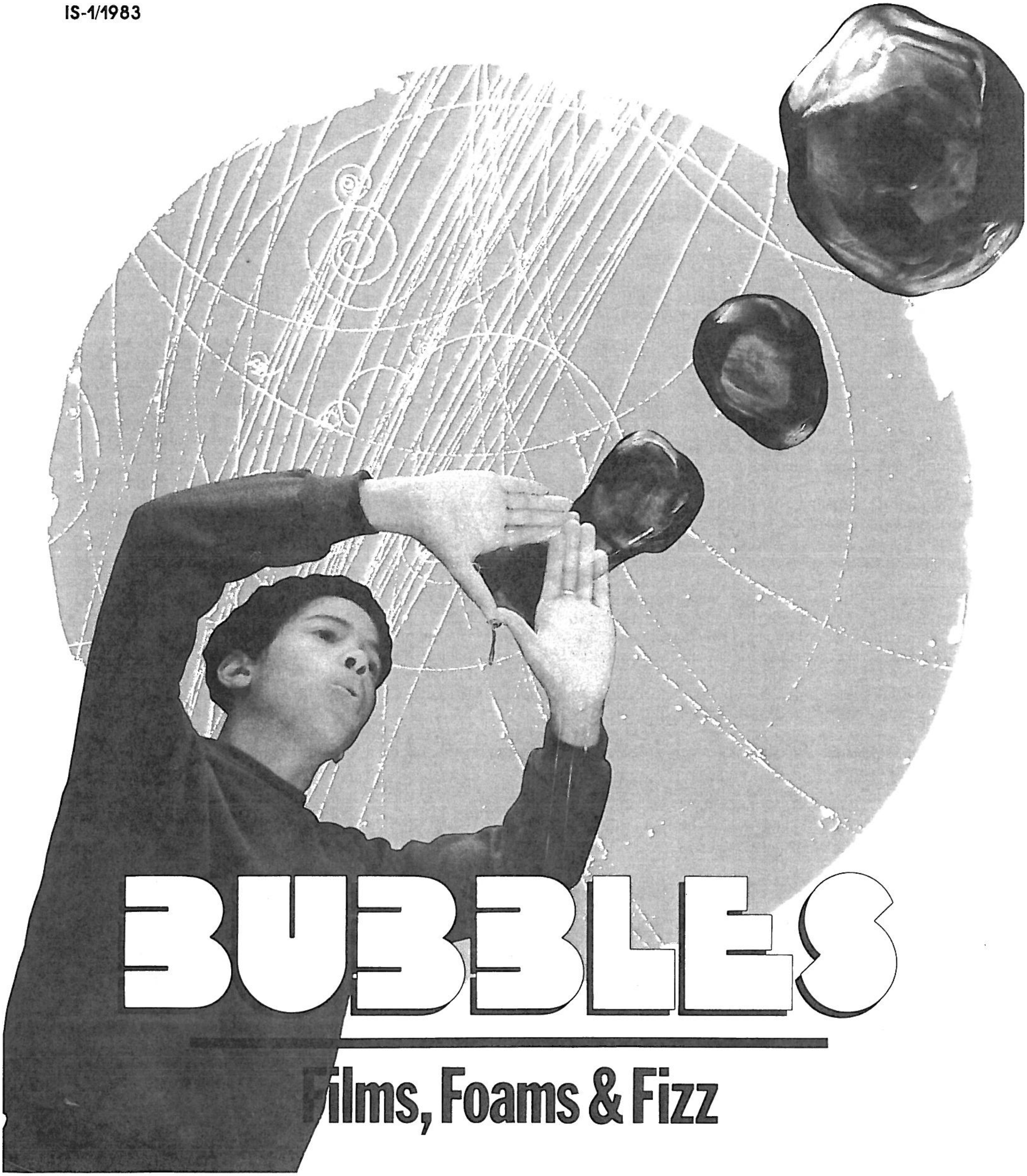
IDEAS IN SCIENCE

Notes for Teachers

IS-1/1983



BUBBLES

Films, Foams & Fizz

Films, Foams, and Fizz: A Brief Introduction to the Variety and Importance of Bubbles

A bubble is more than a thin film of soap and water wrapped around a puff of hot air. To a poet, a bubble is a metaphor for the brevity of life. To a mathematician, it is an example of the elegant minimum. To a chemist, it is a study in the interaction of surfaces. And to a baker of bread or a brewer of beer, bubbles are an essential ingredient, without which their products would indeed be flat.

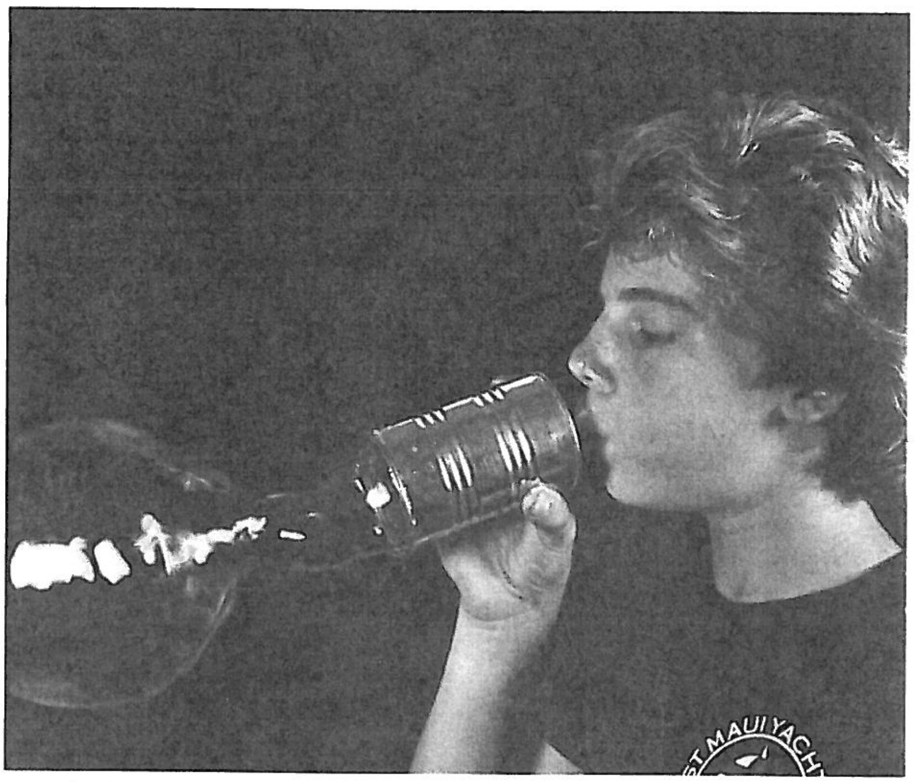
A bubble, by our definition, is encapsulated gas. The material that surrounds the gas could be a soap film; or it could be lemon meringue; or it could be the rock that forms when lava solidifies. By this definition, even a lightbulb filled with inert gas is a bubble. A helium balloon is a bubble. When you hold your breath, you become a human bubble. Our definition is a broad one and may have shortcomings. If a light bulb is a bubble, isn't a vacuum tube a bubble? By our definition, since a vacuum tube does not enclose gas, it is not a bubble. You are welcome to accept our definition, refine it, or develop a definition of your own. Part of the business of science is the making of definitions, the drawing and redrawing of lines. With our definition, we have drawn a line around a variety of interesting natural phenomena.

