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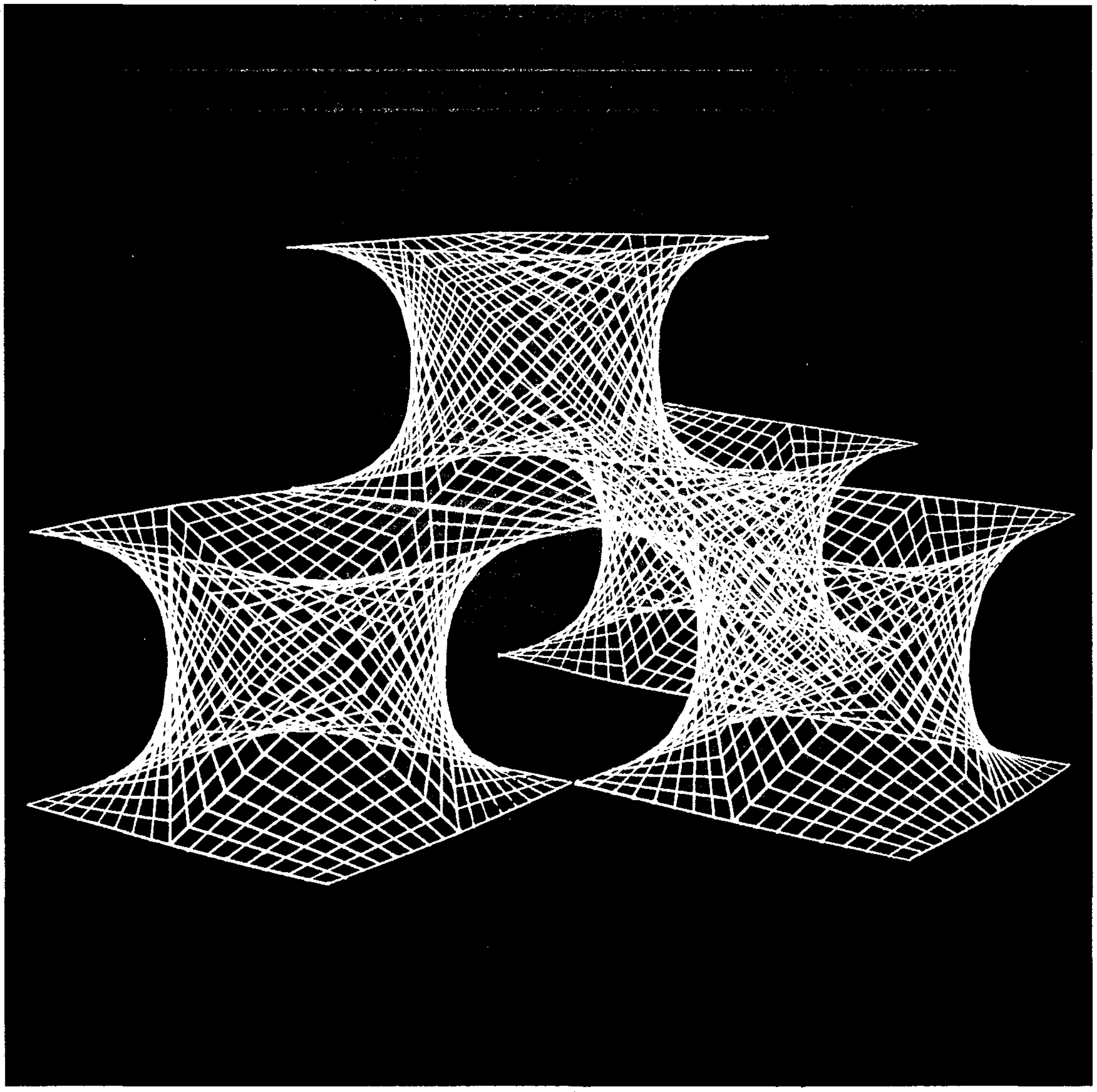

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EXPERIMENTS WITH SOAP BUBBLES

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Abstract: *The lecture comprises some selected experiments with soap bubbles demonstrating:*

a) a simple experimental technique to illuminate a hemispherical soap bubble in such a way as to create brilliant rainbow colors in order to study surface phenomena,

b) a new experimental method to determine the lifetime of soap bubbles statistically,

c) bursting of soap bubbles.

