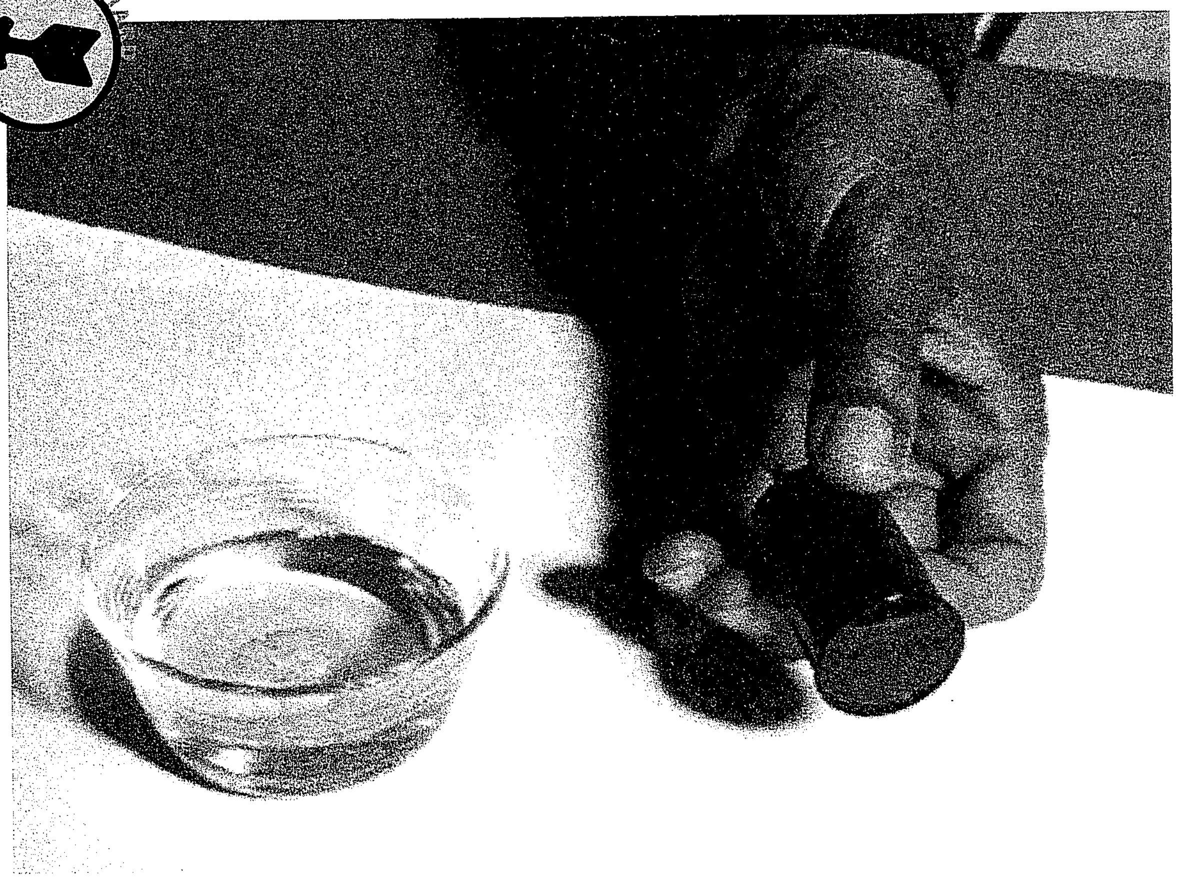
Soap Film in a Can

What light from yonder soap film reflects?

You've probably seen the iridescent colors that appear in a soap bubble when the light strikes it just right. This effect—the result of interactions between light waves and the soap film—can be seen very clearly when you put the soap film in the opening of a black film canister. The colors of the soap film are bright against the black background of the can.



Materials

- dishwashing liquid
- water
- pitcher or bowl with a spout
- shallow dish
- sheet of white paper
- black film canister without lid
- pencil

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ASSEMBLY

1 Make a bubble solution by mixing 1 part dishwashing liquid in 16 parts water. This is equivalent to $\frac{1}{4}$ cup detergent in 1 quart of water (about 60 mL of detergent in 1 L of water). If you want to make a larger quantity, use 1 cup (240 mL) detergent in 1 (4 L) gallon of water.

2 Fill a shallow dish approximately a half inch (1 cm) deep with the bubble solution.

3 Place the white paper on a tabletop.

To Do and Notice

Dip the open mouth of the film canister into the soap solution, and then pull it out.

In a brightly lit place, hold the canister horizontally about an inch (a few centimeters) over the white paper, so that the soap film is in a vertical plane.

Watch the colors form and move in the film. Notice the horizontal bands of color.

Notice that after awhile the top of the film becomes "invisible." Look carefully through this part of the film into the canister. What do you see?

Poke a pencil point into this invisible region of the film. What happens?

What's Going On?

The soap film is a water sandwich. A layer of water is held between two layers of soap molecules. When the soap film is vertical, the water slowly drains down under the pull of gravity, thinning the top part of the film and thickening the bottom part.