The study of bubbles opens the way to analysis of a variety of topics. Thin films, like the iridescent film of a soap bubble, lead to the study of surface tension, chemistry, light and color. Foams, like the suds in a bucket of dishwater, provide an interesting avenue into the study of geometry

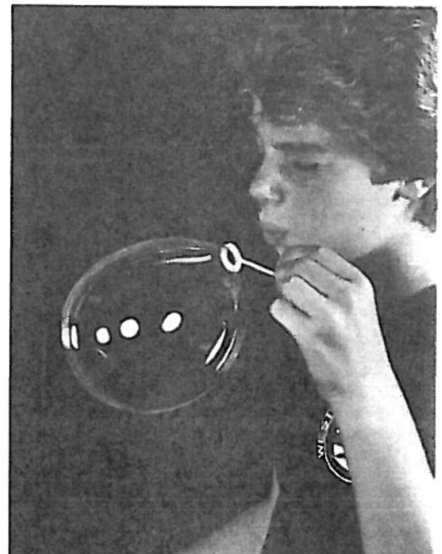
Touch a bubble with a dry finger and you disrupt the bubble film. Touch it with a wet or soapy hand, and the water on your hand merges with the bubble film. You can catch bubbles, stretch bubbles, measure bubbles—as long as everything that touches the bubble is as wet as the bubble itself.

and serve as a model for a variety of natural systems, ranging from honeycombs to plant cells. And fizz, like the sparkling bubbles in a glass of champagne or a bottle of soda pop, can lead to analysis of the effects of temperature and pressure on various states of matter, and of the uses of bubbles in bread, beer, and bubble chambers.

When you take a close look at bubbles—or at any natural phenomenon—you end up looking at the world around you in a new and different way. Start thinking about bubbles and you may find yourself intrigued by the colors of oil films on a wet pavement, fascinated by the changing forms of bubbles in a pot of boiling water, engrossed by the bubble clusters in your dishwater. Bubbles are all around you. We can only provide you with an introduction to them. After that, it's up to you. ○

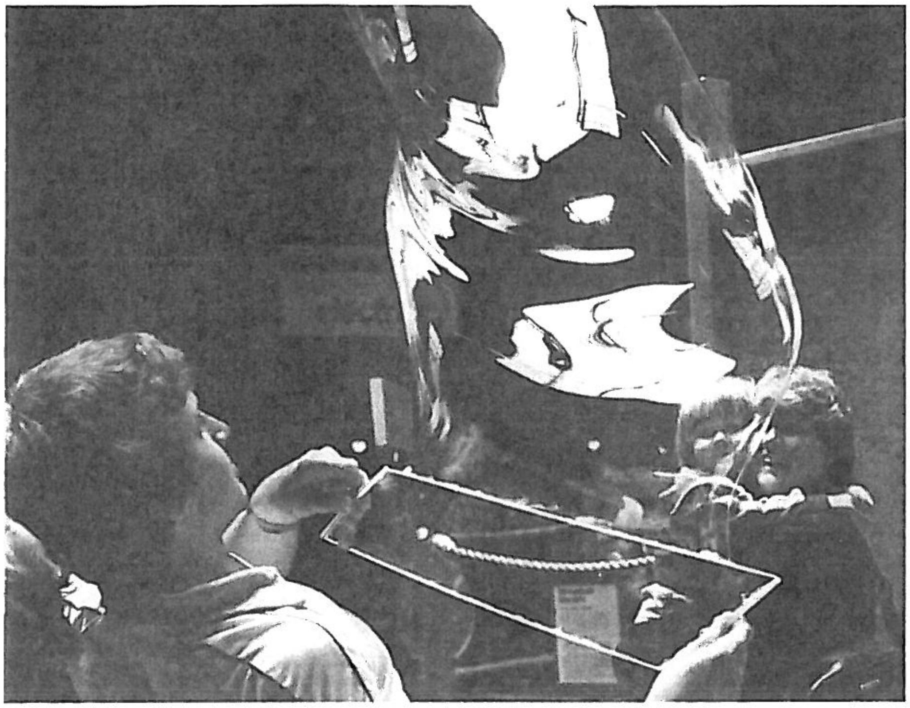


A tube of just about any size is great for bubble-blowing. If you want to work with a delicate instrument, use a plastic drinking straw. If you are going for size, try a can with both ends cut away. Dip the end of the tube in the soap solution to form a soap film over one end; blow in the other end. The longer the tube, the smoother the flow of air at the far end, and the more successful your bubble-blowing.



Knowing the importance of a gentle and smooth flow of air can help you improve your skill with a bubble wand, the bubble-blowing hoop that comes with most commercial bubble solutions. Pay attention to the shape of your mouth and the speed of your puff of air. If you blow hard, you burst your bubble or produce many small bubbles. If you blow more gently, you can produce a big bubble.

Stimulating Students' Thinking About Bubbles



The most familiar bubble hoop is the bubble wand that comes with commercial bubble solutions. But for the serious (or truly playful) bubblologist, the bubble wand is just a beginning. Using plastic drinking straws and string, you can make much larger hoops, designed to be swung through the air to launch enormous bubbles.

Science starts with experimentation, observation, and reflection—trying things out to see what happens, then thinking about what you have seen. Soap bubbles and bubble films provide an ideal experimental medium: they are cheap, easily manufactured from readily available material, and non-threatening. It's true that bubbles are fragile, but when your soap bubble bursts, you will find it easy to replace.

Though most people think of bubbles as frivolous, mathematicians, surface chemists and other scientists take them seriously. In the classroom, soap films and bubble clusters can give students a chance to make observations and deductions. Bernard Zubrowski, an educator who uses bubbles in teaching science and math, explains:

What I hope children will gain from playing with bubbles is the realization that there are many patterns in both natural and human-made phenomena, and that discovering and explaining such patterns is a vital part of science.... The shapes that bubbles take are similar enough to encourage the search for patterns, yet they are always different enough to arouse anticipation.

