Discoveries

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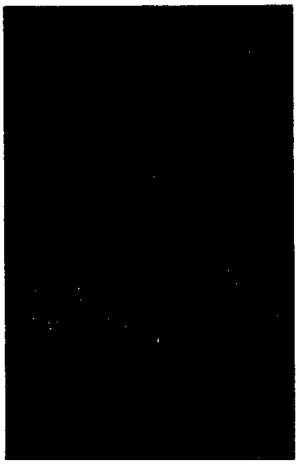
FLASHES OF INSIGHT

During the phenomenon known as sonoluminescence, a sound wave traveling through water suddenly generates an intense flash of light. The flash is shorter than 50 trillionths of a second and produces temperatures hotter than the surface of the sun.

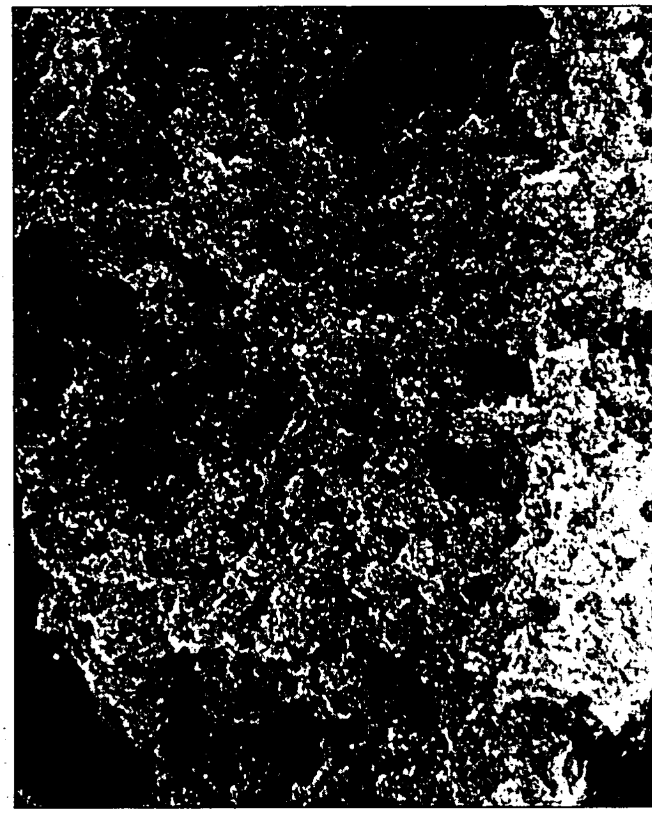


In multiple-bubble sonoluminescence, discovered in the 1930s, sound waves stretch and then compress water as they pass through it. The stretching forms bubbles, which are almost instantly smashed by the compression. That process produces the light and heat energy of sonoluminescence, which appears in this photograph as hazy flashes.

Lawrence Crum/University of Washington

Sean Cordry/University of Washington

University of Washington graduate student Sean Cordry looks into an acoustical chamber where single-bubble sonoluminescence occurs. Sound waves cause a single bubble in water to expand and contract, producing a flash of sonoluminescence with each contraction. The sonoluminescence appears as a tiny white dot in the chamber's center.



Kenneth Suslick/University of Illinois

The cyclical expansion and contraction of bubbles is exploited for a host of high-tech uses. Pictured is iron without any crystalline structure. The iron, produced by Illinois chemist Kenneth Suslick using a process similar to sonoluminescence, has unusual magnetic properties that could make it useful in information storage, petroleum refining and other applications. Normal iron would have a more patterned structure.

Physicists puzzle over process in which sound is converted to light

By Matt Crenson
Science Writer of The Dallas Morning News

There's no reason to be embarrassed if you've never heard of sonoluminescence.

Even Webster's New World Dictionary, which delivers on such wonders as anamorphosis and endomixis, is mum on the phenomenon.

PHYSICS

Not to fear. Sonoluminescence is fairly straightforward. Under the right conditions, sending a high-pitched tone through water produces an eerie glow.

"You actually do convert sound into light," said physicist Lawrence Crum. "It's really quite remarkable."

