Physicists shed light on how wetness affects a phenomenon in foams

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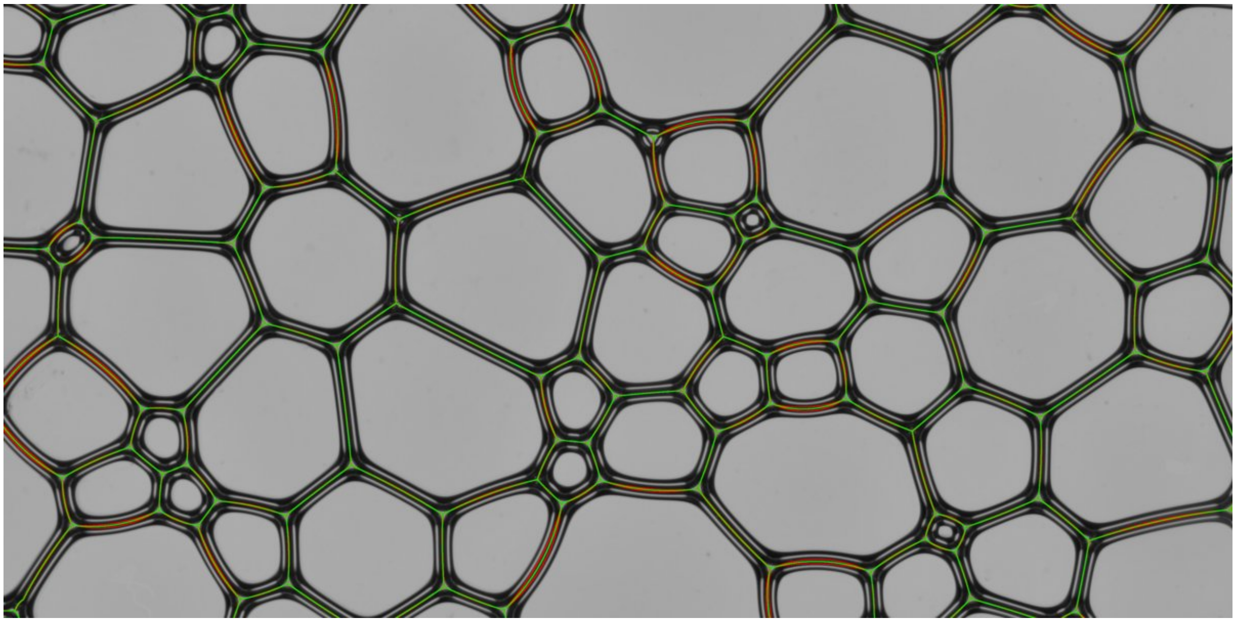

Image of a quasi-2d foam of wet soap bubbles squashed between parallel plates. Credit: A.T. Chieco and D.J. Durian

Whether drinking beer, eating ice cream or washing the dishes, it's fair to say that many people come across foam on a day-to-day basis. It's in everything from detergents to beverages to cosmetics. Outside of everyday life, it has applications in areas such as firefighting, isolating toxic materials and distributing chemicals. But there's still a lot to be learned about this ubiquitous material.

"Foams are nature's ideal random disordered materials," said Douglas Durian, a physics professor in the School of Arts and Sciences at the University of Pennsylvania. "Ordered solids, materials with a crystalline structure underneath, are easy to describe. Where we don't know a lot, but are still learning, is in systems that are disordered and far from equilibrium, and that's this to a T. You could conceivably make an ordered foam by blowing individual bubbles all the same size and stacking them like cannonballs, but you'd be bound to make a tiny error. If one bubble is infinitesimally smaller than all the rest, it'll be under higher pressure, and it'll start to shrink. It naturally evolves to this disordered state where it's polydisperse, and it's just gorgeous."

Since foams are often used in industry, achieving a better fundamental understanding of the material will enable people to control its stability, manipulating it to last longer so that it can better perform its function. It could also destabilize it and prevent it from cropping up in undesirable places. For instance, whenever one has to process liquids in industry, the rate at which that's done is limited by foaming.