Bubble-blowing encourages invention, innovation, curiosity, exploration, and appreciation of beauty. At the same time, it is an essentially playful occupation. Trying to blow a really big bubble is a good exercise in technology; it motivates a student to experiment with different techniques, and consider why one method succeeds where another fails.

Bubblology* helps imprint the notion that science is a playful way of stretching your thinking about the world around you.

The *Doing Science* activities included with this packet describe a variety of bubble-blowing tools and techniques. Experiment and learn. Play a little. The materials are simple; the ideas are inviting, and it's all good clean fun. ○

*If the study of life is biology and the study of mankind is anthropology, then the study of bubbles must be bubblology. Don't worry if you can't find the word in your dictionary. The word is used by bubblologists and bubblesmiths to describe their work, but it has not yet entered common usage.

Bubble Solution

Different bubblologists prefer different bubble-blowing recipes. Each one adjusts their recipe to take into account the mineral content of their local water and the conditions in their particular bubble-blowing environment. A *Doing Science* Activity included in this packet suggests a procedure that you and your students can use to evaluate the bubble-blowing qualities of several detergents.

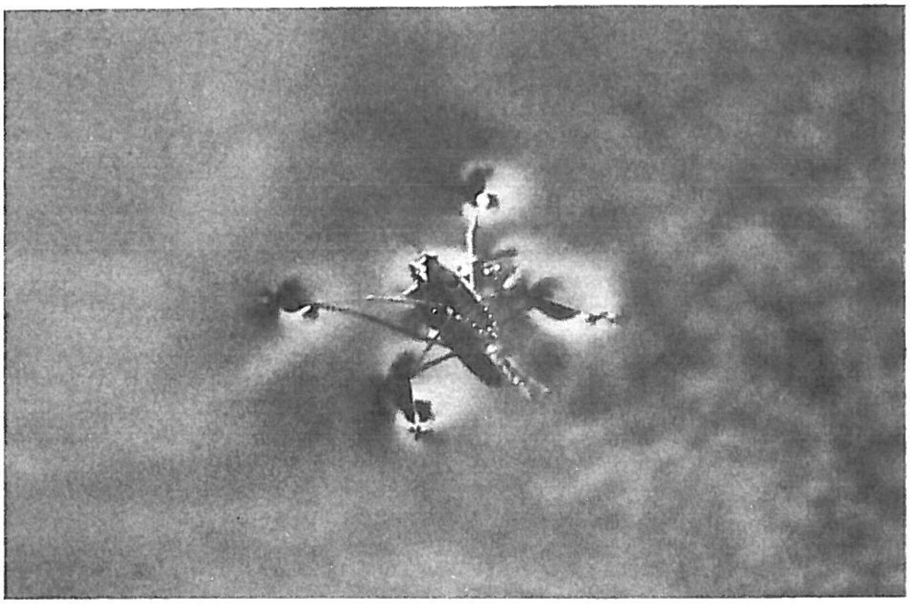
The bubble solution that has proven most successful at the Exploratorium is:

2/3 cup Dawn or Joy liquid dishwashing detergent
1 gallon of water (Distilled water is ideal, though tap water will do.)
1 tablespoon glycerine (optional, available at drug stores)

Glycerine is not essential to a successful solution, but the addition of glycerine to the mixture increases the durability of your bubbles. Bubbles burst when the soap film becomes too thin to contain the air pressure. The film grows thin because water evaporates from it and because the bubble solution drains away from the top of the bubble. Glycerine increases the solution's viscosity, slowing the solution's movement away from the top of the bubble, and reduces the evaporation from the bubble film.

We have discovered through experimentation that aging the solution for at least five days dramatically improves its ability to form bubbles. If you don't want to fool with glycerine, we suggest you age your solution. Why? We suspect that the evaporation of ethyl alcohol (one ingredient in Dawn) from the mixture accounts for the improvement, but we don't know for certain.

Start with Soap and Water



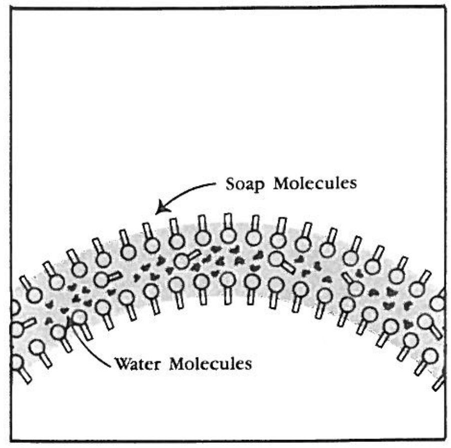
A waterstrider walks on water, never getting its feet wet. Each foot makes a dimple in the water's surface, but does not break through.

Water is fine for drinking, but it is not much good for blowing bubbles or for washing dirty dishes. To make a bubble that lasts for more than an instant or to clean the grease from a dirty plate, you need to add soap. Water—plain, ordinary water—is a very sticky liquid. Water molecules tend to stick together; they are unwilling to spread out to form a bubble film or to surround a bit of grease.

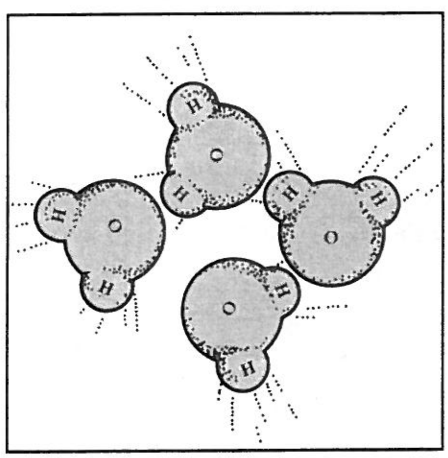
If you have ever watched water striders, the long-legged insects that skate on the surface of still ponds, you know that water acts as if it has a thin film on its surface. Take a close look at a drop of water sitting on wax paper, plastic, or a clean tile or linoleum countertop, and you can see that the drop does not lie flat like a puddle in the street. It looks more like a tiny waterballoon; the water seems to be contained by a stretchy membrane. Add a touch of soap, and the drop flattens like a burst waterballoon. Soap weakens the stretchy skin of the drop.

