N92-30293

Measuring the Surface Tension of Soap Bubbles

Carl D. Sorensen
Brigham Young University, Provo, UT 84602

Key Words

Surface tension; surface energy; bubbles; soap films.

Prerequisite Knowledge Required

Students should probably have completed high school, although this is feasible for advanced high school students. The concepts of surface energy and surface tension should have been explained.

Students should be taught how to do a force balance on a hemispherical bubble, with the pressure inside the bubble balanced by the surface tension force at the equator of the bubble.

Objectives

- Students will gain an understanding of surface tension.
- Students will see that the pressure inside a small bubble is larger than that inside a large bubble.
- These concepts can be used to explain behavior of liquid foams as well as precipitate coarsening and grain growth.

Equipment and Supplies

- Commercial soap bubble solution
- Water colored with food coloring
- A basketball inflation needle or hypodermic needle with the end ground off
- Approximately two feet of clear vinyl tubing with an inside diameter of at least 1/4 in. (1/4 inch tubing works very well for use with a ball inflation needle
- Masonite or pegboard, made into a stand as shown below
- Two six-inch machinists' rules or fine graph paper
- A small watercolor paint brush
- Syringe or eyedropper to add fluid to the manometer
- Toolmaker's microscope or fine wire or drills to measure the inside diameter of the needle

Procedure

Set up the U-tube manometer with the needle pointing down. Pour a quantity of colored water into the manometer. Adjust the rules so the liquid level in the tubes is at the same place on both rules.

Dip the paintbrush into the bubble solution. Wipe the brush across the end of the needle to put a soap film in place. Periodically rub the brush against the side of the needle so fresh bubble solution can continue to drip down the needle.

With an eyedropper, slowly place colored water into the manometer. Because of the surface tension of the soap film, you will notice a higher pressure on the needle end of the manometer. Continue to add water, noting the height of the fluid on each scale.

Eventually, a bubble will form at the end of the needle, and the pressure measured by the manometer will suddenly decrease. Record the maximum pressure indicated. Also, estimate the size of the bubble and record the pressure.

Continue to add fluid to the manometer. The bubble will continue to grow. Record the bubble diameter and pressure at two or three different bubble sizes.

When the bubble pops, repeat the procedure two to three times. Record all data on the data sheet.

Empty the fluid out of the manometer. Using a drill or a toolmaker's microscope, measure the hole diameter of the needle and record it on the data sheet.

Since the soap bubble has two sides, the pressure difference between the inside and outside of the bubble is given by the formula

$$\Delta P = 4\gamma/r \tag{1}$$

where γ is the surface tension of the soap film and r is the radius of the bubble. The pressure outside the bubble is atmospheric; the pressure inside the bubble is atmospheric plus the additional pressure of the water in the manometer tube. The additional pressure due to the water is given by

$$P_{water} = \rho g \Delta h \tag{2}$$

where ρ is the density of the fluid, g is the acceleration of gravity, and Δh is the height difference between the two sides of the manometer. If we consider that atmospheric pressure is acting on both the inside and the outside of the bubble, it is clear that ΔP is just P_{water}. We can calculate P_{water} either from equation (2) or by using conversion factors:

$$1 \text{ atm} = 406.8 \text{ in } H_2O = 14.7 \text{ psi} = 101.4 \text{ kPa} \tag{3}$$

The bubble forms on the end of the needle when the bubble has the same radius as the inside of the needle. The surface tension, then is calculated from

$$\gamma = \Delta P_{max}\, r/4 \tag{4}$$

where ΔP_{max} is the maximum pressure difference recorded.

A second way to measure γ is to make a plot of ΔP vs. 4/r. The slope of the line is γ.

Measure the outside diameter of the drill. Based on your calculation of γ, can you predict the heaviest bubble that will hang on to the end of the needle? Can you think of a way to measure the weight of a bubble?

Sample Data Sheets

Inside diameter of needle: 0.052 in (1.32 mm)

Outside diameter of needle: 0.080 in (2.03 mm)

	Maximum Difference			Bubble 1				Bubble 2			
Run No.	Left	Right	Diff.	Left	Right	Diff.	Dia.	Left	Right	Diff	Dia.
1	2.15	2.90	0.75	2.90	3.16	.26	.25				
2	3.05	3.75	0.70	4.60	4.84	0.24	.32				

Surface tension from maximum pressure difference:

$$\gamma = \Delta P_{max}\, r/4 = \gamma = \Delta P_{max}\, d/8$$

$$\gamma_1 = .75 \text{ in } H_2O \frac{14.7 \text{ lbf/in}^2}{406.8 \text{ in } H_2O} \frac{0.052 \text{ in}}{8} = 176\text{x}10^{-6} \text{ lbf/in}$$

$(30.8\text{x}10^{-6}$ N/mm)

$\gamma_2 = 164\text{x}10^{-6}$ lbf/in $(28.7\text{x}10^{-6}$ N/mm)

Instructor Notes

The U-tube manometer is made from masonite and vinyl tubing. A rectangular piece of masonite is cut; a second piece is hinged to the back to provide a stand. The tubing is wired in place with twist ties, other soft tie wire, or small nylon cable ties (available at Radio Shack or other electronics suppliers). Machinists scales or strips of fine graph paper are used to provide a reading for the manometer. See Figure 1 for details.

