To manufacture such material on a large scale, Lewis imagines large vats filled with a nutrient-rich solution that bacteria would feed on as they produce the silk proteins. He proposes harvesting the proteins by filtering the bacteria from the solution and freezing them, causing the organisms to break open and the strandlike proteins to spill out. After a chemical solution that attracts only silk proteins separates them from the broken shells and other proteins, the strands could be poured into another solution to strip away the chemical attractants. The silken strands could then be stored in water to prevent them from kinking up like a ball of spaghetti before they can be scooped out and fed into a conventional spinning machine.

Engineered Qualities

While such production techniques are still in the conceptual stages, Lewis is already exploring other potentially useful spider products. He has identified the genes involved in producing the thread that spiders apparently use to reinforce the edges of their webs. Lewis speculates that this material, which is stiffer than drag line, could be useful in bullet-proof vests because it is as impact resistant as Kevlar but a bit more flexible and thus more comfortable. Drag line would not be suitable for a vest, he adds, because while it would stop a bullet, it is so flexible that both the bullet and part of the vest would pass all the way through the body before coming to rest.

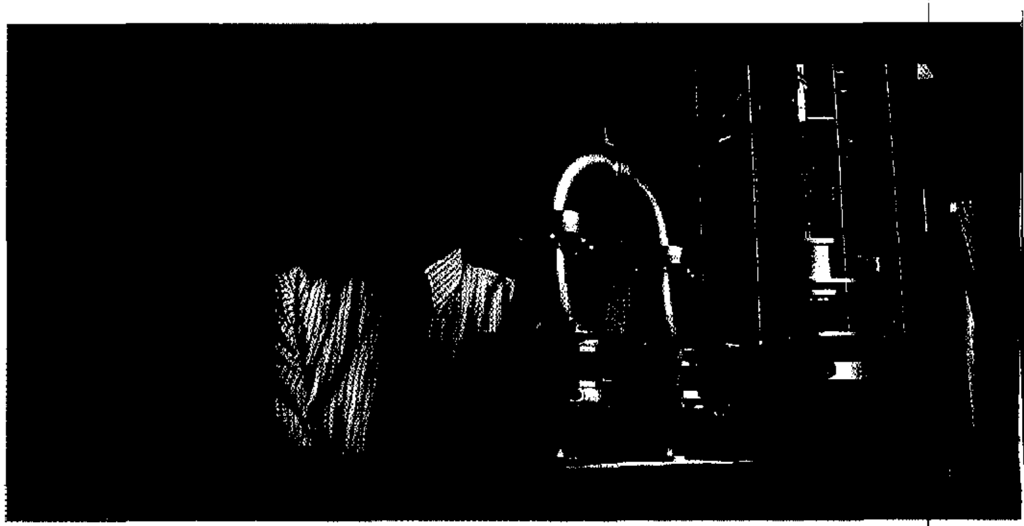
Viney notes that if a second version of synthetic spider thread isn't enough, the silk of 30,000 other spider species may offer yet more enticing qualities. "There's no reason to think this is the best one," he says.

Viney also offers an alternative strategy to hunting down the silk genes in all those spiders to find something better. Researchers could instead alter DNA segments of the silk genes in the golden orb weaver or any other spider and test the properties of the resulting proteins until they engineered the qualities they want. —*DAVID GRAHAM*

The Coolest Sound

In just a few years, refrigerators and air conditioners could be humming a different tune, keeping us cool by applying a recently discovered thermodynamic principle. Called thermoacoustic refrigeration, the process uses only environmentally friendly gases and sound.

The technique is a radical departure from conventional refrigerators and air conditioners, which capture cold from an evaporating liquid. This process starts when a pump injects liquid—in most refrigerators a chlorofluorocarbon (CFC) or in newer models a hydrofluorocarbon (HFC)—into an evaporator, a coiled chamber kept at a near vacuum. When a fluid enters the vacuum, it evaporates. This phase change requires heat, and as tubes from the evaporator weave their way through a refrigerator's cooling unit, they suck the required heat from the surroundings, thus leaving the food-storage area cold.



To complete the cycle, the gas, now laden with heat, is pumped into a condenser, where it is subjected to high pressure. At this point, the phase transformation is reversed: the gas returns to a liquid, and the heat is released to the outside air through a network of tubes usually attached to the rear of the refrigerator. The fluid then returns to the evaporator, ready to start the cycle again.