Water's stretchy skin results from its chemical composition. Each water molecule is made up of two hydrogen atoms and an oxygen atom. Within the molecule, the hydrogen atoms form bonds with the oxygen atom by sharing their electrons. But the electrons are shared unequally: the oxygen tends to grab the negatively charged electrons, leaving the hydrogen atoms positively charged and free to attract the electrons of other oxygen atoms. Very weak bonds (known as **hydrogen bonds**) form between the hydrogen atoms and the oxygen atoms of different water molecules.

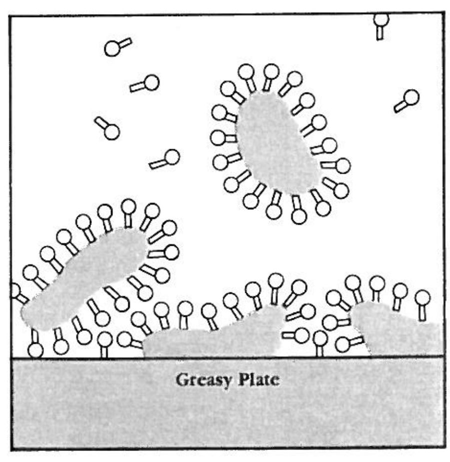
A molecule in a water drop is pulled in many directions by these weak bonds with the molecules that surround it. For a molecule in the center of the drop, each pull from a molecule to the right is matched by a pull from a molecule to the left; each pull upward is offset by a pull down. For a molecule on the surface of a waterdrop, the situation is different. Since there is no liquid water beyond the surface, there is no corresponding pull outward for each pull in, and the bonds with other water molecules pull the surface molecules back into the drop. The pull of these hydrogen bonds makes the water molecules at the surface behave like a stretchy skin, a phenomenon known as **surface tension**.



The surface of a bubble film is crowded with soap molecules. Each soap molecule has one end that is repelled by water. The soap molecules that are near the surface of the film push their water-repelling ends out into the air, squeezing between water molecules and shoving them apart to do so. The weak bonds between water molecules that make water so sticky decrease in strength as the distance between water molecules increases. By separating the water molecules at the surface, soap molecules decrease the water's stickiness and its surface tension.



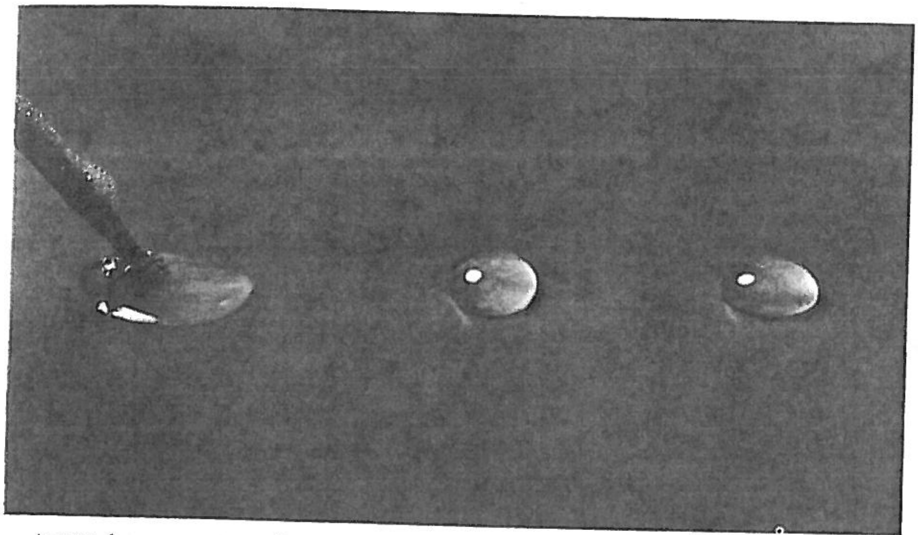
Each water molecule is made up of two hydrogen atoms and an oxygen atom. Within the molecule, the hydrogen atoms form bonds with the oxygen atom by sharing their electrons. But the hydrogen atoms also form weak bonds with the oxygen atoms of other water molecules. It is the existence of these bonds that makes water a very sticky liquid.



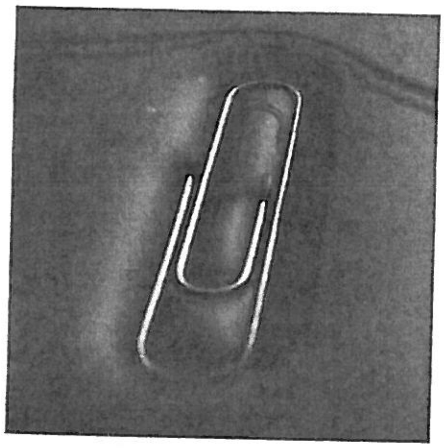
A soap molecule has one end that is attracted to water and one end that is attracted to grease. When you wash a greasy plate with soapy water, the soap molecules attach to the grease with their water-repelling ends, leaving their water-attracting ends in the water. When you rub the plate with a sponge, the water pulls on the water-attracting ends of the soap molecules, which pull on the grease. When the grease is pulled free of the plate, the soap molecules surround it, and it can be washed away with the water.

soap molecules, each with its water-repelling end in the air. Soap does not evaporate, and the crowds of soap molecules on the surface keep most of the water molecules away from the surface, in the safety of the film.

The soap molecule's two-sided nature also helps you clean your dinner dishes. When you wash a greasy plate with a mixture of soap and water, the water-repelling end of the soap molecule attaches to the grease; the water-attracting end remains in the water. When you rub the plate with a sponge or run water over the soapy surface, the water pulls on the water-attracting ends of the soap molecules, which pull on the grease. Once the grease is free of the plate, the soap molecules surround it, and it can be washed away with the water. ○



A water drop on wax paper forms a rounded shape, as if the water were contained by a thin skin. If you poke the drop with a clean toothpick, it reacts but retains its basic shape. Poke it with a soapy toothpick and the drop suddenly becomes a puddle. In your kitchen or classroom, you can compare the profile of a waterdrop to the profile of a drop of vegetable oil or rubbing alcohol, liquids with lower surface tension.



A paperclip will float if you balance it on the prongs of a fork and place it gently on the water's surface. If you have trouble making a paperclip float, try rubbing it with a candle. The thin coating of wax repels water molecules and makes the molecules at the surface even more reluctant to move aside and let the paperclip sink. You can sink a floating paperclip without touching it. How? Just by adding a few drops of soap to the water.

A waterdrop on wax paper forms a rounded shape because the drop's surface tension—the hydrogen bonds between water molecules—opposes the downward pull of gravity. Flattening out would give the drop a larger surface area, which would force more molecules to break their hydrogen bonds with neighboring molecules and move to the drop's surface.