Watching a time-lapse movie of a quasi-two-dimensional foam, one might notice that it evolves over time, the individual bubbles within slowly changing shape. Eventually, the average bubble size in the foam grows, a phenomenon that is called coarsening. This coarsening provides the foam a way of getting rid of surface area. Durian and Cody Schimming, a Penn physics major and now a grad student at the University of Minnesota, have published a paper in *Physical Review E* that investigates how the degree of wetness of a foam affects this phenomenon.

To understand this, one can think about a mixture of soap and water. If one were to squirt a bit of shampoo or detergent in a bottle of water with a few drops of yellow food coloring and shake it up, the bottle would quickly fill up with foam.

"If you looked at it closely," Durian said, "you'd see the tiny bubbles were very wispy and dry and sort of polyhedral up top. As you go down, you'd see more color because there's more liquid in it. You'd also notice that the bubbles down where it's more yellow are actually rounder. So they go from being jammed and polyhedral to essentially unjammed and spherical down near the bottom."

Close up the foam would be dry and wispy towards the top, consisting of little sticks, called Plateau borders, where three films meet. As the foam gets wetter towards the bottom, those sticks get thicker until they start to become spherical. This gradation of structure, Durian said, is the same regardless of what's in the foam or the size of the bubbles.

As time passes, more and more liquid will accumulate at the bottom of the bottle. There are three different mechanisms that cause the gas and liquid to separate. One of them is film rupture, or bubbles popping. Because this process is caused by evaporation, it won't occur in the sealed bottle. The second mechanism is gravitational drainage: gravity pulls the liquid down and the bubbles go up. This is what is causing the separation in the bottle.

But it would be possible to eliminate gravitational drainage if the foam were placed in a microgravity environment, such as the one on the International Space Station. In this case, coarsening becomes the culprit as gas diffuses from small high-pressure bubbles into larger lower-pressure bubbles.

"What people used to assume," said Durian, "was that these Plateau borders would totally block the diffusion of gas, and that gas diffusion would only go across the soap film windows. What Cody did is he actually solved the diffusion equation numerically to figure out what's going on inside these Plateau borders. You might guess that the diffusive current of gas through the Plateau borders is proportional to the reciprocal of their thickness and hence is negligibly small. But Cody showed that it's actually proportional to the reciprocal of the square root of the product of border thickness and film thickness. Since the films are so thin, the current of gas crossing the border is therefore far, far greater than has been assumed."

The researchers applied what they discovered to a law for the rate of change for bubble area by mathematician and physicist John von Neumann. According to von Neumann's law, the rate of change of area is equal to the number of sides minus six. One might expect that how fast the bubble is exchanging gas with its neighbors would depend on things like its size and shape, but, according to the von Neuman law, topology is the only thing that's important. In their paper, Durian and Schimming revisited this argument and incorporated what they learned about border-blocking and border-crossing to see how it gets modified.

"There are these three mechanisms and we're trying to understand the fundamentals of how they work," Durian said. "We have a good picture from the von Neumann law about how dry foams coarsen. The von Neumann law applies only to this ideal limit that there's zero liquid. But no foams are mathematically dry. Real foams have lots of liquid in them, so all these mechanisms get changed in some kind of crucial way, and we're trying to figure out how that goes. If you can understand the fundamentals, then it should be possible to improve all these applications where it's so important to be able to control exactly how fast coarsening takes place."

Durian said that he likes studying foams because, unlike other far-from-equilibrium systems, preparation history doesn't matter.

"I can make foam any old way and if I wait for a while it'll erase its history," he said. "It has its own evolution that brings us to this reproducible state, so it's a way of getting a disordered material that's perfectly reproducible. I also love that the physics is controlled by geometry. These soap films are minimal surfaces of constant curvature. There are topology rules for how the films are connected, so the geometry and topology of the microstructure is governed by beautiful mathematics. Independent of the size of the bubble or the chemical composition, they're just wonderfully ideal random materials to think about."

More information: C. D. Schimming et al. Border-crossing model for the diffusive coarsening of two-dimensional and quasi-two-dimensional wet foams, *Physical Review E* (2017). DOI: 10.1103/PhysRevE.96.032805

Provided by University of Pennsylvania

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