Most of the light striking the soap film passes through the film, but about 4 percent reflects from the front surface of the film back into the air, and another 4 percent or so reflects from the back surface of the film. The light waves reflecting from the two surfaces interfere with each other in different ways, depending on the wavelength of the light and the distance between the front and back surfaces of the film.

For each wavelength of light, there are soap-film thicknesses that will put the two light waves *in phase,* with their crests and troughs lined up as shown in figure 1. These waves *interfere constructively*—they reinforce each other, and the color that corresponds to their wavelength is made more strongly visible. For each wavelength of light there are also soap-film thicknesses that will put the two light waves *out of phase,* with the crests of one lined up with the troughs of the other (see figure 2). These waves *interfere destructively*—they cancel each other out, and the color that corresponds to their wavelength is removed from the light entering your eyes.

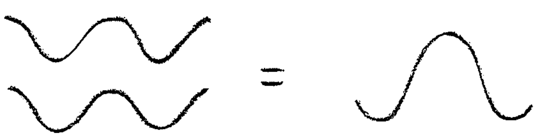

Figure 1 ***Constructive interference***
Combined, these waves reinforce each other.

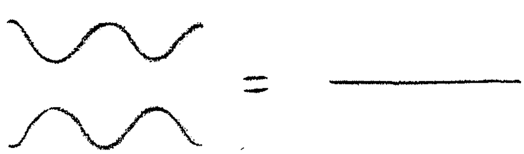

Figure 2 ***Destructive interference***
Combined, these waves cancel each other.

You perceive bands of color on the soap film because at each location on the film a different color of light is being destructively removed. Where the thickness of the soap film causes the destructive removal of one of the primary colors that makes up white light, you see a mixture of the two remaining colors:

white – red = blue + green = cyan (bluish green)

white – green = red + blue = magenta (reddish blue)

white – blue = red + green = yellow

What's causing each specific color you perceive in different parts of the soap film? Let's start with the top part of the film, which should have become invisible. The invisibility of this part of the film is the result of all the light reflecting from it getting canceled out by destructive interference. This occurs because the soap film is thinner than any of the wavelengths of visible light. The back part of the film is so close to the front part that the waves reflecting off the two are barely shifted in relation to each other.

At the same time, it happens that the light waves reflecting from the front of the soap film are inverted—dumped upside down—while those from the back are not. As a result, all the wavelengths of light reflecting from the front of the film are exactly out of phase with the wavelengths of light reflecting from the back of the film, and they all cancel out, as shown in figure 3 on the next page.

Below the invisible portion of the film, you should have noticed a silver-colored region. In this region, the film is about one-quarter of a wavelength of blue light in thickness. For this

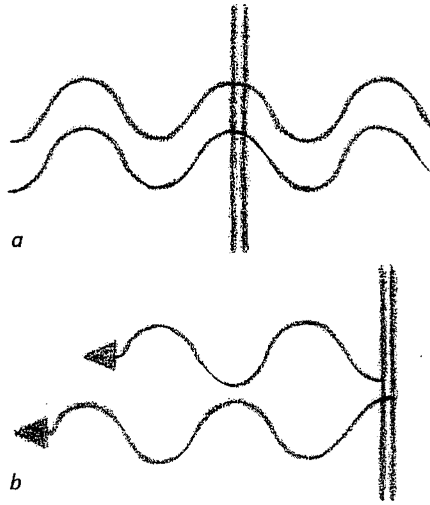

Figure 3 *Behavior of light waves in the thinnest part of a soap film. Most of the light passes through the film (a), but some reflects from the front surface and some from the back surface (b). The light waves that reflect from the front surface are inverted (turned upside down) and become out of phase with the waves reflecting from the back surface; as a result, they cancel each other when they combine.*

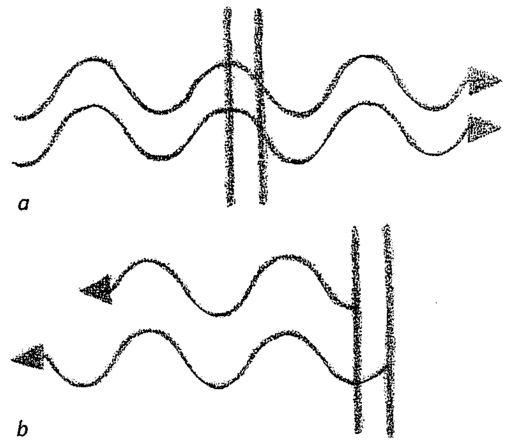

Figure 4 *Behavior of light waves in a soap film that is one-quarter of a wavelength thick. Most of the light passes through the film (a), but some reflects from both the front and back surfaces (b). The wave reflecting from the back surface must travel an extra one-half wavelength—one-quarter of a wavelength in each direction—before it reenters the air in front of the film. The wave reflecting from the front surface is inverted. These two effects put the waves in phase, and they reinforce each other when combined.*

thickness of soap film, the blue light waves reflecting from both the front and back surfaces of the soap film are able to add together to produce a strong blue color (see figure 4). All other colors are also reflected, although somewhat more weakly. The sum of all these reflected colors is bluish-silver.