Hydrogen bonding decreases in strength with distance: the farther apart two water molecules are, the weaker the bonding between them. Adding a touch of soap lets the drop flatten into a puddle. Soap molecules reduce the surface tension of water by separating the water molecules at the surface. All soaps are long molecules with one end that attracts water (the **hydrophilic** end), and one end that repels water and attracts grease (the **hydrophobic** end). In a mixture of soap and water, the water molecules repel one end of each soap molecule. At the water's surface, this repulsion pushes the soap molecule's water-repelling end out into the air. The soap molecule is squeezed between the surface water molecules, holding them apart and decreasing the strength of the hydrogen bonds that cause surface tension.

The suds that form in the wash water when you add soap are one consequence of the reduced surface tension. Water will form bubbles, but bubbles of plain water pop almost as soon as they form. You can see this if you run water in a basin or try blowing bubbles in a glass of water with a straw. The attraction of the water molecules in the film for the molecules in the water beneath them drags the molecules from the film, thinning it until the bubble bursts. The surface tension of water is too great to maintain a film stretched around a puff of air. The film of a water bubble is also very susceptible to evaporation, which thins the bubble film and contributes to the untimely demise of most bubbles.

The addition of soap to water decreases the surface tension to about one-third that of plain water. Soap molecules also help protect the bubble film from evaporation. Both sides of a soap film—the inside and outside of a bubble—are crowded with

Making Water Wetter: Soaps and Detergents

Many bubbles that we call soap bubbles are actually detergent bubbles. Soap and detergent have the same two-sided nature: molecules of both have water-attracting (**hydrophilic**) and water-repelling (**hydrophobic**) ends. Both soaps and detergents are wetting agents, compounds that attract water and also attract oils, fats, and waxes, providing a means by which water molecules can interact with oily, greasy, and waxy surfaces.

The main difference between a soap and a detergent is the chemical composition of the water-repelling end. In soaps, the water-repelling part of the molecule is made from fatty acids, which are found in animal and vegetable fats. In detergents, the water-repelling part is made from a wider range of compounds derived from petroleum.

Analogy

Water molecules can be compared to a group of tourists in a city where they do not speak the language: they tend to stay with their own group. If water molecules are compared to tourists, then soap molecules are like bilingual tour guides: they can provide a connection between the tourists and the residents of the city. When you add soap to water, you give the water molecules a way to connect with the molecules of oil, grease, and wax around them.

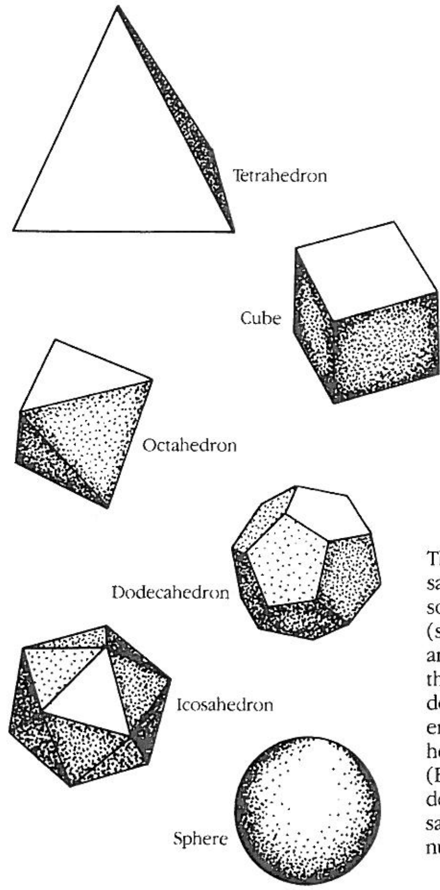
Small is Beautiful: The Patterns of Bubble Clusters

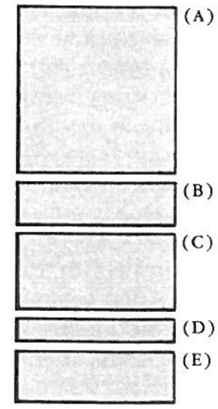
A bubble drifting on a summer breeze seems tranquil, in harmony with its world. Unfortunately, this harmony is an illusion: that iridescent sphere is in a precarious equilibrium, balancing the inward pull of surface tension against the outward push of compressed air. This battle of forces determines the shape of the free-floating bubble.

If you blow a bubble through a square tube, a triangular tube, an oval tube, or an octagonal tube, what do you get? A spherical bubble. The water molecules in a bubble film are attracted to one another, and this attraction pulls them together, making the bubble film contract. The film stops contracting when the push of pressure from the air trapped inside the film matches the pull between water molecules. The film forms the shape with the smallest possible surface area for the volume of air it contains. The table shows the volumes and surface areas of several solids.*

Wherever a bubble film forms, it contracts to a minimal surface area. A bubble resting on a wet surface uses the wet surface as one wall and contracts to form a dome. A bubble dome in a wet bowl climbs the bowl's wall until it fits neatly in the curve of the bowl and minimizes its surface area. A bubble film on a wire frame contracts to the configuration with the smallest possible surface area. A bubble in a cluster with other bubbles makes use of the films of neighboring bubbles to minimize its own surface area.

A bathtub filled with bubbles looks chaotic. But each bubble in a cluster—whether it is in a bubblebath, in the heaps of suds in a basin of dishwater, or in the foam atop a root beer float—always contracts to form the



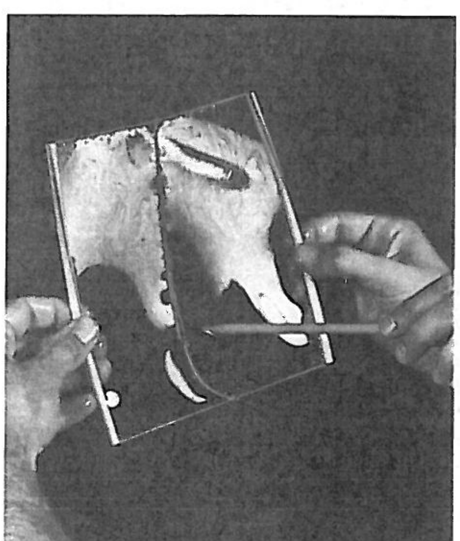


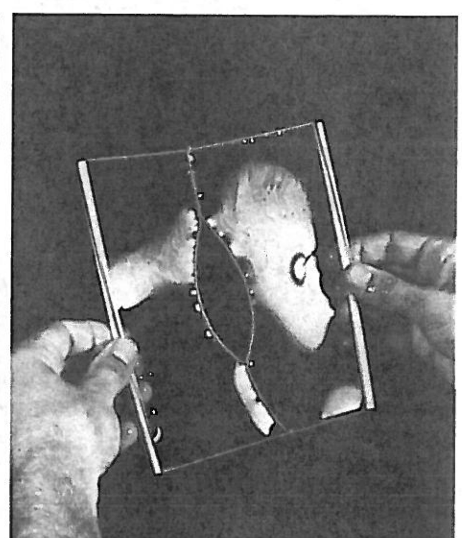
These solids have the same volume, but not the same surface area. A tetrahedron (four-sided solid) has a greater surface area than a cube (six-sided solid). A cube has a greater surface area than an octahedron (eight-sided solid). As the number of sides increase, the surface area decreases. The boxes above show the differences in surface area as you move from a tetrahedron to a cube (A), a cube to an octahedron (B), an octahedron to a dodecahedron (C), a dodecahedron to an icosahedron (D), an icosahedron to a sphere (E), which has an infinite number of sides.

