Mysterious Blue Light of Minute Bubbles Now Finding Practical Uses

By MALCOLM W. BROWNE

For 62 years physicists have marveled at the mysterious light emitted by microscopic bubbles when liquids are bombarded by blasts of high-pitched sound.

The cause of this eerie blue light remains uncertain, but experiments capable of solving some of the mysteries of the phenomenon, known as sonoluminescence, now seem within reach. Moreover, sonoluminescence is beginning to find practical applications.

Speculation in recent years that sonoluminescence might one day be used to force hydrogen atoms to fuse and yield immense amounts of energy has so far come to nothing, aside from its use as a plot device in a recent science fiction movie, "Chain Reaction." Dr. Seth J. Putterman of the University of California at Los Angeles, a leader in sonoluminescence research, has a low opinion of the movie. "It's amazing that Hollywood can throw $40 million at fictionalizing sonoluminescence when scientists have to struggle to come up with $100,000 to keep their research alive," he remarked.

But some less spectacular applications of the phenomenon than hydrogen fusion have turned up, and sonoluminescence, once a mere laboratory curiosity, is maturing as a serious and useful branch of science.

At a meeting of the Acoustical Society of America in Hawaii this month, scientists presented rival theories in an effort to explain sonoluminescence. The organizer of the symposium, Dr. Robert E. Apfel of Yale University, collected 11 different hypotheses submitted by physicists specializing in sonoluminescence, along with their proposals for experiments to test them. Fresh experimental results will highlight two major meetings on sonoluminescence scheduled for 1997.

Certain features of sonoluminescence are clear. One is the tremendous concentration of energy the phenomenon can produce; acoustic energy in the form of ultrasonic waves pumped into oscillating microscopic bubbles is concentrated up to one trillion times to produce pulses of brilliant light lasting only a few trillionths of a second.

The violent collapse of such bubbles produces effects other than light. A closely related phe-

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nomenon called cavitation is a serious problem for boats using high-speed propellers. If the blade of a propeller is moving through water too fast for the water to keep up with it, a vacuum created by the moving blade takes the form of myriad short-lived bubbles. The continuous collapse of these bubbles almost as fast as they form imparts tremendous destructive energy to a cavitating blade, and the propeller rapidly wears away unless it has been specially designed to reduce cavitation effects.

Two somewhat different forms of sonoluminescence are known.

In one, an intense sound "field" created by the equivalent of loudspeakers surrounding a test chamber causes clouds of microscopic bubbles to form spontaneously and collapse. The bubbling liquid in the chamber emits a steady sonoluminescent glow.

In the "single bubble" version of sonoluminescence, one small bubble is boiled into existence by a hot wire immersed in water, and the bubble is then acoustically moored (or "levitated") at the center of the chamber, where sound waves immobilize it and force it to pulsate rhythmically. As long as the sound continues to excite it, the rapidly expanding and collapsing bubble emits pulses of light in time with the frequency of the sound, up to 100,000 times a second.

Most physicists, including Dr. Putterman, believe that sonoluminescent flashes occur when a microscopic bubble suddenly collapses and its spherical wall implodes on itself at several times the speed of sound. This is believed to cause the shock compression of any gas within the bubble, very briefly heating it to a temperature higher than that of the Sun's surface. At this temperature, the compressed gas radiates both visible light and high-energy ultraviolet radiation.

Dr. Putterman said no one has yet proved by photographs or other means that shock waves are the cause of the phenomenon, although the indirect evidence for shock waves is strong.

There are many variations of the imploding shock wave theory.

At the meeting in Hawaii, Dr. Andrea Prosperetti of Johns Hopkins University and Dr. Michael S. Longuet-Higgins of the University of California at San Diego, independently proposed that jets may play a role in sonoluminescence.

Based on his research, which was supported by the Office of Naval Research, Dr. Prosperetti conjectured that an oscillating bubble trapped in a "standing" acoustic wave might develop a jet shooting inward from the bubble wall. The violent collision of this jet with the wall at the other side of the bubble would produce a flash of light, he hypothesized. The jet, moreover, would be aligned with the direction of up-and-down motion of the oscillating bubble.

But several physicists cast doubt on the jet theory, citing the results of recent experiments inside a KC-135A plane used by the National Aeronautics and Space Administration for training astronauts.

By first climbing steeply and then gradually curving over into level flight and then a dive, a pilot can cancel the effect of gravity inside the plane for a few dozen seconds, duplicating the weightlessness of objects aboard orbiting spacecraft.

