Looking Into a Bubble

You would have to be a real curmudgeon not to like bubbles. A person who is not attracted to a big, beautiful bubble must be suffering from an acute, premature loss of childhood, no matter what his or her age.

When people who are interested in optics look at a bubble, they frequently see a beautiful example of colors produced by the interference of light. It is not difficult, at the level of a general physics course, to calculate the path difference between light rays reflected from the two surfaces of a soap film, and for a given thickness of film determine which reflected wavelengths are enhanced by constructive interference and which are diminished by destructive interference. (You can even explain the dark color of the very thin film if you remember to include the phase changes on reflection at the two surfaces.)

The bubble shown in Figure 1 displays the iridescent patches that we can understand as a thin-film interference effect. When I am talking about such things to an audience of non-scientists, I often point out that, for me, understanding the process that produces those colors does not diminish my pleasure in their beauty. The fact that I understand more about interference colors in a bubble than does the average pedestrian allows me to see and enjoy more effects than that hypothetical individual. I think it is a message about science worth spreading to non-scientists and even, as a reminder, to “serious scientists,” who may have forgotten what got them interested in science in the first place. (Shown along with the bubble in Fig. 1 is its creator, my daughter.)

The (more or less) cylindrical bubble in Figure 3 shows the same effect, with a dark tree image running horizontally down the middle of the bubble. The optical system (bubble) is rather simple, and if we can’t explain what the picture shows, we better worry about whether they will take away our license to practice optics. My guess is

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Figure 1. The beautiful, iridescent colors of a soap bubble can be understood to result from the interference of light reflected from a thin film. (Photo by the author.)

Figure 2. Inside the bubble, nearly a meter in diameter, one can see a horizontal band of trees. What are we seeing? (Photo by R.F. Newell or the author; I’m not sure who took the picture.)

Figure 3. A nearly cylindrical bubble containing the horizontal band of trees. (Photo by R.F. Newell.)
that you will come up with the answer after a little thought, as I did. I remembered another photograph I had taken that provided the clue to understanding these pictures.

If I showed you the "clue photo" on this page, you couldn't avoid looking at it. Think about what's causing the image before reading on. Turn to page 64 for your clue if you think you have the answer. Then come back.

The "After Image" photo on page 64 is a self-portrait of my reflection in a soap bubble. The camera taking the photo is located just to the side of my head. The bubble is formed on the end of a glass tube that I am holding in front of my face and camera. The relevant feature is the appearance of two images of my face, one inverted and one upright. It is clear that the images are the result of reflection and, indeed, with a little thought, we realize that one image results from reflection at the back (concave) surface of the bubble and the other from the front (convex) surface.

Figure 4 shows the familiar ray diagrams that locate the images resulting from the two reflections. The back surface forms a real image that is inverted. It is real because rays diverging from a point on the object actually converge to the corresponding point on the image, located in space between the back surface and the bubble center. The front surface forms a virtual image that is upright. It is virtual because the reflected rays diverge as if they came from an image point located between the front surface and the bubble center, even though there are no rays that actually converge to the image at that position.

From the ray diagram, we see that the images don't occur in the same plane, but actually are separated by a distance approximately equal to the radius of the bubble. In the "After Image" photo, you can see that I had the camera focused closer to the upright image than to the inverted image, which is somewhat out of focus. Had I known that I was going to use this photo on this page in Optics & Photonics News, I probably would have tried harder to focus between the two images, with the camera stopped down to increase the depth of field so as to include both of the images.

Understanding the "After Image" photo helps us understand what we are seeing in the big-bubble photos in Figures 2 and 3. We are not seeing the trees in front of the camera, but, in the bubble, reflected images of the trees and sky behind the camera. The upright image shows the sky at the top and the inverted image shows the sky at the bottom, with the band of trees from the two images overlapping. It is not a complicated explanation, but a simple answer to a simple question.

I will end with an illustration of the way scientific terminology is determined—clearly an important matter in the development of science. In Figure 4, we see that the real image is inverted and the virtual image is upright. With some sketching, you can convince yourself that this is the case with converging or diverging lenses or mirrors, with any combination of image and object distances. This idea led to an incident that began in the late 1970s and ended two decades later.

When Peter Franken (University of Arizona, Tucson) was president of the Optical Society in 1977, he sponsored a limerick contest. The limerick had to relate to optics, and there were prizes for the winners. As I recall, Peter offered a 30-cm tall cactus as first prize, and, as second prize, two 30-cm tall cacti! (If I have it wrong, I'm sure he will correct me.) With an election year coming up, I had an idea for a limerick that I worked out shortly after seeing the contest announcement. I knew that if I submitted my entry six months before the deadline, Peter might lose it, since such things are almost never received until the week before (or after) the deadline. So I waited. Here was my entry:

To a politician who would reveal
An Image with public appeal,
Said his optical friend,
"In my view I contend
If it's Upright it's Virtual, not Real!"

Unfortunately, when I thought of it again some months later, I had missed the deadline and someone else had won the fame and cactus.

About 20 years later I was sitting at a scientific meeting dinner next to Robert Resnick, author and co-author of a series of textbooks that have helped to educate generations of students in physics. Knowing that he is a connoisseur of limericks, I recalled the contest and my failed entry, and wrote it on a napkin to show him. He laughed politely, put the napkin in his pocket, and I promptly forgot the incident. When I ran into him a month or so later, he told me, with some enthusiasm, that they were going to use my poem! He had shown the limerick napkin to his co-author, David Halliday. The third edition of their Fundamentals of Physics was in the galley proof stage. Halliday, who was responsible for the optics section, had referred to the virtual images formed by lenses or mirrors as "erect images." However, he liked the poem enough that he went through the proofs and, wherever there was a reference to an "erect image," he changed it to "upright" image so that he could include the poem in the new edition, where it is now found.

If you thought that all decisions about scientific terminology are decided by a room full of serious people gathered about a large conference table in Geneva or Paris, now you know how it really happens.

Figure 4. Ray diagrams showing the real, inverted image formed by reflection from the (a) concave back surface of the bubble and the (b) virtual, upright image formed by reflection from the convex front surface.
Self Portrait in a Bubble.

In addition to the bands of interference colors circling the bubble, we see two images formed by reflection. One is an upright image from the front, convex bubble surface, and the other is an inverted image from the back, concave surface. The images are separated in space, and in this case, the camera was focused closer to the upright image, leaving the inverted image somewhat out of focus. (Photo by Robert Greenler. See “The Light Touch,” page 50.)