Shape	*# of sides*	*Volume*	*Surface Area*
Tetrahedron	4	1 cubic inch	7.21 square inches
Cube	6	1 cubic inch	6 square inches
Octahedron	8	1 cubic inch	5.72 square inches
Dodecahedron	12	1 cubic inch	5.32 square inches
Icosahedron	20	1 cubic inch	5.15 square inches
Sphere	infinite	1 cubic inch	4.84 square inches

Clearly, the sphere is the ideal shape, containing a volume of one cubic centimeter with a surface area of only 4.84 square centimeters.

*The table gives measurements in inches, but the ratio of volume to surface area remains the same regardless of the units you use. If you prefer metric measurements, simply use metric units: replace cubic inches with cubic centimeters and square inches with square centimeters.



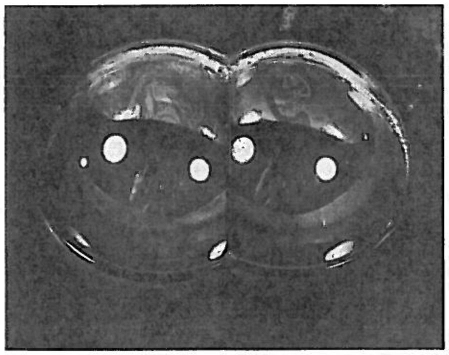


You can demonstrate the shrinking nature of the bubble film with straws and string. Pop the film in the center of the loop and the remaining film takes up the slack, pulling the loop into a circle.

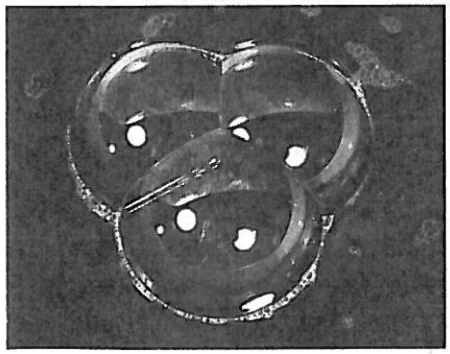
smallest possible surface area. Because of this tendency, the arrangement of bubbles in bubble clusters is somewhat predictable.

For centuries, mathematicians have been intrigued by the geometry of bubble films. The mathematical questions that relate to bubbles are called Plateau's problem, after Joseph A. Plateau, a Belgian physicist who analyzed the geometry of bubble behavior more than a century ago. The rules that relate to bubbles are a demonstration of a mathematical principle known as the area-minimizing principle. Though the mathematics required for a full understanding of the area-minimizing principle are complex, the rules regarding bubble behavior are fairly simple.

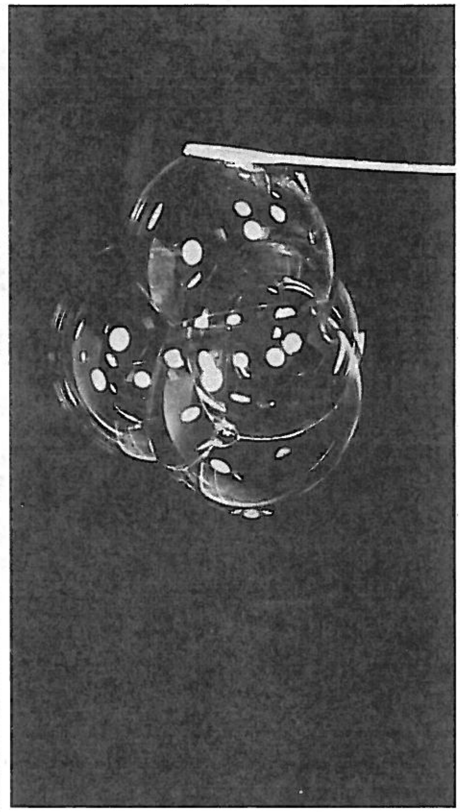
When two bubbles meet, one film flows into the other film at the point of contact, and the two bubbles form a common wall. The formation of this shared surface lets the bubbles decrease their combined surface area. If the bubbles are equal in size, the common wall is flat since that is the smallest possible surface and since the pressure in the two bubbles is equal. What would happen if one bubble were much larger than the other? Remember that a bubble is the result of a balance between surface tension and inside pressure. The surface tension of the bubble film depends partly on the size of the bubble. Think about the effort you expend to blow up a balloon. Getting started is difficult, but as you blow more air into the balloon, inflating it becomes easier. The forces at work in a bubble are similar; the pull of surface tension, like the pull of the balloon's rubber skin, depends on the radius of curvature of the bubble. In a smaller bubble, the surface tension is greater; to balance this greater tension, the pressure is also greater. Because of the pressure difference, the wall between two bubbles of unequal size is not flat—it bulges into the larger bubble, an effect you can observe in bubble clusters.



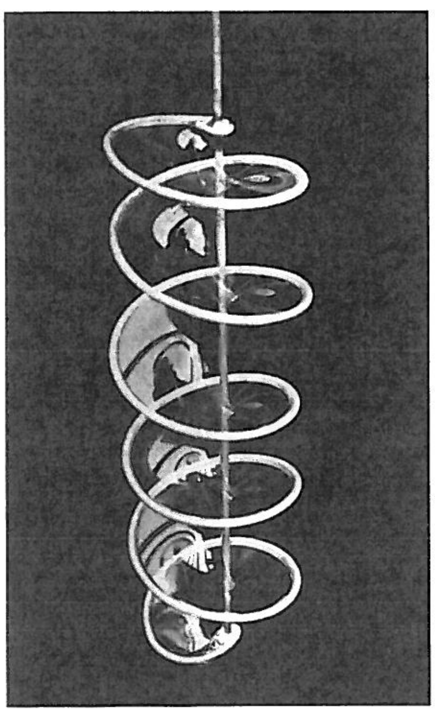
When two bubbles touch, the water in one bubble film begins to flow into the other film, forming a common wall and reducing the overall surface area.