Researchers discovered sonoluminescence in 1934. Six decades later, physicists still can't explain it. But some recent experiments have shed light on the process.

"We're just learning all of the things that you might be able to do with it," said Dr. Crum, a professor in the Applied Physics Laboratory at the University of Washington in Seattle.

The discovery of a new type of sonoluminescence six years ago rejuvenated the field. A special condition known as single-bubble sonoluminescence makes the whole phenomenon easier to study and could lead to practical applications — if not of sonoluminescence itself, then of some related process.

Physicists are eager to learn how sonoluminescence works because it packs an incredible punch. The flash of light lasts less than 50 trillionths of a second and coincides with a release of energy that can heat a tiny space to more than 8,500 degrees Fahrenheit and amplify pressures thousands of times.

"It's very difficult to get those temperatures and pressures in a specific spot on Earth," Dr. Crum said.

Producing intense temperatures and pressures makes possible chemical reactions that would be impossible under less extreme conditions. A whole field of chemistry, known as sonochemistry, has developed around that endeavor. It doesn't necessarily use sonoluminesc-

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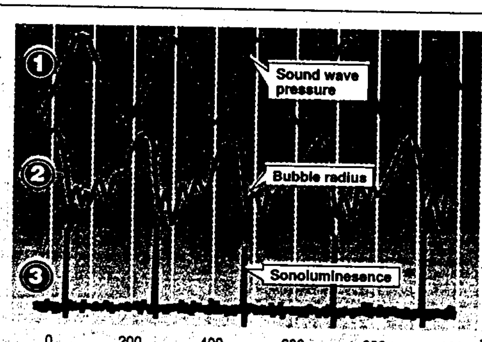
SINGLE-BUBBLE SYNCHRONICITY

In single-bubble sonoluminescence, three events are exquisitely timed — the passage of a sound wave through a bubble; the bubble's expansion and contraction; and the flash of sonoluminescent light emitted.

1. The pressure on the bubble rises and falls as successive sound waves pass through it every 200 millionths of a second.
2. Each time the sound-wave pressure peaks, the bubble is crushed to about one-4,000th its maximum volume.
3. The bubble produces bursts of light (shown as spikes) at each instant when it is most compressed.



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SCIENCE

Process in which sound turns into light is examined

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ence to generate chemical reactions — exposing chemical solutions to sound waves under any conditions can produce interesting and useful results. But sonoluminescence might help chemists understand what's going on in their experiments.

"It's an interesting phenomenon, and it's a very, very exciting laboratory for testing high-temperature and high-pressure conditions," said Kenneth Suslick, a chemist at the University of Illinois at Urbana-Champaign.

For example, Dr. Suslick and University of Illinois chemist Kathleen Kemper figured out how much pressure is produced when a sound wave makes a flash of light.

In the book *Bubble Dynamics and Interface Phenomena*, published this year, they reported that one type of sonoluminescence produces pressures 1,700 times that of Earth's atmosphere at sea level. That sort of information applies not just to sonoluminescence but to many related processes that don't make light.

The key to sonoluminescence is the same as the secret to good champagne — tiny bubbles. As sound waves pass through water or any material, they alternately compress and expand it. The expansion sometimes allows microscopic bubbles to form, and the subsequent compression smashes them.

"The critical part of this is to realize that when you compress gas you get heating. Anyone who's ever pumped a bicycle tire knows that," Dr. Suslick said.

In the form of sonoluminescence discovered in the 1930s, the compressing bubbles reach temperatures hotter than the surface of the sun and more pressurized than the deepest parts of the ocean. Such intense conditions can cause gases in the bubble to glow. But scientists still don't completely understand the process.

If they don't completely understand the form of sonoluminescence that's been known for 60 years, physicists are downright dumbfounded by the newly discovered form.

The old form of sonoluminescence is known as multiple-bubble sonoluminescence. As the sound wave travels through a water chamber, millions of bubbles form and collapse to produce a faint glow.

In the new form, discovered in 1988 by University of Washington graduate student Felipe Gaitan, a single bubble in a small chamber repeatedly produces flashes of light. Dr. Gaitan is now a researcher at the Naval Postgraduate School in Monterey, Calif.

