liquids exhibit a peculiar characteristic. They can exist in a specific metastable state corresponding to a negative pressure value. In this metastable state, even a tiny external influence can cause the system to collapse into one state or another. One can imagine it as sitting at the top of a roller coaster: the slightest touch on one side or the other sends you hurtling down the tracks. In their current research, the scientists are examining the metastable state of liquids with negative pressure. To achieve



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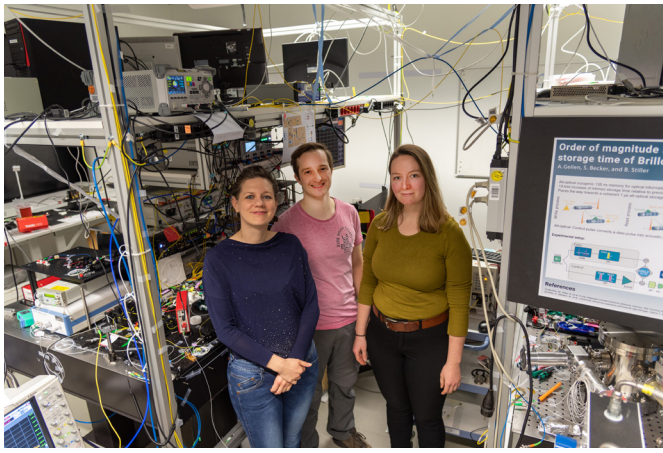
Artist's impression of a liquid-filled glass capillary.

ve this, the research team combined two unique techniques in a study published in *Nature Physics* to measure various thermodynamic states. Initially, tiny amounts - nanoliters - of a liquid were encapsulated in a fully closed optical fiber, allowing both highly positive and negative pressures. Subsequently, the specific interaction of optical and acoustic waves in the liquid enabled the sensitive measurement of the influence of pressure and temperature in different states of the liquid. Sound waves act as sensors for examining negative pressure values, exploring this unique state of matter with high precision and detailed spatial resolution.

The influence of negative pressure on a liquid can be envisioned as follows: According to the laws of thermodynamics, the volume of the liquid will decrease, but the liquid is retained in the glass fiber capillary by adhesive forces, much like a water droplet sticking to a finger. This results in a "stretching" of the liquid. It is pulled apart and behaves like a rubber band being stretched. Measuring this exotic state typically requires complex equipment with heightened safety precautions. High pressures can be hazardous endeavors, particularly with toxic liquids. Carbon disulfide, used by the researchers in this study, falls into this category. Due to this complication, previous measurement



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(From left to right) Research group leader Birgit Stiller in the lab with Andreas Geilen and Alexandra Popp

setups for generating and determining negative pressures have required significant laboratory space and even posed a disturbance to the system in the metastable state. With the method presented here, the researchers have instead developed a tiny, simple setup in which they can make very precise pressure measurements using light and sound waves. The fiber used for this purpose is only as thick as a human hair.

"Some phenomena which are difficult to explore with ordinary and established methods can become unexpectedly accessible when new measurement methods are combined with novel platforms. I find that exciting," says Dr. Birgit Stiller, head of the Quantum Optoacoustics research group at MPL. The sound waves used by the group can detect temperature, pressure, and strain changes very sensitively along an optical fiber. Furthermore, spatially resolved measurements are possible, meaning that the sound waves can provide an image of the situation inside the optical fiber at centimeter-scale resolution along its length. "Our method allows us to gain a deeper understanding of the thermodynamic dependencies in this unique fiber-based system," says Alexandra Popp, one of the two lead authors of the article. The other lead author, Andreas Geilen, adds: "The measurements revealed some surprising effects. The observation of the negative pressure regime becomes abundantly clear when looking at the frequency of the sound waves."

The combination of optoacoustic measurements with tightly sealed capillary fibers enables new discoveries regarding the monitoring of chemical reactions in toxic liquids within otherwise difficult-to-investigate materials and microreactors. It can penetrate new, hard-to-access areas of thermodynamics. "This new

platform of fully sealed liquid core fibers provides access to high pressures and other thermodynamic regimes," says Prof. Markus Schmidt from IPHT in Jena, and Dr. Mario Chemnitz, also from IPHT in Jena, emphasizes: "It is of great interest to investigate and even tailor further nonlinear optical phenomena in this type of fiber." These phenomena can unlock previously unexplored and potentially new properties in the unique thermodynamic state of materials. Birgit Stiller concludes: "The collaboration between our research groups in Erlangen and Jena, with their respective expertise, is unique in gaining new insights into thermodynamic processes and regimes on a tiny and easy-to-handle optical platform."

Original publication in Nature Physics: Geilen, A., Popp, A., Das, D. et al. "Extreme thermodynamics in nanolitre volumes through stimulated Brillouin–Mandelstam scattering"

DOI: [10.1038/s41567-023-02205-1](https://doi.org/10.1038/s41567-023-02205-1)

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Research group leader Birgit Stiller in the lab

Research at the Max Planck Institute for the Science of Light (MPL) covers a wide range of topics, including nonlinear optics, quantum optics, nanophotonics, photonic crystal fibres, optomechanics, quantum technologies, biophysics, and – in collaboration with the Max-Planck-Zentrum für Physik und Medizin – links between physics and medicine. MPL was founded in 2009 and is one of the over 80 institutes that make up the Max Planck Society, whose mission is to conduct basic research in the service of the general public in the natural sciences, life sciences, social sciences and the humanities.