When three bubbles touch, they form common walls that meet at 120 degree angles.



The common walls of three bubbles form 120 degree angles. In a cluster of four, the lines formed by the meeting of the common walls meet at 109 degree angles.



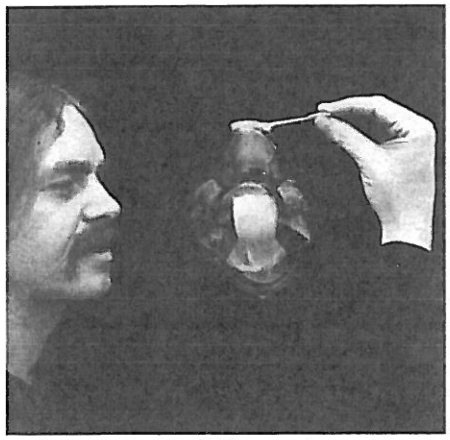
A bubble film always seeks to minimize its area; it will remain in a particular configuration only if it cannot readily shift to a configuration with less tension. You can see this by constructing frames of bent wire or drinking straws and dipping them in bubble solution.

If you were to blow a third bubble that bumped into two joined bubbles, the three would join together in a cluster: each bubble would have a common wall with the other two and the three common walls would meet at 120 degree angles along a line. This particular organization—a group of three—is the most stable arrangement for bubbles. If you have a group of three bubbles and you try to blow a fourth bubble between two bubbles to create a group of four bubbles whose common walls join at 90 degree angles, your efforts are doomed to failure. The bubbles will shift and rearrange themselves so that only three bubbles join at a single line. A number of different stable arrangements of the four bubbles is possible, but in all of them, the bubbles meet in groups of three.

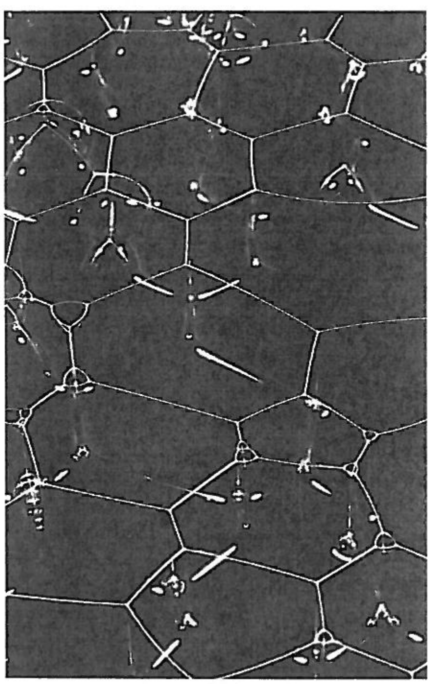
Heaping on more bubbles adds to the apparent confusion, but there is an underlying order even in the mountains of bubbles in a bubblebath. In a heap of bubbles, the common walls formed by a group of three still meet at 120 degree angles, even though each bubble belongs to several groups of three. Wherever the connecting common walls of three bubbles meet, they form a line. Four (and no more than four) of these lines meet at a point, forming 109 degree angles between them. This geometric formation is difficult to imagine. To see it, use a drinking straw to blow a cluster of four bubbles on a bubble wand. You will notice that each bubble joins with the others to form groups of three. With four bubbles (let's call them A, B, C, and D), that makes four possible combinations: A and B and C, A and C and D, B and C and D, and B and A and D. Each combination of three makes a line where the common walls meet, and the four lines meet at a point, forming 109 degree angles between them.

Soap bubbles are only one example of a natural system that minimizes use of materials. If you blow bubbles of a consistent size between two panes of glass or plastic, the pattern of hexagons that forms looks like a honeycomb. Like the bubbles, honeybees want to maximize the volume of each cell while minimizing the surface area and the amount of wax they must use. Bernard Zubrowski points out: *...scientists have noted a consistent similarity between soap bubble arrays and such diverse things as human fat cells, plant cells, cells of dragonfly wings, spots on a giraffe, cracks in dried mud, the way lead shot compacts and the granular structure of metals.*

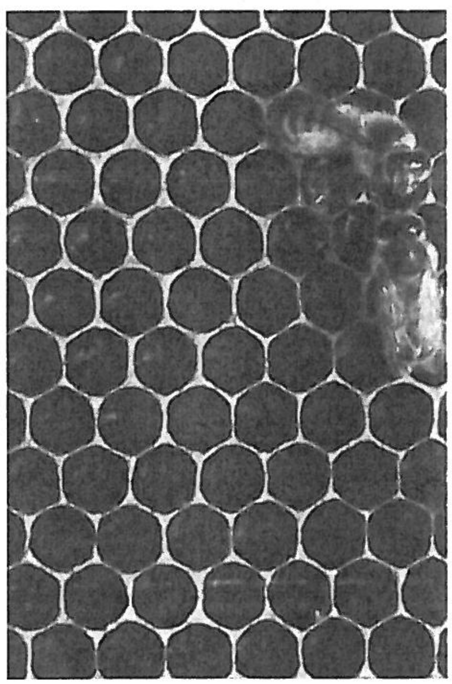
The study of bubbles—in clusters or alone—obviously leads to the study of the minimum. How much can you do with how little? The question concerns everyone from architects to investors, from honeybees to plant cells. ○



When bubbles of similar size meet, they form a common wall that is flat or only slightly curved. As a result, the bubble in the center of a bubble cluster is no longer spherical: its shape is modified by the bubbles around it. Tom Noddy—noted bubblologist and bubble magician—takes advantage of this characteristic of bubble clusters in creating a Bubble Cube. First, he blows a cluster of six bubbles. In the center, he blows a smoke-filled bubble. (The smoke makes the bubble cube easier to see, but you can make the cube without blowing smoke into the bubble.) The central bubble forms common walls with the other six bubbles, creating a six-sided oddity: the Bubble Cube.



Sandwiched between two panes of glass or plastic, a layer of bubbles looks like a honeycomb. The bubbles form a regular pattern—the common walls of three bubbles meet at 120 degree angles. Each bubble has a common wall with six others, forming a pattern of hexagons.



Like the bubble array, the honeycomb is an example of the elegant minimum. The geometric arrangement of the comb lets the bees produce the minimum wax to contain a given amount of honey.