CFCs have been used in this process because they're cheap, nontoxic, and inflammable, and they turn from liquids to gases at temperatures and pressures ideal for food refrigeration. Unfortunately, when CFCs escape into the environment, they rise into the upper atmosphere, where they not only act as greenhouse gases but contribute to the breakdown of the earth's ozone layer.

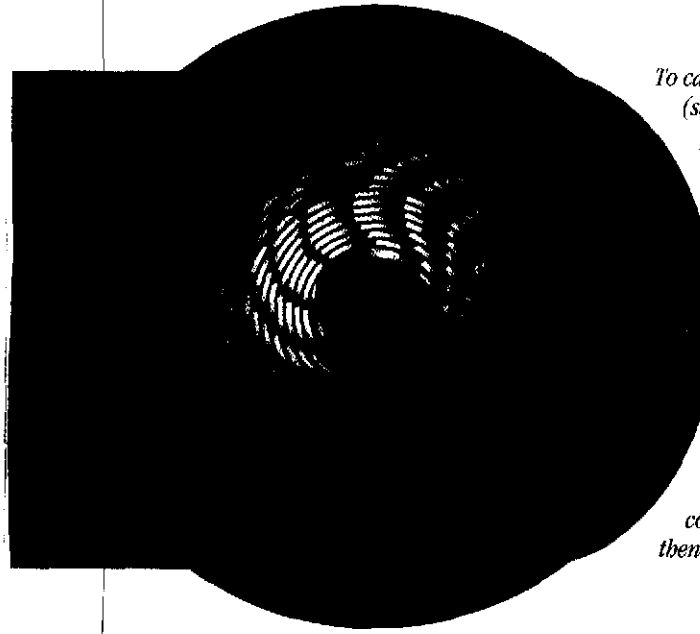
While HFCs contain no chlorine and thus probably do not deplete the earth's ozone layer, the chemicals may still be potent greenhouse gases—possibly more potent than the CFCs that they replace. Michael Oppenheimer, a senior scientist for the Environmental Defense Fund, explains that the chemicals are so new that their behavior in the atmosphere is not well understood. Environmental groups thus consider HFCs only a stopgap solution until a better alternative is found.

Thermoacoustic refrigeration just might be that alternative. The technique uses neither CFCs nor HFCs, exploiting instead an unusual relationship between temperature and sound. Glassblowers have known for centuries that a globe of hot glass at the end of a long metal rod frequently "sings" as it cools. But 10 years ago a group of physicists at Los Alamos National Laboratory—Gregory Swift, Thomas Hofler, John Wheatley, and Albert Migliori—discovered that the

PHOTO: ASSOCIATED PRESS

process by which sound is produced from cooling could be reversed so that cooling could be produced from sound. The group since has been awarded several basic patents for thermoacoustic refrigeration, and several other teams are developing systems.

At the heart of every thermoacoustic cooling device is a loudspeaker mounted on the end of a metal tube—prototype units range from the size of an aspirin bottle to 40-feet long—filled with a mixture of stable inert gases such as helium and argon. When a tone of just the right frequency is played, a standing sound wave is created inside the tube so that the wave's crests form at each end and its trough lies in the middle.



To capture coldness, a plastic coil (shown here in cross section) is placed inside a thermoacoustic device's tube so that gases pass freely through the coil as they are pushed from one end of the unit to the other by a high-intensity sound wave. The gases warm up as they move toward the high-pressure portion of the wave, transferring heat to one side of the coil, and cool off as they oscillate back toward the low-pressure region, transferring cold to the other side. Coolness is then conducted to the desired location.

Because sound is a pressure wave, the crests correspond to regions of highest pressure and the trough to that of lowest pressure. But while the pressure regions remain stationary, the gases in the tube are in constant motion as they are buffeted back and forth between the two high-pressure ends of the tube. When the volume is turned up to levels as high as 180 decibels—an intensity 100,000 times louder than a rock concert and one at which the pounding gases would destroy living tissue—the gases resonate forcefully back and forth.

Gases moving toward high pressure heat up as they are compressed, while those moving toward low pressure cool off as they expand. To capture the cold, most designs call for a simple heat exchanger, usually a strip of plastic rolled up like a jelly roll with an air space where the jelly should go. The coil is placed inside the tube—with its flat sides facing the flow of gases—about halfway between the high-pressure crest at the speaker end of the tube and the low-pressure trough, so gases can travel through the air space in both directions.

