Inferno in a Bubble

Turning sound into light poses a tantalizing puzzle

By JOCELYN KAISER

Seth J. Putterman compares the blue speck of light glowing in a flask of water to a star in the sky. Indeed, the glow seems cool and soothing, like starlight on a summer evening.

Yet just as twinkling stars belie scorching suns, the speck, a tiny bubble of air blasted by sound waves, reaches hellish temperatures. The gas within may even hit millions of degrees Celsius — as hot as the inside of our sun.

Making light from sound, known as sonoluminescence, has generated a whirl of activity among some scientists in recent years. Creating the bubble entails little more than wrapping a flask of water in a couple of small loudspeakers, or transducers, then tuning the transducers to certain high frequencies. Yet somehow the sound energy gets condensed inside the bubble to one-trillionth of its original density. The bubble expands, collapses, and flashes 30,000 times per second, generating light that can be seen without darkening the room.

No theory can fully explain how this happens or why the bubble flashes so briefly and as steadily as a clock. Though research suggests that temperatures and pressures in the bubbles soar astronomically, no one has yet figured out exactly how high.

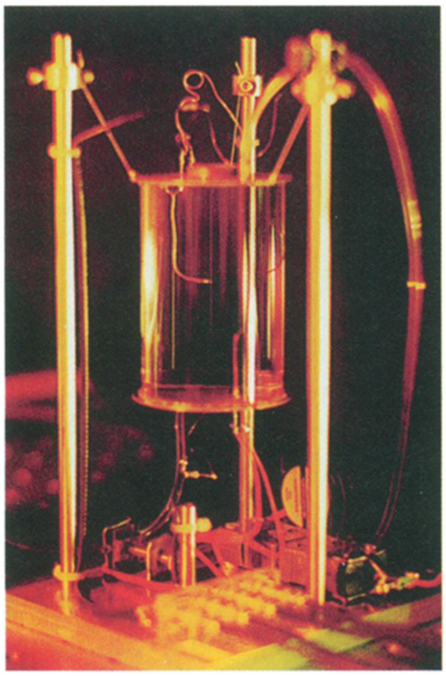
"If the bubble is as hot and as dense as we think it is, then we have a dense plasma. That's an interesting state of matter," says Putterman, a physicist at the University of California, Los Angeles.

Some scientists think the bubbles get so hot that they can use sonoluminescence to weld atoms of hydrogen isotopes. This process, known as fusion, holds the potential for providing a boundless source of energy. Meanwhile, just trying to understand what happens in the bubble is raising questions more quickly than researchers can answer them.

"You have to keep in mind that nobody knows, really, what is going on in this thing," says Michael Moran, an experimental physicist at Lawrence Livermore (Calif.) National Laboratory.

Scientists have known about sonoluminescence since 1934, when two German physicists aimed sound waves at water and created clouds of bubbles that gave off light. Researchers knew then that collapsing bubbles could create high temperatures and pressures, a phenomenon known as acoustic cavitation. More insights came in 1987, when chemists Kenneth S. Suslick and Edward B. Flint of the University of Illinois at Urbana-Champaign made light-emitting vapor bubbles by sending ultrasonic waves through liquid hydrocarbons such as dodecane (SN: 10/10/87, p.229).

By examining the spectrum of the emitted light, the Illinois team showed that the vapor within the bubbles reached remarkably high temperatures — up to 5,000°C, or nearly as hot as the sun's surface. They suggested that the bubbles' collapse created microscopic "hot spots" where vapor molecules broke apart, giving off light.



R. Hiller and S. Putterman/UCLA

Pure noble gases, as well as air, can give off sonoluminescent light. Here, a bubble of xenon in water flashes in sync with sound waves from the transducers at the ends of the glass cylinder.

These clouds of bubbles formed randomly and erratically, making precise studies difficult. In 1988, however, physicists D. Felipe Gaitan and Lawrence A. Crum, then at the University of Mississippi in Oxford, found a way to make a single bubble that alternately grew, then caved in, giving off a flash of light with each collapse. They did this by removing most dissolved air from a flask of water, then tuning high-pitched sound waves to trap the bubble in the liquid.