INTRODUCTION

A soap bubble is actually an example of a supramolecular spontaneously self-organized system. Soap films and bubbles, single or in combination, often exhibit an inherent symmetry of remarkable beauty. They can attract young and old as well as scientist and layman due to their diverse geometrical shapes, brilliant rainbow colors and fragility. Experiments with soap films and bubbles have the capacity to bridge Art and Science and can be used for entertaining, educational or scientific purposes. Moreover, as Caspar Schwabe pointed out to me:

The surface of a soap bubble is a direct visual manifestation of the three space coordinates and that of time, i. e., reflects the fourth dimension!

For an entrance to the literature of soap films and bubbles see refs.[1-8].

EXPERIMENTS

a) Experimental method to study events on the surface of a soap bubble

The history of a soap bubble as reflected by processes in the soap film from its birth to its ultimate collapse presents an ever changing scenario where many interesting observations can be made.

An experimental method to study these phenomena is to inflate a hemispherical bubble blown directly on a milk glass sheet of an ordinary light table. In this way the bubble becomes evenly illuminated by diffuse light and the soap film dome will after a while display marvelous iridescent rainbow color bands due to interference effects. The colors appear when the bubble has become sufficiently thin, of the order of the wavelength of visible light, i. e., 400 - 800 *nm.*

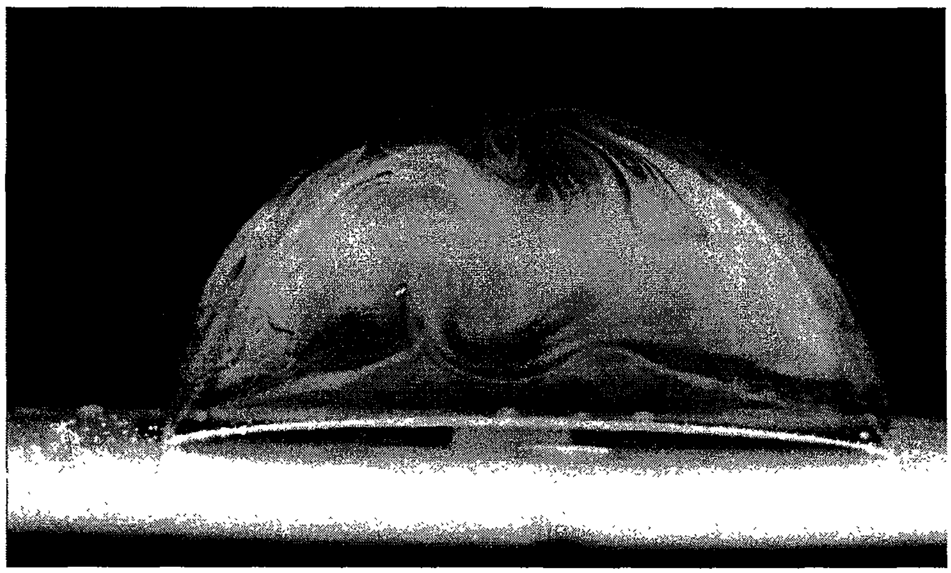

Figure 1

When the bubble is formed the thickness of the soap film is of the order of 10^{-5} *m* and no interference colors can be seen. Draining processes due to viscous flow and gravity convection rapidly brings excess liquid to the base of the bubble collecting at the so-called Gibbs ring. As a consequence the bubble becomes thinner and interference color bands appear. They reflect the gradual and steady increase in thickness of the bubble surface towards the base.

Light waves that are reflected simultaneously by the front and back surface of a soap film interfere with each other. This means that they either reinforce or cancel depending on their wavelengths relative to the thickness of the film. Because the different colors of white light illuminating the film correspond to different wavelengths, the colors are not all reflected in the same way. This is what gives the reflected light its color. Thus, if white light illuminates a film of thickness corresponding to the color yellow having a wavelength of 600 *nm*, this color is canceled by destructive interference, then only blue and red remain in the reflected light and the film appears purple. It was Newton who was the first man to understand these phenomena.

As the thinning process proceeds by evaporation, distortion of the concentric bands eventually takes place. The effect is enhanced by thermal heat from the illuminating lamp and more or less chaotic patterns may arise. Sometimes there will be a spectacular outburst of liquid streams from the Gibbs border due to pressure gradients, spreading over the soap film surface like a mushroom plume eventually dividing into two separate streams finally returning to the border. Sometimes swirls and spiral-formed structures can evolve.

