Forever young
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Global Cosmetic Industry; May 2000; 166, 5; Research Library
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Forever Young

A look at the beauty and chemistry of soap bubbles.

By Steve Herman

"...butterflies and soap bubbles and whatever among men is of their kind seem to know the most about happiness. Seeing these light, foolish, delicate, mobile little souls flutter— that seduces Zarathustra to tears and songs."
—Nietzche, Thus Spoke Zarathustra

Zarathustra was not alone in enjoying the delightful company of soap bubbles. A long line of scientists have found inspiration in the shapes and colors created by the cosmetic chemist's best friend, the surfactant molecule. In soap bubbles, we find a unique combination of beauty, surface chemistry, and playfulness, which can both entertain and inform us.

There are a small handful of books in popular science that have achieved classic status. Perhaps the greatest in this genre is Michael Faraday's "The Chemical History of a Candle," first published in 1861. In this exalted company, we also find a small volume by C.V. Boys, "Soap Bubbles: Their Colors and the Forces Which Mold Them." The revised edition, which dates back to 1911, is still in print.[1]

Boys begins with a discussion of the "elastic properties of the skin," known to modern cosmetic chemists as surface tension. If a drop of water is placed on a solid surface, it

FIGURE 1A Contact Angle on a Solid Surface

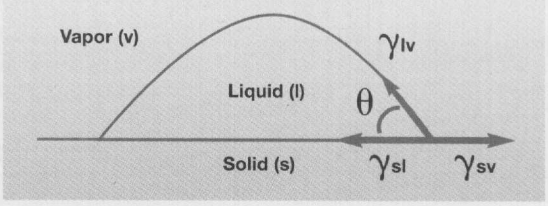
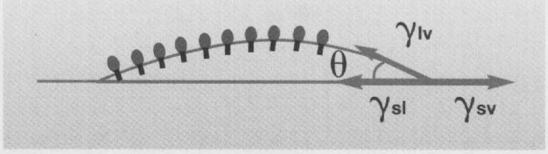


FIGURE 1B Contact Angle After Adding Surfactant



does not spread into a film the thickness of a molecule, but retains the shape indicated in Figure 1A. Each liquid/solid combination interacts differently. A quantitative measure of this interaction was formulated by Thomas Young in his immortal "Young's Equation":

$$S_{LS} = Y_{LA}(\cos\theta - 1)$$

S_{LS} represents the spontaneous wetting on the liquid/solid interface, Y_{LA} is the surface tension on the liquid/air interface, and θ is the contact angle. Adding surfactant reduces the surface tension, decreasing the value of θ (Figure 1B).

Blow some air into Figure 1A, and one creates soap bubbles (Figure 2). After Young, one of the more interesting 19th Century contributors to surface properties was Plateau (1801-1883), whose investigations centered on these same bubbles. "A famous problem of Joseph Antoine Ferdinand Plateau, a Belgian mathematician, solved by Tibor Rado and Jesse Douglas in 1930-31, is to show the existence of a

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*Greek kosmEtikos, skilled in adornment or decorating.

kosmetikos*

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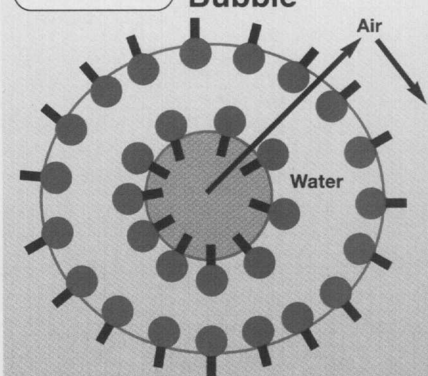
minimum surface with a given boundary curve, a fact physically demonstrable by soap bubble experiments. The solution allows minimal surfaces with singular points."[2]

Soap bubble experiments! Once again, cosmetic science is profoundly connected to another area of inquiry; in this case, topology and differential geometry. Topology refers to the properties of geometric figures that remain unchanged upon deformation without breaking. Differential geometry is—hard to explain! It involves the operation of infinitesimal calculus on geometric figures, and it is easier for a soap bubble to understand than for the average human.

FIGURE 2 Soap Bubble



Soap bubbles illuminate differential geometry by the minimum surfaces they form. Cyril Isenberg's fine book[3] considers many of the mathematical ramifications of soap films. Its geometric discussion starts with the "motorway problem," the calculation of the shortest path connecting an arbitrary number of points. No analytical solution has yet been discovered. Construct the problem physically with pins, add soap film, and voilà, the answer appears! In three-dimensional frames, the surfaces become even more impressive realizations of the mathematical prowess of soap. There are beautiful photographs of many soap surfaces bounded by various three-dimensional polygons in Dr. Isenberg's book, one of which is reproduced in Figure 3.

The bubbles in a concentrated foam, coalesce in a structure happily described as a "froth." In this transitory equilibrium state, the bubbles deform into polyhedra. Plateau established rules for the behavior of soap films, two of which are:

1. Three flat sides of polyhedra meet at

120°, but four or more sides form an unstable configuration; and

2. At the corners of the polyhedra, four edges meet in a regular tetrahedron.

The optimal structure of the foam is the one that creates the smallest total film area. The best calculations taking account of all the Plateau rules gives the result that optimally the polyhedra should have 13.39 sides! Real foam polyhedra usually have 14 sides.

The size of the bubbles, the thickness of the walls, the areas where bubbles come together: all these affect the quality and stability of the foam. Gravity is the chief force driving the instability of the surfactant structures. The draining eventually destroys the foam.

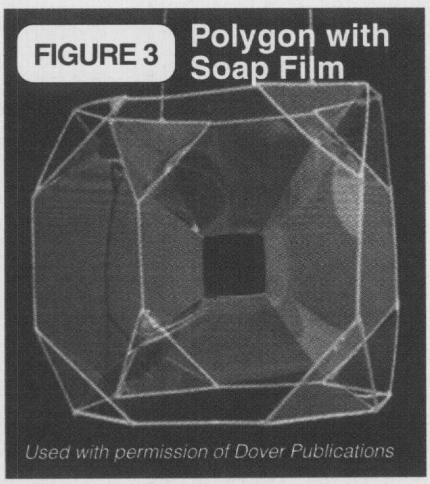


FIGURE 3 Polygon with Soap Film

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Besides Plateau and Young, many noted investigators have donated their names to surface science: witness the Gibbs isotherm, the Marangoni effect, Ostwald Ripening, the Laplace effect. Only a few vignettes from colloid and surface chemistry are presented here. As an interdisciplinary study, floating with undefined borders between physics, chemistry, and biology, it has received less attention than it deserves. ■

References

1. Boys, C.V., Soap Bubbles, Their Colors and the Forces Which Mold Them, Dover, 1959.

2. Encyclopaedia Britannica, 15th Edition, "Geometry, Differential," Macropaedia Volume 7, 1978.

3. Isenberg, Cyril, The Science of Soap Films and Soap Bubbles, Dover, 1992.

For a comprehensive, modern text, see Evans, D. Fennell and Wennerstrom, Hakan, The Colloidal Domain: Where Physics, Chemistry, and Biology Meet, 2nd Edition, Wiley-VCH, 1999.

For a good short introduction to foam:

Rieger, Martin, Foams in Cosmetics: Functionality and Physical Structure, C&T, Vol. 106, March 1991.