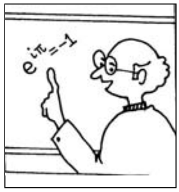
Classroom



In this section of *Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

The Inveterate Tinkerer
7. Antibubbles

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In this series of articles, the authors discuss various phenomena in fluid dynamics, which may be investigated *via* tabletop experiments using low-cost or home-made instruments. The seventh article in this series explores the formation, structure, and properties of antibubbles.

Materials Required

Plastic pipette, deionised water, liquid detergent, magnetic stirrer, glass beaker, corn syrup, micropipette, and high-speed camera with macro lens (optional).

Method

Antibubbles were first reported in a short communication [1, 2] to the journal *Nature* by W Hughes and A Hughes of the King Edward VI School in Southampton, United Kingdom.

A soap bubble comprises a sphere of gas (usually air) surrounded by a thin layer (~1–5 μm) of aqueous soap solution, floating in a gas (usually air). A soap comprises surfactant molecules. These are molecules with an oil-loving tail attached to a water-loving head group. The head groups could be negatively charged (anionic), positively charged (cationic) or neutral (nonionic). In

Keywords
Antibubbles, surfactant, vortex, buoyancy, globules.

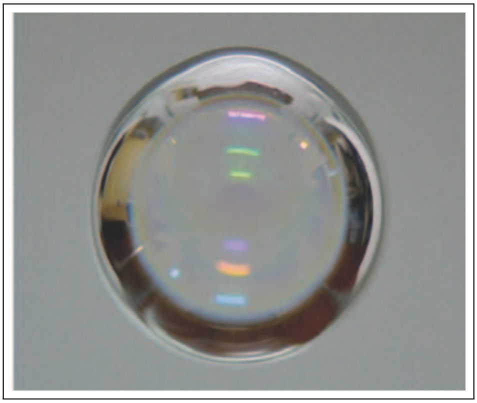

Figure 1. An antibubble photographed with a white backdrop.

Soap bubbles float in air and descend due to gravity on account of higher density of the soap solution, while antibubbles rise due to buoyancy of the air film and float just below the surface of the soap solution.

contrast to the case of soap bubbles, antibubbles (see *Figure* 1) comprise a sphere of soap solution surrounded by a thin layer (~1–5 μm) of a gas, submerged within a soap solution. Soap bubbles float in air and descend due to gravity on account of higher density of the soap solution, while antibubbles rise due to buoyancy of the air film and float just below the surface of the soap solution. Soap bubbles floating on a soap solution bend the surface of the liquid, however, due to lower buoyancy, antibubbles under the surface of the liquid do not bend the surface. Antibubbles have been reported in aqueous solutions containing nonionic surfactants (Polysorbate 20), anionic surfactants (Lissapol), cationic surfactants (Cetyl trimethylammonium bromide), and even in beer (proteins).

Antibubbles are intrinsically unstable due to a variety of factors. The air within the spherical shell rises due to buoyancy and accumulates at the 'North Pole' of the antibubble (a bulge is visible at the top of the antibubble in *Figure* 1). Over a short period of time – of the order of minutes – the air film at the bottom approaches a thickness of ~100 nm, whereupon attractive forces (called van der Waals forces) cause the film to collapse. Therefore, there is a tendency for the antibubble to start bursting close to the bottom. The air film also thins due to the diffusion of air into the inner sphere as well as to the surrounding fluid. On the other hand, soap bubbles are thicker at the bottom *via* drainage of soap solution due to gravity.

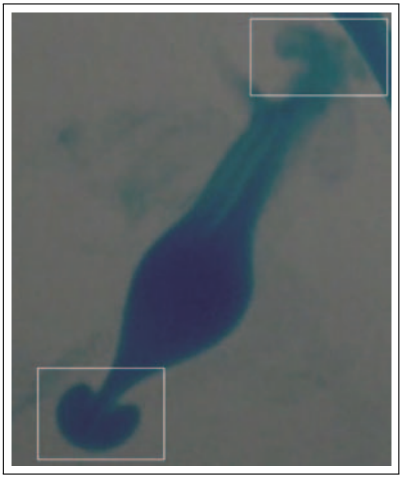

Figure 2. Ejection of oppositely directed vortex rings (white boxes) upon breakup of an antibubble.

150 μl of Fairy liquid detergent (Procter and Gamble) was added using a micropipette to 400 ml deionised water in a clean glass beaker and mixed using a magnetic stirrer. A plastic pipette was filled with the mixture and the contents squeezed out as a vertically falling jet from a height of $\sim$ 1 cm above the surface of the liquid to form antibubbles *via* Rayleigh–Plateau instability (see [3] for an elementary discussion of fluid instabilities) of the liquid column covered with an air film. One may also generate antibubbles by squirting the liquid from the pipette through a layer of soap bubbles floating on the surface of the mixture. Antibubbles may be suspended at the bottom surface of the soap solution by subjecting them to puffs of solution from a pipette. Alternatively, one may create a density gradient by pouring and gently mixing corn syrup at the bottom of the solution. The antibubble is then created using fluid sourced from the bottom of the container. This higher density antibubble tends to sink to the base of the container. Water drops are occasionally seen to skitter across the surface of water and these have been referred to as antibubbles. (see the video taken with a high-speed camera (Phantom M110) and macro lens: `youtube.com/watch?v=2vd_j8XOea0`). However, the author prefers using the term 'globules' (see [2]) as distinct from antibubbles, which are formed under the surface of a liquid and which necessarily contains a surfactant.

