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Scientists measure energy dissipation in a single cavitating bubble

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CHAMPAIGN, Ill. — Like fireflies, bubbles trapped and energized by ultrasound emit light in a periodic rhythm. By holding a single bubble of gas in a standing acoustic wave and driving it into pulsations, the bubble converts sonic energy into light with clocklike regularity. At the same time, the intense energy released by the implosive compression of the bubble rips molecules apart. Chemists at the University of Illinois at Urbana-Champaign have now quantified those effects in a single bubble.

"During compression, the gas inside the bubble is heated, just like the heating when a tire is pumping up. This energy is converted into light emission, chemical reactions and mechanical energy," said Kenneth S. Suslick, a William H. and Janet Lycan Professor of Chemistry at Illinois. "We were able to determine, for the first time, how much of the energy goes into the chemistry of the bubble, and establish an energy inventory during bubble collapse."

The experimental results – reported by Suslick and postdoctoral research associate Yuri Didenko in the July 25 issue of the journal Nature – have important implications for future work on the chemical and physical effects of ultrasound.

The ability of ultrasound to induce chemical reactions has been studied for industrial and medical applications, such as the breakdown of pollutants, development of medical imaging agents, and making catalysts to clean fuels. To truly harness this chemical process, however, scientists must first understand, and then control, where the energy is going.

Sonochemistry arises from acoustic cavitation – the formation, growth and implosive collapse of small gas bubbles in a liquid blasted with sound. The collapse of these cavitating bubbles generates intense local heating, forming a hot spot in the cold liquid with a transient temperature of about 9,000 degrees Fahrenheit, the pressure of about 1,000 atmospheres and the duration of about 1 billionth of a second.

For a rough comparison, these values correspond to the temperature of the surface of the sun, the pressure at the bottom of the ocean, and the lifetime of a lightning strike. Cavitation also is responsible for submarine propeller noise, for erosion of turbines, and for the noise that boiling water makes on the stove.

To study the energy dissipation during bubble collapse, Suslick and Didenko first generate a single bubble about the size of a red blood cell and draw it to the center of a spherical container where it becomes trapped in an acoustic field. Driven by ultrasound, the bubble will periodically grow and collapse. With each pulsation, the bubble emits a flash of light known as single bubble sonoluminescence.

While observing the light from a single bubble is easy, measuring the high-energy chemical reactions occurring within the tiny furnace is a challenge. To measure chemical properties, the researchers use sensitive fluorescent detection techniques.

"As the bubble expands, some of the gas in the surrounding solution diffuses into the bubble and becomes trapped," Suslick said. "Upon collapse, the gas is compressed and heated and undergoes chemical reactions."

Volatile molecules are ripped apart by the intense heat and pressure. "Nitrogen and oxygen molecules get turned into nitrogen oxides, just as they do in an internal combustion engine," Suslick said. "Likewise, water molecules are torn apart, generating hydroxyl radicals and hydrogen peroxide."

According to the researchers' measurements, less than 1 millionth of the bubble's energy is converted into light. A thousand times more energy goes into chemical reactions. But the largest part of the sonic energy is converted into mechanical energy, causing shock waves and motion in the surrounding liquid.

Sonochemistry already has found diverse applications, including making catalysts to remove sulfur from fuels and enhancing the chemical reactions used in making pharmaceuticals.

These findings not only will impact future experiments in sonochemistry, they also pose serious ramifications for the possibility of "sonofusion."

"Some researchers have suggested that conditions within a cavitating bubble might be hot enough and have high enough pressure to generate nuclear fusion," Suslick said. "But we’ve shown that chemistry occurs within a collapsing bubble, and that it limits the energy available during cavitation."

Whenever volatile molecules diffuse into the bubble, they will get shredded during collapse, and that takes energy out of the bubble, Suslick said. Temperatures reached during cavitation, for example, will be substantially reduced by the ensuing chemical reactions.

While sonofusion is therefore unlikely to occur in volatile liquids like water or acetone, "the possibility of fusion occurring in low volatility fluids – such as liquid metals and molten salts – cannot be ruled out at this time," Suslick said.

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