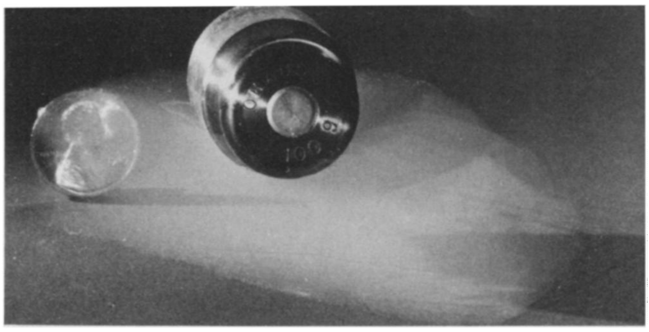
# The Art of Making Insubstantial Things

## *Whipping up ultralight solids that resemble frozen mist*

By IVAN AMATO



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*Although this aerogel may seem the closest thing to nothing at all, it can support 1,600 times its weight.*

Which weighs more: a gallon of air or a quart of the world's lightest solid?

It's almost a toss-up. The wispy, nearly transparent solid — known as an aerogel or "solid smoke" — is extremely porous, with only three or four times the density of dry air. Thus, the aerogel plus the air in a quart-sized carton would weigh only slightly more than a gallon of straight air.

These high-strength, ultralight materials, once found only in the arcane settings of particle physicists, now seem poised to enter the most familiar of places: the home.

Heavier versions of aerogels have existed since the early 1930s. Physicists have used them to detect high-energy particles emerging from collisions inside atom-smashing accelerators. When subatomic streakers from these violent clashes rush headlong into an aerogel, they reveal themselves to experimenters by triggering an emission of bluish light, called Cerenkov radiation. More recently, plasma physicists have begun exploring aerogels' potential for holding fusion fuels while lasers blast into them. The dearth of mass in the aerogel diverts only minimal amounts of the laser's energy from the fuel.

New ways of making a wider range of aerogels could open residential doors to the materials in coming years. Thermal insulation ranks among the more likely applications. Aerogels might replace the moderately insulating air that now occupies spaces in double-pane windows; in cooling devices, they might replace the traditional insulating foams whose production can release ozone-destroying chlorofluorocarbons into the stratosphere.

Space scientists want to use aerogels in loftier places, about 200 miles above residential roofs. On satellites, aerogels might serve as a gentle mitt for catching speeding micrometeoroids without shattering these relics of the solar system's beginning into a useless powder. Moreover, since the cost of orbiting objects grows with their weight, the unmatched lightness of aerogels makes them candidate materials for building space structures.

In the laboratory, aerogels' astoundingly porous interiors might host dye molecules and serve as components of new lasers. Loading the microcaverns with catalytic metals could lead to new ways of transforming starting chemicals into more valuable products such as fuels or polymer feedstocks.

Last January, Lawrence W. Hrubesh and his co-workers at the Lawrence Livermore (Calif.) National Laboratory announced they had created the lightest aerogels yet. The team makes these near-phantom materials out of silica (silicon dioxide), the stuff of sand. Depending on the use, the researchers can whip up aerogels with densities ranging from just over three times that of air to nearly 700 times that of air (about the same density as cherrywood or dry leather). More than 400 businesses and even some artists have queried Livermore's technology-transfer office this year about adapting aerogels to their needs.

To make the silica aerogels, he and his colleagues start with molecules shaped something like an X with a half-twist at the waist. Dissolving these tetramethoxysilane molecules into a mixture of alcohol and water with a good pinch of hydrochloric acid transforms them into a dense silica oil containing small, stringy assemblies of the Xs.

The next step involves putting space between the molecular assemblies by adding fluid wadding such as acetone to the oil, along with more water and a catalyst. As the silicon atoms of the oil molecules hook together — via oxygen atoms from the water — into a delicate three-dimensional network, they must reach around the wadding fluid. Removing the liquid — no easy feat since the tortuous network tends to trap liquids inside — leaves behind an aerogel. The researchers control the density of their "solid smoke" by regulating the amount of wadding fluid added.

The aerogel family gained new members in September with an announcement by another group at Livermore. "We looked at the silica aerogel chemistry and we asked ourselves: 'Can we do this with organic chemistry?,'" recalls polymer chemist Rick W. Pekala.

He and his co-workers proved they could. Like the other aerogels, theirs "is very strange material," Pekala says. The team makes it nebulous solids by adding a powder of either resorcinol or melamine to formaldehyde solutions spiked with a reaction-initiating base. Over the next several hours or days, the molecules link into a water-impregnated gel. The researchers then empty the gel's tiny pores in a series of steps, sometimes involving high pressures and temperatures. The resulting formaldehyde-resorcinol or formaldehyde-melamine aerogels, though slightly denser than their silica cousins, represent a new branch of the ultralight family, Pekala says.

The melamine aerogels aren't quite as transparent as silica-based versions but should offer more thermal-insulating power, he adds. Where transparency doesn't matter — as in refrigerator-door insulation — these may become the aerogels of choice. Pekala's group has also made opaque black aerogels consisting almost entirely of carbon atoms. Because these can conduct electricity, they may open additional applications, perhaps serving new electronic or catalytic roles.

Aerogels contain remarkably labyrinthine and diaphanous interiors. If you could flatten out all the surfaces lining the caverns within a grape-sized nugget of some of these materials, they would cover up to four basketball courts, Pekala says. That makes for poor heat conduction — a most desirable property when it comes to insulation materials.

That same convoluted interior seems well suited for hosting catalysts, notes John F. Poco, who works with Hrubesh. For example, pumping methane gas through an aerogel containing catalytic metal particles might yield larger fuel molecules such as propane. Since some aerogels are nearly transparent, researchers might boost these reactions by beaming in light energy, he suggests.

Might the future hold an aerogel that's lighter than air? Poco speculates that somehow excluding air from the labyrinth of today's lightest aerogels might do the trick, yielding solid materials that float in air like clouds or helium balloons. The prospect remains a dream for now, he says — but who knows? Castles in the air might someday take on substance. □