Meeting Report: Norris Address

Bursting Bubbles

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Xun Zi (about 313 – 238 BC), a follower of Confucius, wrote:

不闻不若闻之，闻之不若
见之，见之不若知之，知之不若行之。学至于行之而止矣

Roughly translated it means: “I hear and I forget, I see and I remember, I do and I understand.” It seems that hands-on learning was highly appreciated long before modern educators made this phrase so popular. This time-honored insight inspired this year’s Norris Lecture, which was titled “Chemical Fizzics.” True to its name, the lecture treated the audience to numerous demonstrations on bubbles, foam, froth, and fizz. Once again, the outcome of a lecture demonstration that contradicts prior conceptions proves to be most memorable. Moreover, such demonstrations can also be both enlightening and entertaining. Space constraints do not allow a full description of all the fizzics covered in this lecture[1] – why bubbles grow as they rise in a carbonated beverage, why bubbles in some carbonated beverages fall along the sides of the container as the beverage settles, and why women often leave less foam in a glass of champagne or a mug of beer than men do. One example might serve to give the flavor of what was presented.

Consider the life cycle of a bubble in a pot of water that is brought to a boil. Bubbles first form on the sides and bottom of the container, lift off when large enough, rise to the surface, and pop. Why are no bubbles formed inside the liquid? Why do bubbles only appear on the container’s walls, often in places that have been nicked or scratched? This phenomenon is an everyday occurrence. Few of us stop, however, to puzzle why bubbling action takes this form.

Some elementary physical chemistry considerations lead to a solution to this problem. In forming a bubble, the steam wishes to expand. The work it does is the difference in pressure between the gas inside the bubble and the water pushing on the bubble multiplied by the volume of the spherical bubble. A competing process is the work needed to stretch the bubble skin, both inside and outside the bubble, which is given by twice the surface area of the spherical bubble times the surface tension. Indeed, the reason why bubbles are spherical in shape is that this geometry has the minimum surface area for a given volume and thus requires the least amount of work to maintain its shape.

The actual size of the bubble is determined by counterbalancing the rate of change of these two energy terms as a function of the change in the radius of the bubble. This analysis[2] tells us that the excess pressure needed to keep a bubble at a certain size is proportional to the surface tension and inversely proportional to the radius of the bubble. Put into other words, *the smaller the bubble, the larger the excess pressure needed maintain it.*

This conclusion has amusing and sometimes counterintuitive consequences. Take for example what happens when two balloons, made of the same material but inflated to different sizes, are connected to one another by means of a tube having a closed valve, as shown in Figure 1a. When the valve is opened, as shown in Figure 1b, the pressure equilibrates. But contrary to the expectations of many, the smaller balloon becomes smaller and the larger balloon becomes larger!

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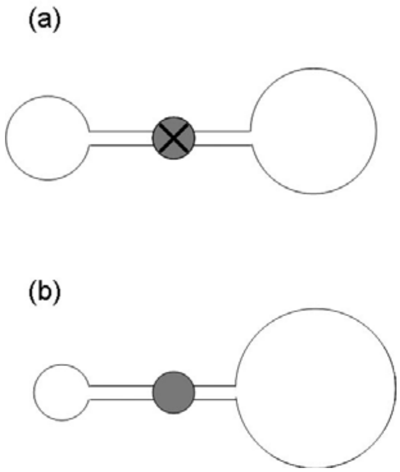

Figure 1. Two identical balloons inflated to different sizes and connected by a valve that is closed in **(a)** and then opened in **(b).**

Why does this happen? The answer is that it is easier to increase the volume of a larger balloon than a smaller one, as everyone knows who has suffered through the initial stages of inflating a balloon. Thus, to equalize the pressures, the smaller balloon shrinks while the larger balloon expands. The above demonstration is just another illustration of the conclusion: the smaller the bubble is, the larger must be its internal pressure.

Figure 2. Double bubbles: when a smaller bubble contacts a larger bubble, the higher pressure of the smaller bubble causes it to protrude into the larger one.

This principle also accounts for what happens when two bubbles meet and touch. If the bubbles have the same size, that is, the same radius and hence the same excess pressure, then the interface between the two bubbles is a flat common wall. But if the bubbles have unequal radii, then the smaller bubble with the larger pressure pokes into the larger bubble, causing the interface to be bent with the smaller bubble protruding into the larger one, as shown in Figure 2:

So, how does this concept apply to boiling a pot of water? When we try to bring water to a boil, by definition, the vapor pressure of the water becomes the same as the outside atmosphere. But bubbles cannot form in the pure water. Its surface tension is just too large, as everyone knows who has tried to blow bubbles with pure water. To form a bubble, we need either to decrease the surface tension, which can be achieved by adding soap to the water (and is definitely not recommended for cooking!), or to sequester the steam bubble from the water that wants to crush it. This sequestration is best done in small cavities, nooks, and crannies that the liquid water cannot penetrate. Hence imperfections on the walls of the pot are the place where bubbles form. These imperfections cannot be too small because once again the excess pressure required would be too large. Indeed, a critical size of the cavity exists for bubble formation.

Of course, the same concept of a roughened surface promoting bubble formation is employed routinely by chemists when they add boiling chips to solutions to keep them from bumping when they are heated. Making phase changes from liquid to gas or from liquid to solid is notoriously difficult. It explains why in pure water in a clean, smooth vessel it is easy to superheat the water past its boiling point or supercool it past its freezing point. We find ourselves wondering about the complex phenomenon of nucleation in causing phase changes to occur. Although bubbles first sound like something that is only child's play, deeper consideration shows that this topic has profound aspects. It also has practical ones, such as how clouds produce rain or snow.

What fun it is to know the science behind such phenomena. Its realization also gives us a deeper appreciation of the world and helps us to understand that science is all about us, not just in the laboratory. By engaging the audience in a quest to understand various phenomena involving bubbles in a "minds-on" if not hands-on manner, it was hoped that it was possible to validate the last part of the Chinese proverb: "I do and I understand."

In closing, if I may be permitted a few personal observations about the James Flack Norris Award for Outstanding Achievement in the Teaching of Chemistry, let me express my profound gratitude and pleasure in being selected by the Northeastern Section of the American Chemical Society for this great honor. Teaching and mentoring are both fairly private activities whose effectiveness is hard to judge, even by those most closely associated with the effort, and often only after the passage of much time! Yet, it is one of the most important activities we can do to renew the love of inquiry and spark the imagination of the next generation. I am mindful that many, many others are qualified – I daresay some more qualified – to receive this honor, and I accept it on the behalf of so many of us whose efforts usually go unmarked and unsung. This activity is so significant in preparing future chemists. I am grateful to the Northeastern Section for celebrating its importance.

[1] For a wonderful account of bubbleology in a common drink, see the recently published book, Gérard Liger-Belair, "Uncorked: The Science of Champagne," Princeton University Press, Princeton, NJ, 2004.

[2] In mathematical terms, this balancing act becomes $(d/dr)((4/3)(\pi r^3 \Delta p)) = (d/dr)(8\pi r^2 \sigma)$ where r is the radius of the bubble, Δp is the pressure difference, and σ the surface tension. It follows that $\Delta p = 4\sigma/r$. ◇