Pop goes the plasma: Extreme conditions inside imploding bubbles

Photo courtesy Hangxun Xu and Ken Suslick

Plasma emission from collapsing bubbles: The imploding bubbles move around after each collapse, tracing out a lit path, like a person flinging their arm around while holding a flashlight.

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CHAMPAIGN, Ill. — High-intensity ultrasound waves traveling through liquid leave bubbles in their wake. Under the right conditions, these bubbles implode spectacularly, emitting light and reaching very high temperatures, a phenomenon called sonoluminescence. Researchers have observed imploding bubble conditions so hot that the gas inside the bubbles ionizes into plasma, but quantifying the temperature and pressure properties has been elusive.

In a paper published in the June 27 issue of Nature Physics, University of Illinois chemistry professor Kenneth S. Suslick and former student David Flannigan, now at the California Institute of Technology, experimentally determine the plasma electron density, temperature and extent of ionization.

Suslick and Flannigan first observed super-bright sonoluminescence in 2005 by sending ultrasound waves through sulfuric acid solutions to create bubbles.

“The energies of the populated atomic levels suggested a plasma, but at that time there was no estimate of the density of the plasma, a crucial parameter to understanding the conditions created at the core of the collapsing bubble,” said Suslick, the Marvin T. Schmidt Professor of Chemistry and a professor of materials science and engineering.

The new report uses the same setup, but now with a detailed analysis of the shape of the observed spectrum, which provides information on the conditions of the region around the atoms inside the bubble as it collapses.

“The temperature can be several times that of the surface of the sun and the pressure greater than that at the bottom of the deepest ocean trench,” Suslick said.

“What’s more, we were able to determine how these properties are affected by the ferocity with which the bubble collapses, and we found that the plasma conditions generated may indeed be extreme.”

The duo observed temperatures greater than 16,000 kelvins – three times the temperature on the surface of the sun. They also measured electron densities during bubble collapse similar to those generated by laser fusion experiments. However, Suslick emphasized that his group has not observed evidence that fusion takes place during sonoluminescence, as some have theorized possible.

In addition, the researchers found that plasma properties show a strong dependence on the violence of bubble implosion, and that the degree of ionization, or how much of the gas is converted to plasma, increases as the acoustic pressure increases.

"It is evident from these results that the upper bounds of the conditions generated during bubble implosion have yet to be established," Suslick said. "The observable physical conditions suggest the limits of energy focusing during the bubble-forming and imploding process may approach conditions achievable only by much more expensive means."

Suslick also is affiliated with the Beckman Institute of Advanced Science and Technology at Illinois.

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