That way, as gas molecules rush toward the high-pressure region and heat up, they blast through the coil, bumping into its walls and transferring heat to the plastic. An instant later, they reverse direction and dance through the coil toward the low-pressure trough, cooling down and transferring cold to the plastic walls. Each time the molecules oscillate, they move a tiny bit of heat in one direction, a tiny bit of cold in the other direction. With millions of molecules shifting back and forth, a significant temperature differential builds up at the two sides of the coil.

Steven Garrett, a physicist at the Naval Postgraduate School in Monterey, Calif., was one of the first to pursue practical uses for thermoacoustic cooling, serving as a consultant to the Los Alamos group. Since then he has designed thermoacoustic units to provide vibration-free cooling for sensitive electronic components and sensors used in military satellites and by NASA—one flew aboard the space shuttle in 1992—and has recently set up his own lab to build commercial models. To demonstrate the effectiveness of a tabletop unit built for demonstration purposes, he flips a switch and a digital thermometer showing the temperature of the side of the coil facing away from the loudspeaker begins to change. After a few seconds, the temperature drops 5 degrees. After 10 minutes, it drops nearly 30.

Garrett explains that for spot cooling in uses such as electronic circuit boards, the cold can simply be conducted toward the desired object with a piece of metal called a heat pipe. For large-scale applications such as home refrigeration and air-conditioning, in which refrigeration would have to be delivered over greater distances, any environmentally safe heat-exchange fluid, even water, could be used to transfer coldness.

Thermoacoustic systems have two other potential advantages, Garrett maintains. The first is that thermoacoustic systems are quiet. Although the sounds inside can reach dangerous levels, the pressure vessel is so rigid that it does not vibrate at the same frequency as the gas inside. In fact, the only sound heard coming from Garrett's device is the slight hum of the pump moving the heat-exchange fluid.

The second advantage is control: "In an ordinary refrigerator, you have binary control: the system stays on and cools until it's too cold, then it shuts off until it's too warm," says Garrett. Conventional refrigerators therefore waste energy by overcooling. But a thermoacoustic device could avoid overcooling, he says, because it could be set to continuously maintain an exact temperature.

Such precision temperature control may also help make thermoacoustic devices more efficient than their conventional counterparts. "Unfortunately, it's kind of hard to make the comparison

PHOTO: JAY ADEFF

right now," says Garrett. The reason is that he has yet to build a refrigerator with efficiency in mind.

"My refrigerator is overpowered," admits Garrett. When he recently took an off-the-shelf refrigerator and replaced its compressor with a thermoacoustic system, the unit chilled the refrigerator's contents in half the time normally required. Instead of using the smallest amount of energy necessary to keep an ice-box cold, Garrett's unit spends a lot of energy for high-speed chilling. "That's not exactly what you want if you are going for the efficiency specs," he says.

However, rapid cooling may be ideal for coolers in water fountains and beverage vending machines. In fact, Garrett is helping an undisclosed company build a prototype of such a unit that he expects will be on the market in a few years.

Several other companies are quietly looking at some form of thermoacoustic-based cooling. In Detroit, the Ford Motor Co. is "doing exploratory laboratory research," says George Mozurkewich, an acoustic research scientist who is working on the project full time. In Oregon, Tektronix is exploring the use of thermoacoustics for cooling electronics in high-speed test equipment. In California, loudspeaker manufacturer JBL is pursuing research on the devices, seeking to capitalize on its experience with acoustics and possibly open up a new business area. And in Florida, Cool Sound Industries has bought the rights to the Los Alamos group's patents for using thermoacoustics in air-conditioning in hopes of building units for the home and office.

—SIMSON GARFINKEL

Using Thoughts to Control Computers

An enduring science-fiction fantasy has been the notion of linking the human brain directly to a computer. An individual would need only to think a command and the computer would respond.

That fantasy is no longer purely the stuff of fiction. A handful of scientists have begun devising interfaces that enable people with severe motor disabilities to use their thoughts to push a cursor around a computer screen, flip switches on and off, and even mentally type out words.

The novel brain-computer connections rely on electroencephalography (EEG), in which electrodes placed on the