The Physics of Whipped Cream

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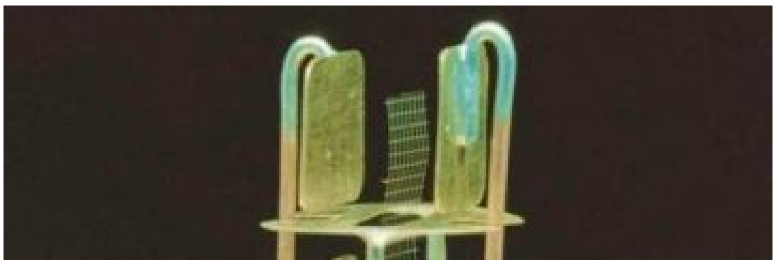

The thumbnail-sized patch of "window screen" suspended between the electrodes is the paddle that stirred the CVX-2 xenon sample.

Let's do a little science experiment. If you have a can of whipped cream in the fridge, go get it out. Spray a generous dollop into a spoon and watch carefully.

Notice anything interesting? The whipped cream just did something rather puzzling. First it flowed smoothly out of the nozzle like a liquid would, and then, a moment later, it perched rigidly in the spoon as if it were solid. *What made it change?*

(While you're pondering this question, insert spoon into mouth, in the name of science.)

Whipped cream performs this rapid changing act because of a phenomenon called "shear thinning." When part of the foam is forced to slide or "shear" past the rest of the foam, the foam "thins." It becomes less like honey and more like water, allowing it to flow easily until the shearing stops.

Shear thinning occurs in many substances--e.g., ketchup, blood, motor oil, paint, liquid polymers such as molten plastic--and it is often crucial to how a substance is used. For instance, excessive shear thinning of motor oil is unwanted because it reduces the oil's ability to protect engines from wear, while shear thinning of paint allows it to flow smoothly from the brush but stay put on the wall. It also allows ketchup to flow from the bottle but not drip off your french fries.

Yet, for years, scientists have asked themselves the same question you just did: *What made it change?* The inner workings of shear thinning are not fully understood.

"Details depend on interactions in the fluid at the molecular level and those interactions can be devilishly complex," says fluid physicist Robert Berg of the National Institute of Standards and Technology. "Even for very simple fluids, fundamental theories have never been directly verified."

Until now. The first real-world confirmation of a theory for how shear thinning works in a simple fluid has come from an experiment that flew aboard the final flight of Space Shuttle Columbia.

"We showed that a leading theory is basically correct, " says Greg Zimmerli, Project Scientist for the experiment at NASA's Glenn Research Center. "This is an important step," adds Berg, the experiment's principal investigator.

Most of the data from the experiment, called Critical Viscosity of Xenon-2 (CVX-2), was beamed down to scientists on the ground before the shuttle's destruction during reentry into Earth's atmosphere.

Remarkably, the hard drive from the experiment survived the disaster and was found amid the wreckage, and technicians were able to recover the rest of the data.

CVX-2 was designed to study shear thinning in xenon, a substance used in lamps and ion rocket engines. Xenon is chemically inert, so its molecules consist of a single atom -- it's about as close as you can get to the flying billiard balls of an idealized gas or liquid. Unlike whipped cream, which is made of long, complicated organic molecules, xenon would be relatively easy to understand.

"It's a simpler fluid for the theorists to try to grasp," Zimmerli says.

Simple liquids like xenon don't normally experience shear thinning. They're either thick or thin, and they stay that way. But this changes near the "critical point" -- a special combination of temperature and pressure where fluids can exist as both a liquid and a gas simultaneously. At their critical point, simple fluids are able to "shear-thin" (a verb) just like whipped cream does.

Xenon at the critical point resembles a hazy fog, a slurry of microscopic pockets of slightly higher or lower density. These tiny regions of varying density are constantly appearing and disappearing in a seething froth, giving the pure xenon some of the structural complexity of mixtures like blood.

CVX-2 had to be done in space: Critical-point fluids are easily compressed. On Earth they collapse under their own weight and become denser at the bottom. In orbital free-fall those differences vanish -- a key requirement for a good experiment.

To test shear thinning, CVX-2 adjusted the temperature and pressure in a small cylinder to bring xenon to its critical point, and then gently stirred the fluid with a nickel-screen paddle. By measuring how strongly the fluid resisted the movement of this paddle, the experiment could determine the xenon's thickness. CVX-2 searched for changes in this thickness as it slowly changed the speed of the stirring and the temperature of the fluid.

Results nicely matched the predictions of dynamic mode-coupling theory. "This more fundamental understanding could help us build better theories for shear thinning in fluids more complex than xenon," Zimmerli says.

That would be good news for, say, engineers who want to design high-performance oils for automobiles or manufacturers who would like to create liquid plastics with just the right shear thinning properties for a particular mold. The sky's the limit.

Whether it would be possible to improve whipped cream, however, is highly debatable.

Source: by Dr. Tony Phillips, Science@NASA

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