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Sound Is Shaped Into a Dazzling Tool With Many Uses

Ultrasonic beams can make, break or rearrange molecules and levitate objects in midair.

By MALCOLM W. BROWNE

USING beams of intense sound pitched above the limit of human hearing, scientists are learning to create novel substances that are expected to spawn remarkable technologies in the next century.

Physicists and chemists report that the development of powerful sound generators has prompted new research in the applications of ultrasound, sound emitted at frequencies of 20,000 cycles per second or more. These generators are capable of producing narrow beams of sound which, although inaudible to humans, are far more intense than the roar of a jet engine. (Normal hearing extends only to frequencies up to about 16,000 cycles per second.)

Ultrasonic beams, directed into ordinary liquids, can create microscopic hot spots that glow with a heat nearly as intense as that of the surface of the sun. The beams can make, break or rearrange molecules, control the crystalline structure of matter and even levitate objects or blobs of liquid. Ultrasonic irradiation, some experts believe, will underlie much of the technology of the 21st century.

Among the products that may result from ultrasonic processes are high-temperature superconducting ceramics, which, unlike ordinary superconductors, can conduct electricity without resistance even at temperatures far above absolute zero.

> In liquids, sound beams create spots nearly as hot as the sun.

Ultrasound also permits the melting and processing of materials suspended in midair, free of contact with any contaminating container. Such techniques are expected to yield mineral and metallic glasses with remarkable electronic and optical qualities. New types of lenses, electronic components, structural materials and fuel pellets for nuclear fusion reactors are all possibilities.

High-frequency sound beams have found many applications in the last 60 years. They are used by hospitals to obtain images of internal organs, by manufacturers to weld plastics and by engineers to test airplane parts and other machinery for hidden flaws. Low-power ultrasound generators have even found their way into homes in jewelry-clearing baths and humidifiers. But scientists say that the recent development of improved equipment has brought a surge of research in ultrasonics.

Most of the powerful new generators are based on a ceramic called lead zirconate titanate, a "piezoelectric" material, meaning that it vibrates when alternating current is passed through it. (Piezoelectric materials also produce electric current when vibrated by sound waves, and can therefore be used as microphones.)

When a high-frequency alternating electric current is applied to lead zirconate titanate, it vibrates at the same frequency as the current, thereby producing a high-pitched beam of sound. In an ultrasound generator, the ceramic is bonded to one end of a tapered bar of the metal titanium, called a "horn," which channels and di-

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rects the sound wave to its target.

Among the scientific mysteries that appear to have been solved by recent research in ultrasonics is the phenomenon of sonoluminescence, the peculiar glow that water and other liquids emit when irradiated by powerful ultrasonic beams. Dr. Kenneth S. Suslick, a chemist at the University of Illinois, has concluded that the glow is caused by intense heat generated in the collapse of microscopic bubbles created by sound waves.

In an interview, Dr. Suslick noted that although scientists have experimented with ultrasound for many years, only lately have observations begun to shed light on how sound initiates and influences chemical reactions.

In a recent paper in the journal Nature, Dr. Suslick and his colleague, Dr. Edward B. Flint, reported that they had induced sonoluminescence, a "cold, blue flame," in a hydrocarbon liquid called dodecane. The achievement marked the first time sonoluminescence had been triggered by ultrasound in a liquid other than water, and Dr. Suslick believes the discovery has settled a longstanding debate over the cause of the phenomenon.

Previously, many scientists had believed that sonoluminescence was an electrical effect or was caused by the recombination of split water molecules.

But Dr. Suslick believes he has proved that sonoluminescence is really the result of heat produced by the sudden collapse of microscopic bubbles. He explains that high-intensity ultrasound has sufficient power to overcome the attractive force between molecules of a liquid thus ripping them away from each other. The sound wave opens a tiny cavity in the liquid, he says, and the cavity begins oscillating in resonance with the sound.

Sudden Collapse of a Bubble

Liquid surrounding the cavity vaporizes into gas, and as gas enters, the cavity expands into a small bubble. But at a certain point the bubble becomes too large for the resonating wave of ultrasound to sustain, and the cavity collapses. The sudden collapse of the microscopic bubble compresses and heats the gas inside it to an enormously high temperature, high enough to emit blue light and cause unusual chemical reactions.

Dr. Suslick discovered that the blue light given off by dodecane when irradiated by an ultrasound beam has spectral features identical to those of the flame produced by burning this hydrocarbon in air.

"We knew that the speed at which a chemical reaction proceeds is a function of its temperature," Dr. Suslick said. "By measuring the yields of two reactions taking place in the irradiated dodecane during a given period of time, we were able to deduce the temperature of the hot spots driving the reactions. We found it to be around 9,000 degrees Fahrenheit, nearly the temperature of the surface of the sun."