Alternatively, a commercial manometer may be used. However, most manometers do not have scales as fine as a machinist's rule.

A fluid with a lower density than water could be used to give larger readings. However, my experience is that low density fluids are either toxic or oily, so the problems they cause are not worth the benefits they bring.

The relationship between the radius of the bubble and the surface tension is found by considering equilibrium of a half bubble (Figure 2). The upward force is provided by the pressure and has a magnitude of $\pi r^2 \Delta P$. The downward force is provided by the inner and outer surfaces of the bubble; it has a magnitude of $2(2\pi r\gamma)$. Equating the two forces and solving for ΔP gives equation (1).

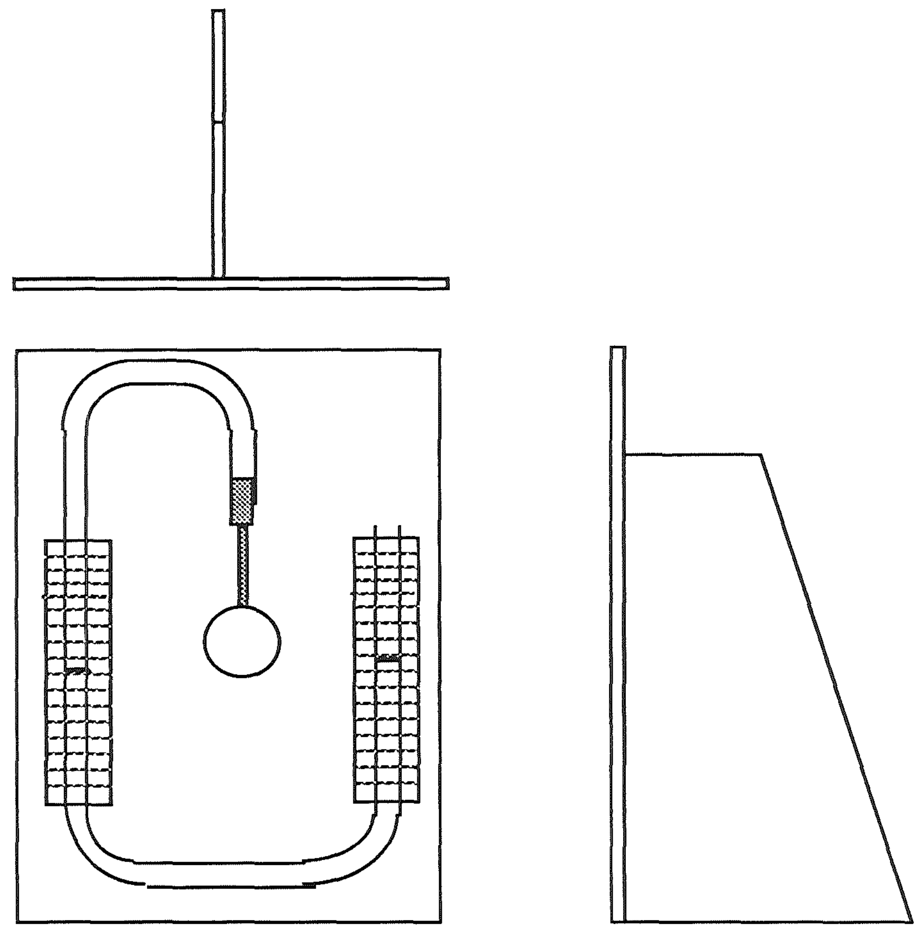

Figure 1: A sketch of the U-tube manometer. Details of the tube are omitted from the top and side views. The stand that holds the manometer vertical is hinged for storage. The vinyl tube is attached to the masonite background with soft wire. The needle must be placed far enough away from the backplate that the bubble will not touch the plate.

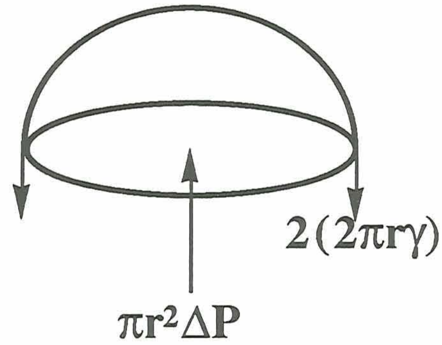

Figure 2: The forces acting on a hemispherical soap bubble in equilibrium.

References

Boys, C.V., *Soap Bubbles, Their Colors and the Forces Which Mold Them*, New York: Dover Press, 1959.

Cassidy, John, with David Stein, *The Unbelievable Bubble Book*, Palo Alto California: Klutz Press, 1987.

Source of Supplies

Supplies are readily available at hardware or discount stores.