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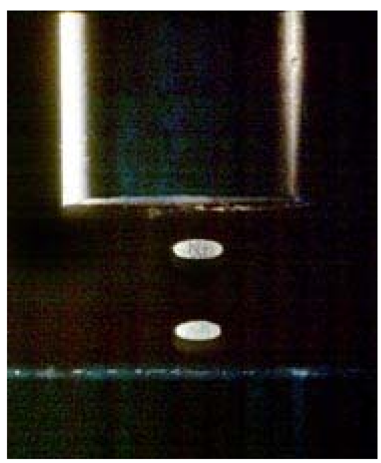
The Physics of ... Foam Bubble, Bubble

The toil and trouble of foam research reveals some magical results

by Jennifer Ouellette

On any given day visitors to Glynn Holt's laboratory at Boston University are likely to see a peculiar sight: a single drop of foam suspended as if by magic in midair. What they can't see are the acoustic waves that Holt uses to levitate the foam. By keeping the foam from touching the sides of a container, which would distort its shape and behavior, Holt can get more accurate measurements of its properties.

Holt is one of a growing number of researchers intrigued by foams and their unique qualities. Foams exist at all scales, from quantum gravitational bubbles in the fabric of space-time to the galactic structure of the cosmos itself. They permeate our daily lives, popping up in popular foods and beverages, personal grooming products, household soaps, and works of art.



Suspended on a 30 kHz cushion of sound waves, two drops of aqueous foam float for researchers at Boston University.

Photograph by Felice Frankel

Sidney Perkowitz, professor of physics at Emory University and the author of *Universal Foam,* cites foams as examples of soft matter: They don't flow freely like a true liquid, but neither are they a crystalline solid like a diamond. "We're very good at explaining hard matter like crystals; the entire semiconductor industry is based on them," he says. "Soft matter seems to tell us a lot more about nature and biology." Although particle physicists believe that a grand unified theory will rest on a more complete understanding of elementary particles, condensed-matter physicists think that the key lies in deciphering how physical laws evolve in complex systems like foam.

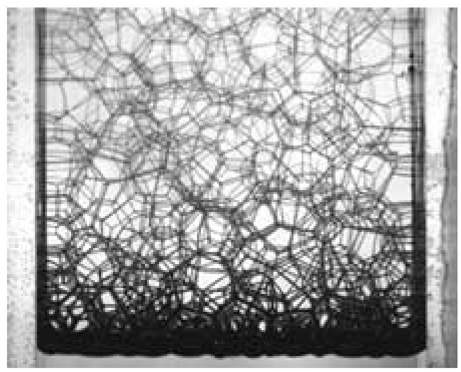
The origins and macrostructure of foams are well understood. "We're not discovering foam; it has existed for a very long time," says Douglas Durian, a physicist at the University of California at Los Angeles. "We're just trying to figure out how it works." Most foams contain a *surfactant* (short for "surface active agent"), a collection of complex molecules that aggregate at the bubbles' surfaces. A surfactant— fats or proteins in edible foams, chemical additives in shaving cream— prevents a foam from collapsing under surface tension by keeping the bubbles separate and by repelling water from their surfaces, which keeps them from popping. Milk fat, which makes up 20 percent of heavy cream, acts as the surfactant in whipped cream. In nondairy varieties, milk fat is replaced by vegetable oil, which has an even higher fat content than cream.

Scientists know a great deal about the individual bubbles in such foams and how they "talk" to one another through simple friction. But when many bubbles clump together to form a foam, the resulting material exhibits a host of unexpected properties and behaviors. Liquid foams, for instance, are composed of roughly 95 percent gas and 5 percent liquid, yet they tend to be far more rigid than their components. This is due to a phenomenon called jamming. Because the bubbles are so tightly packed, when a foam is pressed down, the bubbles can't hop around one another. The more the bubbles are jammed together, the greater the pressure inside them grows— and, consequently, the more they take on the characteristics of a solid.