Putterman and his colleagues at UCLA homed in on these bubbles soon afterward, pinning down their diameter — each bubble expands to 50 micrometers and shrinks to less than 2 micrometers — and how quickly they formed (SN: 5/11/91, p.292). To their amazement, they found that the flash was too brief to measure. At most, it lasted fifty-trillionths of a second — 1,000 times faster than bubble theory predicted. Surprisingly, the flashes appeared to be steady and in sync with the sound waves.

Putterman and UCLA's Robert J. Hiller looked at the spectrum of emissions and found something peculiar. While multiple bubbles gave off a light profile corresponding to the liquid's chemical bonds, single bubbles didn't. What's more, the light from a single bubble reached into the ultraviolet, indicating temperatures of at least 72,000°C, more than 10 times what Suslick had seen.

Putterman concluded that while the single bubble began its collapse according to conventional theories of fluid motion, something very different must account for the light.

Trying to explain just what happens when the bubble flashes has kept several theorists busy over the past few years. "There are probably 10 different models right now," says Crum, now at the University of Washington in Seattle.

Many of them begin with a notion Putterman's group proposed — that as the bubble collapse triggered by sound waves concentrates energy within a tiny core, spherical shock waves occur. A shock wave takes place when material moves faster than the sound traveling through it. In sonoluminescence, the collapse may send the bubble wall crashing in on itself at supersonic speeds, touching off shock waves that converge and then explode outward.

These waves would create tremen-

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dous temperatures and pressures, but they don't tell the whole story. Still unexplained is the mechanism that generates the light. Some researchers think the gas becomes a plasma, a super-hot cloud of electrons and particles that emits light. If so, temperatures could reach more than 1,000,000°C.

Not everyone thinks the bubble's contents get that hot, however. Lothar Frommhold of the University of Texas at Austin and Anthony Atchley of the Naval Postgraduate School in Monterey, Calif., propose that the light could come from collisions between neutral molecules, not electrons. "I can explain the amount of light emitted with an assumption of only 10,000° or 20,000°," Frommhold says.

His and Atchley's theory may also explain another mystery reported by Hiller, Putterman, and their group in the Oct. 14, 1994 Science: Small amounts of noble gases dramatically enhance the bubble's glow (SN: 10/15/94, p.247).

Others claim they can explain the light without a shock wave. Chemist Thierry Lepoint of the Institut Meurice in Brussels, Belgium, and his team propose that the bubble's oscillations inject tiny jets of liquid carrying electric charge into the bubble, and these jets emit light.

Robert Hickling of the University of Mississippi proposes that high pressures cause the water to freeze, and the light comes from cracking ice. In the Nov. 21, 1994 Physical Review Letters, he suggested that a shock wave could initiate this process, but he told Science News he now thinks the idea wouldn't require a shock wave.

And before his death last year, UCLA physicist and Nobelist Julian Schwinger proposed that the bubble's radiation could come from a subtle quantum effect involving electrons. He predicted temperatures of 100,000°C. The theory is "very, very intricate," Putterman says, and "extremely interesting." No one has tested the idea yet, but at least a few theorists are trying to develop it further, Suslick says.

In fact, the same holds for all the theories. With only ballpark figures for the bubble's smallest radius and the timing of the flashes, and with indirect measurements of temperatures, there's not much experimental evidence to support any one hypothesis. Scientists don't even know whether the bubbles emit X rays, a sign of very high temperatures. Water absorbs X rays, making it futile to try to detect them from outside the flask.

"All the mechanisms get down to the point where you've got a gas really hot and the molecules are colliding with each other," Crum says. "So when you get it down to the details of whether it is the electrons giving off the light, or the molecules colliding with each other, or electrical discharge, you kind of blur things and people can calculate whatever they want."

Many scientists agree, however, that the imploding shock wave-plasma theory offers the most plausible explanation to date. "It's a nice, simple little thing, and it appears to work," Crum says.