"When that shock wave hits the center, you get incredible heating," Dr. Suslick said.

The bubble gets squeezed down to thousandths of its original size. But for some reason, it stops collapsing when it reaches about one-2,500th of an inch across — the size of a human red blood cell. The bubble makes a light flash, then rebounds to its full size.

Under the right conditions, a bubble can give off flash after flash, emitting 25,000 pulses of light a second. Dr. Crum and his colleagues have no idea how a bubble can do such a thing.

"There's an enormous amount of energy associated with this collapse," Dr. Crum said. "Why doesn't this thing destroy itself?"

A clue to the bubble's durability during single-bubble sonoluminescence may lie in a paper published last month in the journal *Science*.

Robert Hiller, Keith Weninger, Seth Putterman and Bradley Barber of the University of California, Los Angeles, noted that the intensity of a sonoluminescent flash depends on the composition of the air in the bubble. A tiny amount of a noble gas — including helium, argon and xenon and the other elements that lie on the right edge of the periodic table — added to nitrogen produces a flash more than 10 times as intense as either nitrogen or a noble gas by itself.

"This is a mystery. We don't understand it at all," Dr. Putterman said.

It is curious, however, that plain old air is about 1 percent argon. That's just the right proportion to enhance the sonoluminescence effect.

"The presence of the argon in the air turns it from being a phenomenon that might have been overlooked, or not discovered, to a bubble which is sufficiently bright to be seen with the unaided eye," Dr. Putterman said.

The UCLA physicists also found that with helium in the mix, the flash produced is incredibly rich in ultraviolet light. Even the sun produces a lower proportion of ultraviolet to visible light.

Researchers don't yet know why noble gases contribute so much to sonoluminescence, Dr. Putterman said. Their results do suggest that there must be more to single-bubble sonoluminescence than an imploding shock wave, however, because that mechanism on its own wouldn't be affected by noble gases.

Understanding the details of sonoluminescence could lead to practical applications. The phenomenon is part of a field, known as sonochemistry, that uses sound waves to stimulate chemical reactions.

"The achievement of repetitive single-bubble sonoluminescence enabled this phenomenon to be examined in considerable detail. That analysis has led to some remarkable discoveries," Dr. Crum wrote in the September issue of *Physics Today*.

Most remarkable is that single-bubble sonoluminescence and multiple-bubble sonoluminescence seem to occur by completely different mechanisms.

"They're related phenomena, but they're not the same phenomenon. And that in and of itself is a little bit of a surprise," Dr. Suslick said.

Single-bubble sonoluminescence produces temperatures far beyond those of multiple-bubble sonoluminescence. Estimates of the temperature in a single-bubble flash go as high as 53,000 degrees Fahrenheit. But researchers warn that such measurements rely on many assumptions and that talking about a temperature that extreme existing in such a small space for such a short time doesn't mean much.

Researchers reason that to be so much more intense than multiple-bubble sonoluminescence, single-bubble sonoluminescence must work by a different mechanism. They hypothesize that a shock wave is produced as the bubble collapses. In a shock wave, material moves faster than the speed of sound traveling through it.

In one sonochemical application, Dr. Suslick makes iron with no crystalline structure. He and two University of Illinois colleagues, Mark Grinstaff and Myron Salamon, described the properties of amorphous iron last year in *Physical Review B*. The material is "useful in any situation where you have a rapidly oscillating magnetic field," Dr. Suslick said, such as audio tape recording.

The idea in making amorphous iron is to cool molten iron droplets quickly. Even if the conditions aren't right for sonoluminescence, sound waves can make and then squash bubbles extremely quickly.

"You get cooling rates of billions of degrees per second," Dr. Suslick said. "They (the iron droplets) freeze so quick that they don't have time to form an organized crystalline array."

Although he has had a lot of success with sonochemistry in general, Dr. Suslick doesn't think that sonoluminescence will necessarily lead to anything practical. But it is important to understanding how sound waves concentrate energy by creating and destroying bubbles in fluids.

"It's a useful probe of the conditions and chemical species formed in bubble collapse," Dr. Suslick said.