Then there's the matter of shape. A foam's properties are largely determined by the shape of its individual bubbles, but the exact nature of that shape is one of the oldest mathematical conundrums. In the 19th century, England's Lord Kelvin, of absolute-zero fame, came up with a shape eponymously dubbed Lord Kelvin's cell— a complex figure with six square and eight hexagonal faces that Perkowitz describes as "a demented soccer ball." In 1994 Denis Weaire and Robert Phelan, of Trinity College, Dublin, used a computer program to find a foam with even more efficiently packed bubbles. Their Weaire-Phelan structure, which comprises two different shapes of equal volumes, is an improvement on Kelvin's cells, but it has not yet been proven whether this is the most economical structure possible.

The biggest challenge facing sudsy scientists is to create predictive models of foam rheology, that is, the way it deforms and flows over time. As foams age, gravity drains their liquid downward, and smaller bubbles are absorbed by larger ones, a process called coarsening. But until quite recently our understanding of this process has been limited by the inherent difficulties of studying such an ephemeral material. Foams are fragile, and they usually have to be confined to a glass container to be studied, which itself alters their behavior.

For Holt, who was trained by NASA as a payload specialist for spaceflights, the solution was simply a matter of defying gravity. By using sound waves to suspend a drop of foam, he can manipulate its position and squeeze the bubbles to make them oscillate. "This is not simply attraction force on the surface of the drop," he says. "The sound propagates within the foam, which is how we're able to levitate it. So we can get a sense of how it responds as we manipulate it." A video camera hooked up to a monitor records the complex vibrations, which Holt then analyzes to get a better grasp of the foam's mechanical properties— most notably the point at which it begins to act more like a solid.



Bubbles in a soapy froth, held in a Plexiglas container one inch wide, clump in complex geometrical formations first conjectured by England's Lord Kelvin in the 19th century. Photograph courtesy of John Sullivan, Matt Fetterman, and Siggi Thoroddsen

Douglas Durian has taken a different approach. In 1990, while still with Exxon, he placed some shaving cream in a small glass cell, shone a laser beam through one end, and measured the amount of light that emerged through the opposite side— a technique known as diffusing wave spectroscopy. Over time, he found, the light's intensity fluctuated as the bubbles both consolidated and rapidly shifted position. As the foam shifted, its internal stresses grew, until groups of tightly packed bubbles suddenly snapped from one configuration to another like a slow-motion avalanche. If Durian applied enough pressure, the bubbles would rearrange constantly, flowing like a liquid.

It is this wide range of unique mechanical properties— from elastic solid to viscous fluid— that makes foams so useful for everyday applications. Most recently, a new anti-terrorism foam was used to decontaminate congressional office buildings and mail rooms in Washington, D.C. Developed at Sandia National Laboratories, the foam neutralizes toxic chemical and biological agents such as anthrax and sarin nerve gas within minutes. The foam, sprayed from handheld canisters, expands to about 100 times its liquid volume as air is drawn into the spray. It fills crevices and other elusive hiding places, then collapses back to its compact liquid state a few hours later.

The foam neutralizes toxic substances in much the same way a detergent removes stains from clothing. Its surfactants and mild oxidizing substances digest the chemical agent, seeking out the phosphate or sulfide bonds holding the molecules together and chopping them into bits. Sandia researchers aren't entirely sure how the foam kills bacterial spores, but they think the surfactants poke holes in the spores' protein armor, allowing the oxidizing agents to attack the genetic materials inside.

As practical as foams can be, their true appeal to physicists lies in their unique behavior. Ultimately, foam research may help explain the structure of plant cells and the ways in which biological systems emerge and evolve— subjects as complex as foam itself.

RELATED WEB SITES:

Perkowitz, Sidney. *Universal Foam: Exploring the Science of Nature's Most Mysterious Substance.* New York: Alfred A. Knopf, 2001. And for the history and science of foam physics, visit www.tcd.ie/Physics/Foams.