Dr. Thomas J. Matula, Dr. Ronald A. Roy, Dr. Larry A. Crum and Dr. David L. Kuhns, all of the University of Washington in Seattle, reasoned that if jets really did form inside collapsing sonoluminescent bubbles, and the direction of the jets was determined by gravity, then changes in gravitational force should change the amount of light emitted by the bubbles.

But in a preliminary report, the group said it had conducted sonoluminescence tests under three different gravitational conditions: in the microgravity of the KC-135A airplane, at rest on the ground and in a centrifuge that doubled the force of normal terrestrial gravity. No differences in sonoluminescence were detected between the experiments. Gravity therefore has no evident influence on sonoluminescence, the scientists concluded, and the existence of a jet therefore seems unlikely.

But even without jets, sonoluminescent bubbles are often irregularly shaped and not perfectly spherical, as once thought. Using an ultrafast stroboscope, Dr. Apfel's group at Yale photographed sonoluminescent bubbles as they expanded and collapsed, and showed that some bubbles assumed very irregular shapes. With a different apparatus using a fast pulsed laser, Dr. Putterman's team found that the sonoluminescence emitted from a single bubble in a test cell was not uniform in all directions but varied in intensity as if the bubble had two opposite poles.

Several research teams have hypothesized that the temperature inside a sonoluminescing bubble is so high that the gas should emit not only visible light and ultraviolet rays but also X-rays. If this is true, the gas might be hot enough in principle to ignite nuclear fusion, although no one has yet induced sonoluminescence in hydrogen bubbles — an essential first step toward fusion.

The detection of X-rays from a sonoluminescent bubble would offer hope that at least the temperature could be raised to a level at which fusion could be ignited — provided someone finds a way to make hydrogen bubbles undergo sonoluminescence. (The gases that do emit sonoluminescence include xenon, argon and other inert gases, but not hydrogen or its isotopes.) But even if X-rays are produced, the rays from such tiny sources cannot penetrate the water in which the bubbles form, and thus there is no way to detect them outside the test apparatus.

A possible solution to this problem was suggested by Dr. Philip L. Marston of Washington State University at Pullman and his colleagues. They proposed a system for injecting a surface-active agent (similar to a detergent) into the surface of a sonoluminescing bubble. A fluorescent dye sensitive to X-rays could be bonded to the surface-active agent, they said, so that X-rays emitted by the gas in a bubble would not need to penetrate any water to excite the fluorescent chemical to emit visible light. This light could be detected and measured outside the test vessel.

Among the scientific tools applied to fathoming the secrets of sonoluminescence are powerful computer codes developed for the design of hydrogen bombs. A group from Lawrence Livermore Laboratory headed by Dr. William C. Moss applied some of these codes to compute the likely behavior of sonoluminescent bubbles and to make some predictions that can be tested in future experiments. Their mathematical model, which is partly based on the behavior of thermonuclear explosions, suggests that shock waves are the likely cause of sonoluminescence. Among other things, their model predicts that sonoluminescent flashes caused by shock waves will produce no afterglow.

Dr. Kenneth S. Suslick, a chemist at the University of Illinois, Champaign-Urbana, reported that his group had found a method using sonoluminescence to manufacture microscopic clusters of iron atoms that can be used for the magnetic imaging of the human body, channeling therapeutic drugs to specific sites, coating magnetic recording disks, making loudspeakers and many other applications.

In Dr. Suslick's system, sound bombards a chamber containing a liquid similar to gasoline, in which a volatile iron compound, iron pentacarbonyl, is dispersed. A cloud of oscillating bubbles forms in the fluid, and as the bubbles violently collapse, the pressure of the gas inside them rises to a level some 1,000 times greater than that of the atmosphere, and the temperature reaches 9,000 degrees Fahrenheit.

At this temperature, Dr. Suslick said, molecules of iron pentacarbonyl split up, lose carbon monoxide, and form clusters of iron atoms only one ten-thousandth of an inch in diameter. A feature of these microscopic iron clusters is that the magnetic "spins" of all the hundred or so iron atoms in a cluster are aligned so that each cluster behaves as if it were a tiny magnet. By coating these clusters with a chemical stabilizer, they can be dispersed in lubricants and magnetic fluids called "ferrofluids" with many potential uses.

"Ultrasound can break carbon-to-carbon bonds very efficiently, and interesting chemistry is certain to evolve from ultrasound experiments," Dr. Suslick said.