BOOKS: PHYSICS

All Kinds of Bubbles

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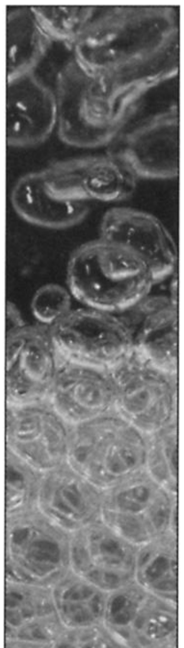
In foams, such as the frothy top on a glass of beer, the bubbles are shaped by surface tension forces acting to minimize the area of the liquid films. For dry foams, where the films are very thin, the bubbles themselves must be packed to completely fill space and they take the form of polyhedra. This explains the interest of foam scientists in a celebrated mathematical problem addressed in 1887 by William Thompson (later Lord Kelvin) who was concerned with the structure of the universal ether: What ordered structure of bubbles (of equal size) would have the lowest total surface area? Kelvin's answer for the ideal space-filling cell was a tetrakaidecahedron, a 14-sided polyhedron with six flat quadrilateral faces and eight curved hexagonal faces. When placed together in a base-centered cubic structure, bubbles of this shape save over 11% of the surface area required by a simple array of cubes with identical volume. Although Kelvin's solution could not be proved, it survived the test of time for more than a century. Then, in 1994, mathematical physicists Denis Weaire and Robert Phelan presented a new structure that shaved off another third of one percent of the surface area. Their structure combines two basic polyhedra: one with 12 curved pentagonal faces and another that adds 2 hexagons to the 12 pentagons. There is, as yet, no proof that this new minimum cannot be bettered, but computer searches indicate further reduction is unlikely. The story of Kelvin's problem is just part of the fascinating aggregation of topics and techniques that are discussed in *The Physics of Foams* by Weaire and Stefan Hutzler, his colleague at Trinity College, Dublin.

The Physics of Foams
by Denis Weaire and Stefan Hutzler
Clarendon Press, Oxford, 1999. 260 pp. $80, £47.50. ISBN 0-19-850551-5.

Universal Foam From Cappuccino to the Cosmos
by Sidney Perkowitz
Walker and Company, New York, 2000. 206 pp. $24, C$35.95. ISBN 0-8027-1357-2.

The abstract cell shapes of Kelvin, and of Weaire and Phelan, represent the equilibrium structures for many important materials—foam is a ubiquitous form of "soft matter." Both structures can be obtained in clever laboratory demonstrations (involving collections of bubbles painstakingly assembled in glass tubes), but neither is particularly prevalent in actual foams. As Weaire and Hutzler point out, the physics surrounding foam formation and bubble dynamics explains this absence. Quite simply, real foams are built with unavoidable structural disorder and they contain pockets of excess liquid between bubbles that prevent them from achieving the perfect, ordered structures of dry foams. The authors' clear and efficient explanations of the role of disorder and the impact of the "wet" cell borders realize their goal of providing "a guide to research and a stimulus ... in teaching." With similar success, Weaire and Hutzler describe the dynamic processes of draining, coarsening, and topological rearrangement so that the trapped foam structures in soap, in metal foams, and in beer can be understood in terms of their particular histories of formation.



Whereas Kelvin established his tetrakaidecahedral solution by scribbling an analysis in his notebook (the jottings are reassuringly straightforward), Weaire and Phelan used the specialized software package called Surface Evolver. Developed by Kenneth Brakke, this package has revolutionized research on structures driven by surface-tension forces, and its use is featured throughout *Physics of Foams*. Weaire and Hutzler also explain, in very readable terms, simple computer simulations of foam structures, which follow the dynamics of cell vertices and edges. In one way, Weaire and Hutzler provide yet another indication that computer solutions are becoming acceptable as answers to well-posed mathematical problems. But that is not all: Skilled users of Surface Evolver have little difficulty including finite volumes of liquid in the channels between bubbles. Therefore, Weaire and Hutzler can pose new problems, such as the identification of minimal surface solutions for objects that occupy only a specified fraction of space. (In the wet limit, the gas in foam only occupies about 85% of the volume.) Similar problems are currently relevant in many areas of applied research because control of the liquid fraction is often used to engineer foam properties. Computer simulations will undoubtedly play a key role in future developments in the field, and the authors' coherent account will benefit researchers at all levels. In addition, *Physics of Foams* includes many beautiful photographs and computer-generated illustrations of foam structures (in two and three dimensions) that will ensure the continued fascination of all readers.

Sidney Perkowitz's book offers an altogether different perspective on foam, but it is no less enlightening. Perkowitz, a condensed-matter physicist at Emory University who previously has written a popular account of light and vision, considers foams and their influences in science, technology, and culture. His discussion of bubbles in beer delves into the nature of the trapped gas; the consumer requirements for color, stiffness, and smell of the head; and the "lacing" patterns formed by the adherence of the foam to the glass. Other foods also provide extensive material for foam science: Perkowitz examines bread, meringue, whipped cream, and the crema of espresso. Each is a complex alliance between chemistry and physics that manifests itself as palatable foam, and the author pursues this alliance from the kitchen to the laboratory.

Perkowitz extends his coverage of foam to include solid structures like pumice, systems like the intricate connected channels of ocean sponges, and collections of mobile bubbles such as the huge volume of white sea froth (which, at any moment in time, covers an area of Earth's surface equivalent to that of the United States). In each case, he illuminates his description with insights and anecdotes. Champagne bubbles dissipate faster in wide bowl-shaped glasses than in slim, elegant "flutes," but, according to legend, the wider goblets may still provide the most stimulating of vessels for drinking this effervescent wine.

Universal Foam highlights the impact of low-density, high-surface area, partitioned structures in many diverse scenarios. From the use of aerogel (consisting of 98% air or more) to insulate electronics on the Mars Pathfinder rover Sojourner to the color-coded "peanuts" used for packaging, Perkowitz provides details and perspective without overburdening the reader with analyses. Foams can be viewed on galactic and quantum scales, from the three-dimensional structure of the universe to the fluctuations at the origin of space-time; Perkowitz makes this range both accessible and enjoyable to explore.

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