Where the film is one-half of a wavelength of blue light thick, the blue waves cancel. (**Note:** The wavelength of light in the soap film is shorter than the wavelength in air by about 30 percent.) But at this location the film is also one-quarter of a wavelength of red light thick (red light has a wavelength about twice that of blue light). Here, the red waves are reinforced by constructive interference for the same reason that blue waves are reinforced where the film is one-quarter of a wavelength of blue light thick. The result of canceled blue light and reinforced red light is a reddish band.

In general, where blue light is strengthened, red light is weakened, and vice versa. The result is alternating bands of color. Red and blue are not the only colors involved; the same thing is happening to other colors (green, yellow, etc.) at each film thickness. The color bands are not pure colors; rather, they are the overall result of the combining of the varying intensities of many colors at each particular thickness of film.

So What?

The coatings applied to camera lenses affect light in much the same way as soap films do. The thin-film optical coating deposited on many camera lenses is chosen to minimize the reflection of light in the middle of the visible spectrum (orange, yellow, and green). The thickness of the coating causes the reflecting waves in these wavelengths to cancel each other. By minimizing reflection from the lens, transmission of light through the lens is maximized, and more light reaches the film in the camera. When reflection is minimized in the middle of the spectrum, however, it is not minimized at the ends of the spectrum (red and blue). Thus the reflected light is relatively richer in red and blue, and the lens looks purple or magenta.

Sometimes you see colors of an oil slick on a puddle in the street. These colors look a lot like the soap film colors you see in this snack. The layer of oil that makes these colors is about the same thickness as a wavelength of light. The light reflecting from the top and bottom of the oil layer combines to create colors in the same way that light reflecting from the soap film does.

Going Further

Soap Film Dome

Drill a hole in the bottom of the film canister with a $\frac{3}{16}$-inch drill bit. Create a soap film over the mouth of the film can, then blow through the hole. The soap film will bulge out into a dome. Then allow the air to rush out of the hole. You can feel the breeze coming from the hole with your hand or see it by holding the hole near a candle flame. Notice the dome flatten out. The pressure in the film can is greatest when the radius of curvature of the dome of soap film is least.

The interesting thing is that the radius of curvature is least when the dome is largest (see figure 5). So the larger the dome, the higher the pressure and the faster the air rushes out of the can. Therefore, the soap film dome deflates rapidly at first and slows down as it flattens. If you plug the hole and place the film can with the opening facing upward surmounted by a soap film dome, colored rings will appear in the soap film.

Did You Know?

Hooke's Mistake

Robert Hooke, a seventeenth-century English scientist, may have been the first to observe a soap film that was thin enough not to reflect light and thus appear invisible. But instead of describing it as invisible in his letter to the Royal Society, he wrote that it appeared not to exist and that some force held the rest of the bubble film in place. You prove Hooke wrong when you poke the invisible part of the film and cause the whole film to break.

The Thickness of Black

Soap bubbles have two different stable thicknesses that look black. The thicker of these is called the common black film. It is 30 nanometers thick—the thickness of about 300 atoms, or 10 soap molecules, or $\frac{1}{20}$ the wavelength of red light. The thinner film is called the Newton black film. It is about 6 nanometers thick—the thickness of two soap molecules, or $\frac{1}{100}$ the wavelength of red light. The Newton black film is much more transparent; that is, much "blacker."

Credits

Linda Hjelle contributed to the development of this snack.

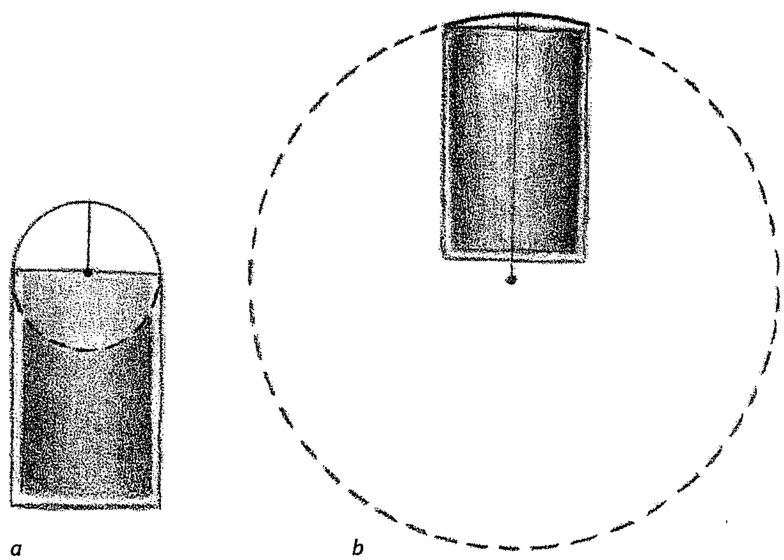

Figure 5 *The soap film makes a part of the sphere over the mouth of the film canister. The dashed lines show the entire sphere. Note that the soap film portrayed in (b) is part of a larger radius sphere.*