Videotaping the bubble during its lifetime makes it possible to study more in detail the continuously changing thickness and topography of the soap film surface as reflected in the dynamics of the different colors caused by static and dynamic processes. Under favorable conditions, that is if the bubble survives long enough, the bubble can develop an ultrathin so-called "black film" starting at the top of the hemisphere, the thickness of the film being about 30 *nm* when formed. This occurs when the bubble survives long enough to drain and reach a thickness that is considerably less than one-quarter of the wavelength of the incident light, the reflected light from the outer and inner surfaces suffer from destructive interference. All colors are weakened to about the same extent and the film reflects little light, then it looks black against a dark background.

b) Experiment designed to measure lifetime of Soap Bubbles statistically

The lifetime of an individual soap bubble can easily and trivially be determined simply using a stopwatch. More informative is to use methods for a quantitative estimation of the lifetime of an ensemble of soap bubbles. The most obvious and easiest way to do this is to produce a large number of bubbles in order to get some statistics and then count the number of remaining bubbles after suitably selected time intervals. We face two problems: 1) the bubbles have to be of equal size, thickness, and 2) we want to produce all the bubbles at the same time.

A simple experiment turned out to satisfy these requirements. When touching the surface of a soap solution with an ordinary drinking straw, a thin soap film is produced across the open end of the tube. Next, the straw was turned upside down and dipped once more into a liquid that can be simply water. Obviously, in this way a bubble is produced at the upper end of the tube, the size of the bubble being dependent on the extent the straw is depressed into the liquid.

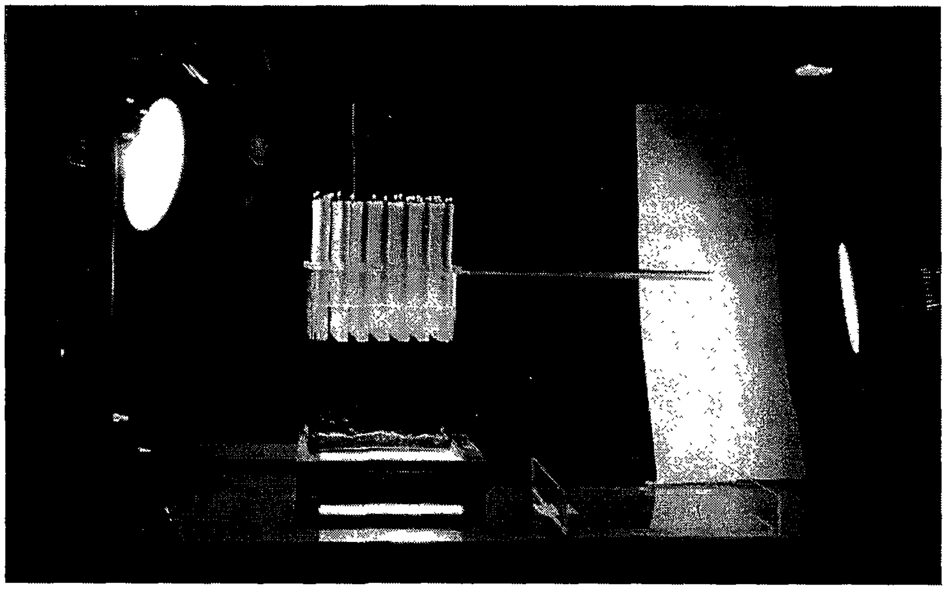

Figure 2

This experiment was the foundation for constructing a so-called "bubble-organ". In Figure 2 the experimental arrangement is depicted. This bubble plate holds 42 symmetrical placed plastic tubes of the same diameter and length depressed into the liquid to the same depth, producing instantaneously a corresponding number of bubbles, all of the same size. The length of the tubes was 20.0 *cm*, the diameter 15.0 *mm* and the spacing between the centers 30.0 *mm*. One must make sure that the distance between the tubes is such that a bursting bubble does not trigger the collapse of other bubbles in the vicinity. In fact, this is an effect that must be interesting to look at in more detail!

The number of remaining bubbles can be counted at selected time intervals and the half-life, $t_{1/2}$, determined. In order to facilitate the counting of bubbles it was found convenient to videotape the bubble field for later analysis. This method is convenient to use especially when the lifetime of the bubbles is rather short.

