

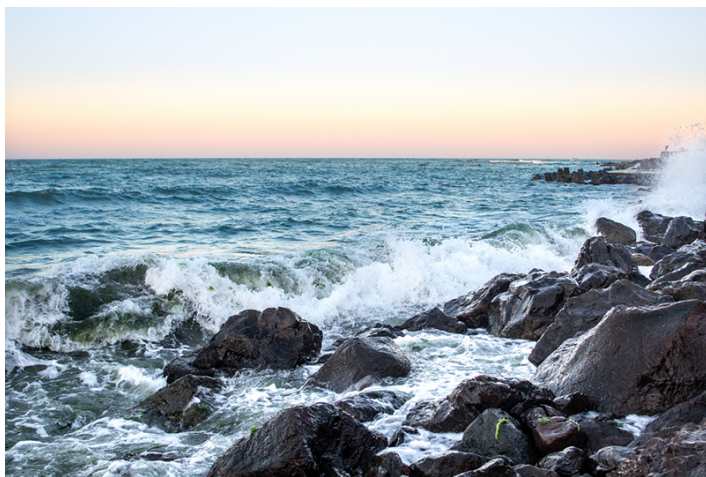
Why Seawater Is Foamy

Observations of air-bubble mergers in water explain why dissolved salt slows this process and leads to foam.

By **Mark Buchanan**

Air bubbles churned up in pure water can easily merge. But bubbles merge far more slowly in seawater or in other liquids containing dissolved impurities, which is why such liquids often generate enduring foams. Now a team of engineers believes that it has identified the fundamental cause of the difference—subtle forces set up by electrolytes, mobile ions created when substances dissolve in liquids [1]. In a collision between two bubbles, these forces greatly reduce the rate at which the liquid separating the bubbles can flow away. This understanding, the researchers say, explains why foams arise so easily in salty seawater and could be useful in many industrial applications.

Solutions with high electrolyte concentrations often produce persisting foams, so researchers have suspected for decades



The foamy brine. Foams made of long-lasting bubbles form readily in salty seawater, which contains many dissolved ions, but do not form as easily in freshwater rivers or lakes.

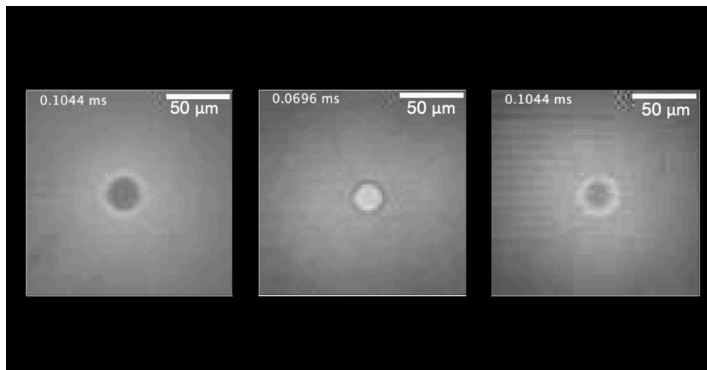
Credit: Michael Sapryhin/stock.adobe.com

that dissolved electrolytes somehow slow bubble mergers. The effect has remained mysterious, however, and many theories even suggest that electrolytes should speed up bubble mergers, says mechanical engineer Bo Liu of the University of Alberta in Canada.

So, Liu and colleagues undertook a series of experiments to measure more precisely how the presence of electrolytes affects bubble mergers. They submerged the end of a glass capillary below a liquid surface and created an air bubble at the tip. They then forced the bubble downward at a speed of 3 mm/s until it merged with a bubble below that was attached to a silica surface. Using interferometry, the team could measure the thickness of the liquid film separating the bubbles with nanometer precision and monitor this thickness as it decreased to zero.

In pure water, the bubbles acted like rigid spheres, approaching without changing shape and then merging on contact. However, bubbles in a variety of electrolyte solutions engaged in a strikingly different, two-stage merger process. At first, the bubble surfaces grew closer, as in pure water. But once the separation decreased to roughly 40 nanometers (nm), the “leading edges” of the approaching surfaces flattened as if there were some repulsive force. This flattening delayed the bubble merger by 2 to 14 milliseconds, according to experiments with a selection of electrolytes and bubbles of various sizes.

These experiments, says Liu, are the first to show so clearly that the presence of electrolytes slows bubble mergers in the final stage, when the liquid film between the bubbles becomes very thin. But explaining the effect theoretically proved to be harder. Working with various colleagues, team member Rogerio Manica, also of the University of Alberta, had spent years studying bubble mergers and, in particular, the physics



The three panels show the interferometric light signal for merging air bubbles in pure water (left), a salt solution (center), and a sugar solution (right). In each case, the disk or ring enlarges as the bubbles get closer and disappears when they merge. Bubble contact occurs at around 0.18 milliseconds (ms) for pure water, but the signals persist in the other two solutions until nearly 1 ms. This delay results from a flattening of the approaching bubble surfaces and a slowed draining of the liquid from the film between the bubbles.

Credit: B. Liu *et al.* [1]

influencing how the thin liquid film between two approaching bubbles can drain away. Even so, he says, “nothing we had in hand could explain the observed experimental data.”

In studying the results of experiments by others, however, Liu, Manica, and their colleagues noticed significant differences in measurements of surface tension in several electrolyte solutions compared with pure water. These observations, says Manica, encouraged them to develop a detailed mathematical model of the transport of electrolytes in the thin film between merging bubbles. Using fluid dynamics equations, they were able to describe how the flow of electrolytes should influence surface tension in the film.

The researchers found that when the thickness of the film drops

to 30–50 nm, there is a difference in electrolyte concentration between the film and the rest of the fluid. This difference generates a small surface tension gradient and an associated force that slows the outward flow of liquid from the film.

In simulations of the transport equations, the researchers found, this effect slows the film drainage just enough to delay film rupture—and final bubble merger—in precise agreement with the experiments. “In short,” says Liu, “the electrolytes greatly delay the coalescence of bubbles by prolonging the life of the thin liquid film.”

This scenario explains why whitecaps form so easily in saltwater oceans, which contain lots of electrolytes, but are less common in freshwater rivers and lakes, Liu says. This new understanding, he suggests, may also find some future industrial applications, for example, in the electrochemical splitting of water molecules for hydrogen production. In this process, the ways in which bubbles form and coalesce in a solution have a fundamental impact on the energy consumed and on the efficiency of production.

“This is elegant work,” says materials scientist Adrien Bussonière of the French National Center for Scientific Research (CNRS) in Paris. He notes that the mechanism the researchers identified includes effects at both the nanoscale, where individual ions interact with the thin film, and the much larger scale at which the fluid flow phenomena operate. “This mechanism appears to be universal for the different salts and resolves many unexplained electrolytes experiments.”

Mark Buchanan is a freelance science writer who splits his time between Abergavenny, UK, and Notre Dame de Courson, France.

REFERENCES

1. B. Liu *et al.*, “Nanoscale transport during liquid film thinning inhibits bubble coalescing behavior in electrolyte solutions,” *Phys. Rev. Lett.* **131**, 104003 (2023).