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In Bubbles and Metal, the Art of Shape-Shifting

By KENNETH CHANG

The next time you stare into a beer, contemplate the bubbles.

Mathematicians and scientists do. But for the thousands of years that brewers have been brewing beer, those beer-drinking researchers have not had an equation to describe how the bubbles change over time.

Now they do.

David J. Srolovitz, a professor of physics at Yeshiva University in Manhattan, and Robert D. MacPherson, a mathematician at the Institute for Advanced Study in Princeton, N.J., reported the solution last month in an article in the journal Nature.

Anheuser-Busch and Guinness may not have noticed, but that was not the point. "At the end of the day, I don't think it's going to revolutionize beer making," Dr. Srolovitz said. "This is mathematics."

Of more practical use, the equation also applies to metals. A piece of steel or aluminum might look like one uniform piece, but it consists of a conglomeration of many tiny crystalline grains, and the strength and flexibility of a metal depend largely on the size, shape and orientation of the grains.

That has been known, intuitively, at least, as long as there have been blacksmiths. The smiths' "heat and beat" technique, in addition to bending metal to the desired shape, alters the grains and properties of the metal.

When heated, atoms jump from the surface of one grain to a neighboring one. Some grains grow, and some shrink. "This grain-growth process is what happens when you anneal and hold it at different times and different temperatures," Dr. Srolovitz said.

In beer bubbles, air diffuses from one bubble to the next, and the bubbles change size and shape. The two processes — growth of bubbles and metal grains — are mathematically almost identical.

Foundries today are bigger and more complex, but the underlying knowledge remains based more on experience rather than science. Even when material scientists know of a desirable arrangement of metal grains, they have to discover by experiment a process that can produce it.

"It's completely trial and error," said David Kinderlehrer, a professor of mathematics at Carnegie-Mellon who wrote an accompanying commentary in Nature.

More than half a century ago, John von Neumann, mathematician and computer science pioneer, solved the two-dimensional version of the problem almost as a passing comment on someone else's scientific paper. "It was intuitively obvious to him," Dr. Srolovitz said.

The problem in three dimensions, however, eluded solution. Dr. Srolovitz and Dr. MacPherson started their work after Dr. MacPherson, who was looking to apply his mathematical knowledge to science, sat in on one of Dr. Srolovitz's classes at Princeton, where Dr. Srolovitz was a professor before moving to Yeshiva last year.

Their solution is surprisingly simple. A boundary between two grains or bubbles moves at a velocity proportional to the boundary's curvature. "This equation will basically tell you the relationship between time and grain size," Dr. Srolovitz said.

That, in turn, could aid in engineering novel materials like shrink-wrap steel or less corrosive batteries, Dr. Kinderlehrer said. "This is really a signature achievement. The result is so simple you can use it."

Materials scientists will still have to add other complications to their computer simulations like the effects of impurities.

It also does not provide a full solution to the beer foam, because it does not account for effects like gravity, which pulls liquid down the beer bubble walls until the walls are too thin and bubbles pop..

On the other hand, Dr. Srolovitz and Dr. MacPherson's equation works not only for three dimensions, but all possible dimensions. That could be useful for someone wanting to contemplate, for instance, what happens to a 67-dimensional beer.