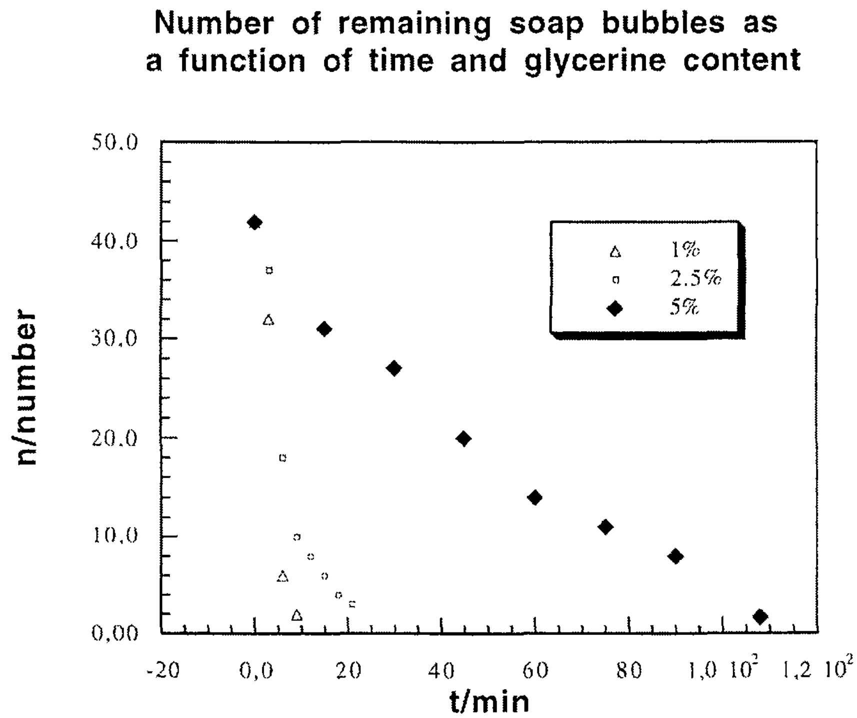

Figure 3

Typical results from experiments using the bubble plate with 42 tubes is shown in Figure 3. The average value of three identical experiments is presented. The number of remaining bubbles at selected points of time has been plotted as a function of time. Three different soap solutions were used containing 1.0, 2.5 and 5.0 % of glycerine, all of them having 1 % by weight of a commercial concentrated liquid dishwasher solution.

c) Experiments with bursting bubbles

Blowing a soap bubble and allowing it to settle on a piece of paper became the starting point for a series of interesting experiments with the aim to study the resulting pattern from bursting bubbles. A soap bubble on a piece of paper rests in the form of a half-sphere, a hemisphere. Of course it bursts sooner or later and the fragmented film gives a more or less symmetrical reminiscent pattern on the paper. In order to reveal the pattern powdered carbon was sprinkled over the paper surface. The carbon particles selectively stick to the soap patches on the paper and the excess carbon can be wiped off the surface by shaking the paper slightly. An aesthetically very attractive pattern appears.

A more systematic analysis of the distribution of these droplets was performed under different experimental conditions. For instance, bubbles derived from different soap solutions were deliberately punctured at specific spots. Moreover, these experiments were found to be more conveniently conducted by producing the bubble from a colored soap solution using the dye Congo red. In this way an excellent colored fingerprint of the reminiscent of the bursting bubble was obtained. Figures 4a and b give examples of droplet patterns that can be obtained from these experiments.

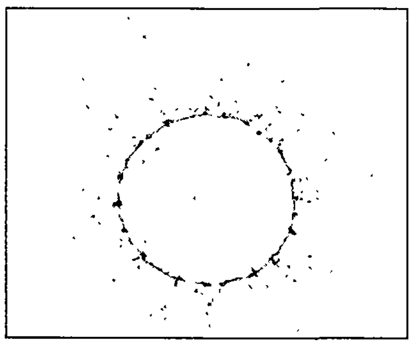

Figure 4a

Figure 4b

Figure 4a shows a bubble that has been punctured centrally at its highest point, giving a highly symmetrical droplet pattern on the paper. When a circular hole is generated in the film, it expands uniformly and radically due to action of the surface tension and the release of the excess pressure in the bubble defined by the equation $\Delta p = 4\gamma/R$, γ being surface tension and R radius of the bubble. The liquid is collected in the growing rim forming a cylinder that becomes unstable, collapses and creates droplets of different sizes which are thrown out. Depending on the composition of the soap solution as many as 1000 droplets can be produced. Figure 4b shows a bubble that has been punctured close to where the bubble is supported by the paper. In this case the droplets from the fragmented soap film have been thrown out within a very narrow angle on the opposite side of the point of rupture. A more detailed description of these experiments on exploding bubbles of various kinds is given in ref. [8].

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