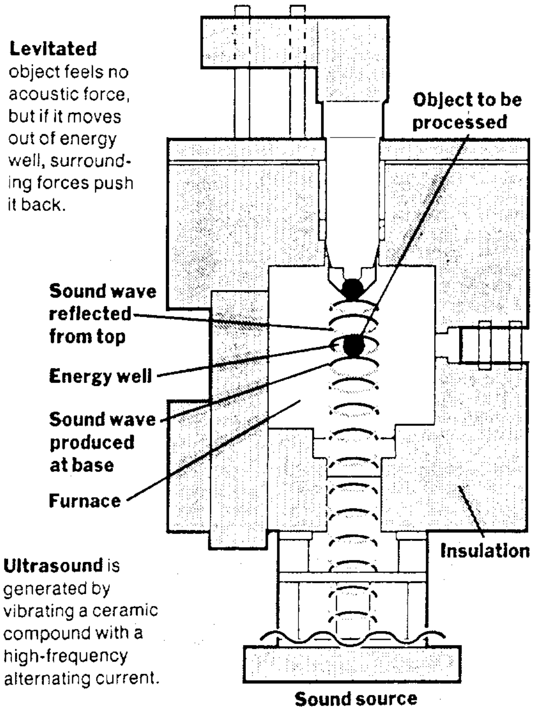
Each microscopic hot spot persists for only one millionth of a second or so, he said, and its heat is so quickly dispersed that the overall temperature of the liquid scarcely rises. But the transient burst of energy released by a hot spot is often enough to trigger or accelerate chemical reactions, Dr. Suslick said. In some cases, ultrasonic irradiation has speeded up reactions by 100,000 times.

Products of such reactions include new molecules containing both metal and carbon, and "intercalated" substances, in which sheets of molecules

Sound Is Shaped Into a Dazzling New Tool

How Sound Beams Hold an Object in Midair

With ultrasound, objects can be held in midair, to be melted and processed without contamination by a container. In one type of furnace, a sound generator produces two beams of ultrasound. One beam flows past the object and is reflected back to meet the first beam. Interference between the two beams creates lens-shaped "energy wells" where they cancel each other; the largest well holds the object.



Dr. Charles A. Rey, president of Intersonics Inc., levitating foam balls using sonic energy. His company is working on ultrasound for use on earth and space.

Illustration: The New York Times/Al Granberg; Photo: The New York Times/Steve Kagan

are stacked like pancakes to produce materials with unusual qualities. Scientists believe many new technologies may emerge in coming decades from these materials, including high-temperature superconductors.

Making Glass in Midair

Meanwhile, scientists are learning to make things without touching or contaminating them, by suspending them in midair on intersecting beams of ultrasound.

Most mineral objects, from rocks to frying pans, are made of crystals, clusters of atoms arranged in orderly, repeating arrays. But there is another class of solids, the glasses, that scientists regard as vital to the development of many new technologies. In the glasses, which include special forms of metal and other minerals as well as common window glass, atoms and molecules are haphazardly arranged. Some glasses have electrical and physical properties unequaled by their crystalline counterparts, and scientists are seeking better ways to make such glasses.

Under contract with the National Aeronautics and Space Administration, an Illinois laboratory, Intersonics Inc., is developing ultrasound levitation as a technique for making new glasses. The company's president, Dr. Charles A. Rey, a physicist, said in an interview that containers of any kind can spoil glass.

"Some things, like the silicon dioxide in ordinary window glass, love to solidify in non-crystalline form from their melts," Dr. Rey said. "But with many other materials, the least little thing will make them crystallize instead of solidifying into glass. Even the microscopic irregularities on the mirror-smooth surface of a container are enough to initiate crystallization in many melted materials, including some of the oxides we hope to develop as optical switches in a new generation of computers.

"But we're learning to prevent crystallization by melting and solidifying these new glasses in midair, holding the stuff in place with ultrasound beams."

Dr. Rey's organization built ultrasonic levitation furnaces that were sent into the weightless environment of space aboard the space shuttle in 1983 and again in 1985. His company is developing the technique for future experiments on the ground and in space.

The Force of Sound

He said that a beam of intense sound exerts a force known as radiative pressure against any object it strikes. If two or more sound waves pass through each other, the crest of one wave may coincide with the trough of another, and when this happens, their combined energies cancel each other, creating an "energy well." A solid object positioned in such a well feels no acoustic force, but if it wanders, the surrounding forces reassert themselves and force it back. The object is thus fixed in place and can even be suspended in midair.

A mixture of minerals suspended in an acoustic energy well can be melted by laser, microwave beam or other means and then cooled into solid glass, with much less chance of crystallizing the material than by using a conventional container. "Moreover," Dr. Rey said, "there are no container materials with which the melted glass can react."

In one technique, Intersonics uses a single sound generator to produce the two intersecting beams that trap an object. The generator directs a beam that pushes and flows past the object, striking a concave reflector on the other side. The curved wave produced by the reflector bounces back, meeting the oncoming beam from generator. Interference between the two beams results in a string of lens-shaped energy wells, the largest of which is used to hold the levitated object.

In other schemes the company is developing, several sound generators are used to produce intersecting beams.

"It's much easier to do this in the microgravity of space than on earth," Dr. Rey said, "but by increasing the power of the beams, we make it work on earth as well. We have levitated objects weighing up to an ounce, using beams with up to 160 decibels of power." (Someone standing next to a jack hammer is exposed to about 100 decibels; a person 300 feet from a jet aircraft taking off is exposed to about 120 decibels. Each increase of 10 decibels represents a tenfold increase in the power of a sound.)

Among high-priority objectives of ultrasonic processing are tiny glass capsules to be used as fuel cells for future nuclear fusion reactors. Hollow glass spheres would be filled with hydrogen fuel and simultaneously blasted from all directions by powerful lasers. The lasers would vaporize the glass causing an implosion violent enough to heat the hydrogen to fusion temperature.

A major problem is the need to make the spheres perfectly uniform, both inside and outside; the slightest irregularity would prevent the uniform implosion needed to trigger fusion. Experts believe that manufacture of the spheres in an ultrasonic levitator aboard a space station may be the best approach.

"In any case, ultrasound is going to be one of the keys to our future," Dr. Rey said.