Open Research Problems

1. *Diameter and Lifetime of Antibubbles*

The author noted a typical antibubble of diameter ~1 cm with a typical lifetime of ~ 2–5 minutes. On one occasion, a lifetime of ~20 minutes was recorded. The addition of glycerol to the antibubble solution dampens capillary waves (which arise due to surface tension forces) during the formation of antibubbles and increases the surface modulus, which in turn, enhances the lifetime of the antibubbles. In [4], it has been shown that the lifetime of antibubbles is dramatically shortened with the use of degassed water for preparation of the antibubble solution. Antibubbles with a stabilised lifetime may potentially find use as a means of controlled delivery of drugs *via* encapsulation of chemicals (see [5]).

An open problem: What is the theoretical limit to the diameter and lifetime of antibubbles ?

2. *Breakup of Antibubbles*

Whether an antibubble is broken up by contacting with a syringe needle or if it breaks spontaneously (see the video `www.youtube.com/watch?v=XiqwUmP0iEM`), the inner fluid is ejected as two oppositely directed vortex rings (see *Figure* 2) in accordance with the conservation of angular momentum, while the air film coalesces into an air bubble which rises to the surface of the liquid. The ratio of the (asymmetric) mass distribution of the inner fluid between the two ejected vortex rings remains an open problem. Also see *Figure* 3 and the video taken with a high-speed camera and macro lens: `youtube.com/watch?v=nSiBXZ3dL8A`

3. *Antibubble Foam*

Can one produce a stable antibubble foam, which presumably floats under the surface of the soap solution? To the author's knowledge, there is no published method.

4. *Antibubble Fission*

Inspite of multiple attempts, the author did not observe 'fission'

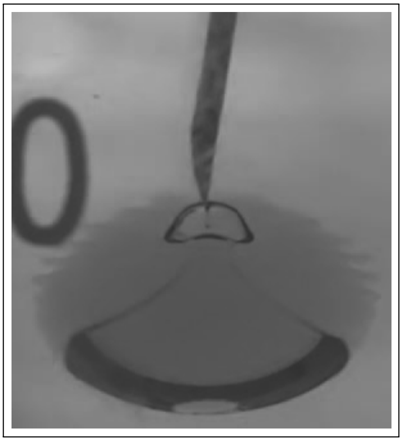

Figure 3. An antibubble undergoing breakup, note the expanding circular hole at the bottom.

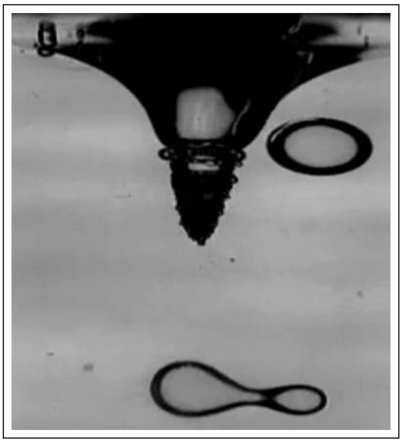

Figure 4. An antibubble trapped in a vortex flow, just prior to breakup.

of the antibubble into two smaller antibubbles (see *Figure* 4), an observation which is worthy of theoretical investigation. In the following video, taken with a high-speed camera and macro lens, we used a magnetic stirrer to create a vortex flow in the antibubble solution and injected an antibubble close to the swirling flow at the centre of the vortex: `youtube.com/watch?v=qhhVmzSNDjc`

5. *Antibubble Formation in a Non-Newtonian Fluid*

The author was unable to produce stable antibubbles when 50 ppm of polyacrylamide was mixed with the antibubble solution. The antibubbles were observed to form a relatively long thread under the liquid surface which eventually snaps causing the antibubbles to collapse, as seen in the video taken with a high-speed camera and macro lens: `youtube.com/watch?v=YCQy6ir59_Y`

6. ***Biliquid Antibubbles***

Can one form biliquid antibubbles, such as antibubbles with water-air-oil as the three fluids (inner phase: water, outer phase: oil) or oil-air-water as the three fluids (inner phase: oil, outer phase: water)? See [6] for an extensive discussion of multilayer fluid structures.

7. ***Effect of Temperature Variation***

What is the effect of temperature variation of the soap solution on the stability of antibubbles?

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Suggested Reading

[1] W Hughes and A Hughes, Liquid Drops on the Same Liquid Surface, *Nature*, p.59, Vol.129, 1932.

[2] C Stong, Amateur Scientist: Curious Bubbles in Which a Gas Encloses a Liquid Instead of the Other Way Round, *Sci. Amer*., p.116, April 1974; See the website: `antibubble.org`

[3] E Guyon, J Hulin, L Petit and C Mitescu, *Physical Hydrodynamics*, Oxford University Press, 2nd ed., 2015.

[4] B Scheid, J Zawala and S Dorbolo, Gas Dissolution in Antibubble Dynamics, *Soft Matter*, Vol.10, p.7096, 2014.

[5] A Poortinga, Long-Lived Antibubbles: Stable Antibubbles Through Pickering Atabilization, *Langmuir*, Vol.27, p.2138, 2011.

[6] A Anwander, R Grant and T Letcher, Interfacial Phenomena, *J.Chem. Educ*., Vol.65, p.608, 1988.

[7] Magnetic antibubbles have been produced with an internal phase comprising an aqueous dispersion of iron oxide microparticles, See: J Silpe and W McGrain, Magnetic Antibubbles: Formation and Control of Magnetic Macroemulsions for Fluid Transport Applications, *J. Appl. Phys*., Vol.113, p.17B304, 2013. See the video: `youtube.com/watch?v=CDaG5VXbezQ`