The shock wave idea is seductive, too, because the sky-high temperatures and pressures it predicts in the bubble could set off fusion. That is, conditions might be sufficient to combine atoms of the hydrogen isotopes deuterium and tritium, yielding helium nuclei and energy. The reaction would also produce neutrons, which researchers look for as a sign that fusion is occurring.

Using fusion as a power source remains a major goal of modern physics. Researchers have worked for years on billion-dollar projects like the Tokomak magnetic confinement apparatus at Princeton University to get energy from fusion. Doing it in the laboratory at a cost of only a couple thousand dollars seems almost beyond belief — not that the notion hasn't come up before. Six years ago, two scientists claimed they saw neutrons from fusion at room temperature. But others failed to reproduce their results, and claims of "cold fusion" have largely faded.

Unlike cold fusion, using sonoluminescence to make neutrons "is well-understood physics," says William Moss of Livermore national lab, a physicist who models the effects of nuclear bomb explosions. "We're talking about conventional thermonuclear fusion. When nuclei get hot and they get dense, they can fuse. There's no magic."

Using supercomputers to model the shock wave scenario, Moss has concluded that fusion might take place if a jolt of extra acoustic energy were added to the bubble at a certain point during the collapse. His latest results, which have been submitted to Physical Review Letters, predict one neutron per hour.

That's not much fusion. "If you covered the earth with these machines, after an hour you'd have enough energy to heat a cup of water a couple degrees. So we're not talking a lot of energy here," Moss says. But even if scientists couldn't get out more energy than they put in, producing neutrons would still be extremely interesting — both because it would defy conventional wisdom and because the system could be used for stidying shock waves and other experiments. As Suslick says, "It's a beautiful microscopic physics laboratory for extreme conditions."

One stumbling block has been that nobody has succeeded in making bubbles with deuterium. However, Ritva Löfstedt and others in Putterman's group recently discovered a new kind of single-bubble sonoluminescence. By carrying out the experiment at low partial pressures — less than 1 percent of atmospheric pressure — they made single bubbles with deuterium, ethane, and other gases that previously had eluded single-bubble sonoluminescence.

"It turns out this new phase is the only place where you can make deuterium bubbles turn sound into light," Putterman says. His group's results will appear in the May Physical Review E.

Livermore's Moran has begun tests with deuterium and uses Moss' scheme for spiking the acoustic energy. Physicist Steven Jones of Brigham Young University in Provo, Utah, in collaboration with Ronald A. Roy and others from Washington, also strives to detect neutrons in sonoluminescing bubbles. Jones works under a mountain, where a low background level of neutrons makes these particles easier to detect.

Jones emphasizes that his expectations reach no further than understanding the phenomenon. "I don't anticipate energy production," he told Science News. But as a probe of temperatures in the bubble, he says, "the neutrons become a very useful tool."

Others attack the problem from different angles. For example, Crum wonders whether at very high pressures, multiple bubbles could get as hot as single bubbles. To find out, "I think it is a critical experiment to determine whether there really is a shock wave inside single bubbles," he says. So he and colleague Sean Cordry are measuring how efficiently a single bubble converts sound into light. If the bubble collapses symmetrically — a necessary condition for a shock wave — then the conversion should not vary from pulse to pulse.

Putterman thinks that at low pressures, his group can make single bubbles in liquids other than water, another experiment that nobody has been able to pull off.

Single-bubble sonoluminescence might yield practical applications. Putterman says it could replace costly lasers for experiments that require ultrafast flashes of light. Crum suggests using the system to destroy toxins such as nerve gas. "Just imagine if you had this furnace that you could bleed chemicals into, and the temperature was 100,000°C. It's all going to come out in terms of its basic atoms," he says.

Even if nothing as dramatic as fusion takes place in the bubbles, the mystery of sonoluminescence keeps scientists fascinated.

"There's no experiment that's been performed that gives a good validation of any prediction that anybody's made," Moran says. "So it keeps people wondering what's going on, and it keeps the field open to new people coming in and making suggestions and contributing. So it stays kind of small and fun." ☐