The Nature of Things

Wave of excitement

Andrew Derrington on how sound creates enormously high temperatures

It is common knowledge, although few of us have seen it happen, that a musical note of just the right pitch can shatter a wine glass. Much less widely known is the phenomenon known as sonoluminescence: high intensity sound waves in water cause such high temperatures that light is given off.

Although it sounds like the stuff of fantasy, sonoluminescence is causing a wave of excitement among serious chemists and physicists. According to Kenneth Suslick, of the chemistry department at the University of Illinois, sonoluminescence is exciting because it generates unique conditions, extremely rapid heating and cooling, and enormous temperatures and pressures.

These conditions can be harnessed to produce new materials with unusual physical and chemical properties.

Physicists are trying to measure exactly what goes on during sonoluminescence. Lawrence Crum of the Applied Physics Lab at Washington University is trying to push the conditions to even greater extremes and drive even more elusive chemical and physical reactions.

The latest calculations suggest that the temperatures reached during sonoluminescence can go as high as 2m°C – about half that required to produce nuclear fusion, the ultimate dream source of energy.

How could sound waves, which are nothing more than rapidly alternating increases and decreases in pressure, cause such violence? We learn at school that a wine glass shatters because it has a natural frequency of vibration, the same frequency as the note that sounds when it is rubbed or tapped gently. When a note of the same frequency sounds continuously, the pressure fluctuations in the air cause the glass to vibrate with increasing violence until it shatters.

Sonoluminescence, on the other hand, is caused by bubbles. The bubbles form because the boiling point of water, the amount of gas it holds, and the volume of a fixed quantity of gas all depend on pressure. The sound wave alternately reduces and increases the water pressure thousands, or even millions of times a second.

> The high temperatures generate oxidising agents, useful in a range of chemical applications

When the pressure falls gas bubbles form and grow, and then when it rises again they collapse violently, compressing and heating the gas so that it glows. Theoretical calculations suggest that the temperature in the bubbles should reach 7,000°C.

Chemists have been using sound waves to promote chemical reactions since reliable sound generators became available in the 1980s. Chemistry has provided important information about what is going on during sonoluminescence.

Suslick has estimated the temperature of clouds of collapsing gas bubbles from their effect on the rate of chemical reactions, and from the colour of the light they emit. Both figures come out at about 5,000°C, reasonably close to the theoretical estimate.

The high temperatures in sonoluminescence generate potent oxidising agents, which are useful in a range of chemical applications from cleaning polluted water to synthesising artificial blood.

According to Suslick, the usefulness of sonoluminescence comes not only from the temperature extremes, but also from the incredible rapidity of the temperature changes.

A collapsed bubble cools about a million times faster than a hot poker plunged into ice water. This makes it possible to generate amorphous metals, which are formed in chemical reactions in the bubbles and then cool and solidify them so rapidly that they do not have time to generate the metal's normal crystalline structure.

Suslick's group has successfully made amorphous iron, which is a useful chemical catalyst and an extremely magnetisable material with great potential for making transformers and tape recorders.

Physicists have developed the trick of reducing the amount of gas in the liquid so that only a single bubble forms, carefully directing the sound waves to counteract the natural buoyancy of the bubble and keep it in one place.

In single bubble sonoluminescence (SBSL), physicists have observed directly what happens when an isolated bubble collapses, with astonishing results.

The biggest surprise was that the light flash lasts less than 50 picoseconds (million-millionths of a second), 400 times less than predicted. Not only did this mean that something must be missing from the theory, it also hinted that the temperature predictions from the old theory might grossly underestimate the actual temperature.

Physicists now agree that the missing factor is a shock wave, a tiny supersonic boom generated because the bubble collapses faster than the speed of sound.

Because the shock wave is launched inside a collapsing sphere, it is perfectly focused on the centre of the bubble, and so, although it only affects a tiny volume, the temperature, according to the latest theory, could reach 2m°C.

These temperature estimates, and the theory that generates them, cannot be confirmed by measuring the colour of the light because water absorbs the short wavelengths that are emitted at high temperatures.

Crum's group is trying to test how well the new theory predicts the speed of the bubble's collapse.

Naturally they are also looking at new types of sound system to make the bubbles collapse even faster . . .

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