The Importance of the Minimum

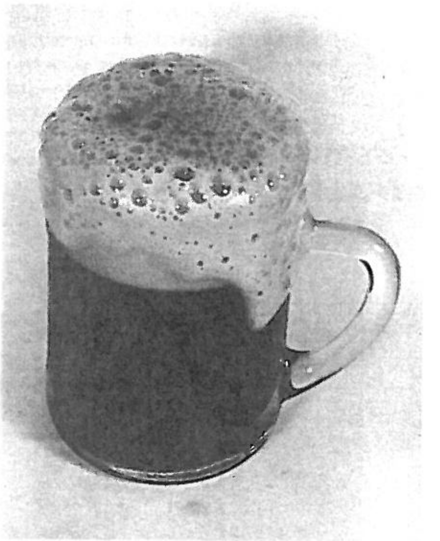
Most people try to be efficient, saving money, energy, and time whenever they can. Physical systems also tend toward efficiency, seeking the position of least energy. When you stretch a rubber band, it tends to snap back; if you put a ball bearing in a bowl, it rolls to the lowest point; if you stretch a bubble film around a puff of air in a bubble, it forms the shape in which the film must stretch the least.

This tendency also applies to physical phenomena you cannot observe directly. Light traveling through a complicated medium always takes the quickest route. Subatomic particles move in a way that minimizes the product of energy and time.

Often the minimum represents the position of maximum stability, a point of equilibrium or balance. Sometimes, a local minimum can be a position of stability: a ball rolling down a flight of stairs hits a local minimum at each step; the electron of an excited hydrogen atom occupies a certain orbital, a local minimum.

To learn about physical phenomena, scientists seek out minima. Consider the path of a baseball thrown straight up into the air. The ball's speed decreases as its height increases. At the point of minimal speed, the ball reaches its maximum height; it stops going up and starts going down, a significant event in the trajectory of the ball. This point also has another characteristic of minima: in a system where conditions are changing, the minima is generally the place where the rate of change is the least—the optimum place for measurement.

Boiling and Buoyancy: Bubbles in Liquids



In some beverages, the film bubbles pop almost immediately; in others, bubbles form a thick raft of foam—the head of the beer or root beer. Soft drink manufacturers create drinks that foam by adding foaming agents, which reduce the liquid's surface tension and allow the formation of long-lasting bubbles. Can you estimate the number of bubbles in a head of foam?

Every time you pour a glass of the bubbly—whether it's a soft drink, sparkling wine, beer, or soda water—you liberate thousands of bubbles. These beverages are **carbonated**; they contain dissolved gas under pressure.

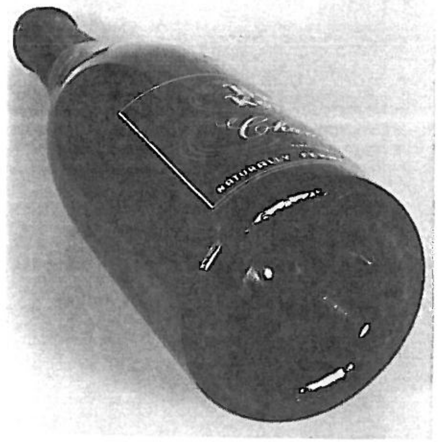
To add fizz to their beverages, soft drink manufacturers inject pressurized carbon dioxide into chilled liquid, then bottle the drink under pressure. Makers of champagne and wine rely on the services of a useful single-celled fungus: the yeast **Saccharomyces cerevivisiae**. During the fermentation, the yeast produces ethyl alcohol (the drinkable variety) and carbon dioxide.

To keep the carbon dioxide dissolved, makers of bubbly beverages must keep their product under pressure. Two conditions determine how much carbon dioxide can be dissolved in a liquid: temperature and pressure. The lower the temperature and the higher the pressure, the more gas will dissolve in a liquid. (This is true for all liquids and gases. If you run a glass of cold tap water and leave it out overnight, the bubbles that form on the glass's sides are dissolved air, leaving solution because the pressure has been reduced and the water has grown warmer.)

A refrigerated can of Seven-Up (at 50°F or 10°C) has an internal pressure of about 30 pounds per square inch, about twice the atmospheric pressure. When you open the can, you release this pressure, sending a shock wave through the liquid and creating regions where the water molecules are farther apart. The dissolved gas can gather in these regions of lower pressure, bubbling out of solution.

When a prankster shakes a can of soda, he makes the liquid very turbulent, providing many regions where the water molecules are farther apart and the gas can come out of solution. When you open the can, the change from dissolved carbon dioxide to bubbles is so rapid that the can cannot contain it. The drink seems to explode with bubbles that push liquid out of the can along with the foam.

When you pour a glass of soda, there is an initial burst of bubbles in areas of turbulence. After that, the fizz calms down. In a still glass of soda, bubbles collect slowly on the sides and bottom, forming at imperfections in the glass where a bit of dust or a scratch holds a pocket of air. The carbon dioxide comes out of solution at the meeting of air and water and joins the air, making a bubble.



Compare a champagne bottle to an ordinary wine bottle and you will learn something about the explosive power of expanding gases. Quality sparkling wines are fermented twice: once in unsealed barrels and once in sealed bottles that trap the carbon dioxide formed by the yeast. This second fermentation is known as **prise de mousse**, or "grabbing the bubbles." The champagne bottle has thick glass and a concave bottom designed to withstand an internal pressure that is six and a half times atmospheric pressure.

The addition of ice cubes to a glass of soda revives the fizz because air pockets on the surface of the ice provide sites for bubble formation. Theoretically, if there were no turbulence and no impurities in the solution, the soda would not bubble; carbon dioxide would leave the solution only at the surface where the solution meets the air.

The formation of a bubble and its escape to the surface is a battle between surface tension and buoyancy. Since the gas is lighter than the liquid, buoyancy pushes the bubble upward. The surface tension of the liquid resists the bubble's efforts to break free of the crack or imperfection where it formed, since the rising bubble will push apart water molecules that would rather stick together. Carbon dioxide continues to enter the bubble, and eventually buoyancy overcomes the surface tension. The bubble breaks free and heads for the surface. As the bubble rises, it expands as the pressure of the surrounding liquid decreases. When the

In a glass of soda water, you can provide sites where bubbles can accumulate just by dropping in a raisin. Immediately, the fizz increases as bubbles form on the raisin. Some bubbles form on the raisin, then escape to the surface. Others cling to the raisin, carrying it with them as they rise from the bottom of the glass to the top. When the raisin hits the surface, the bubbles pop; the raisin drops back to the bottom, and the process begins again.

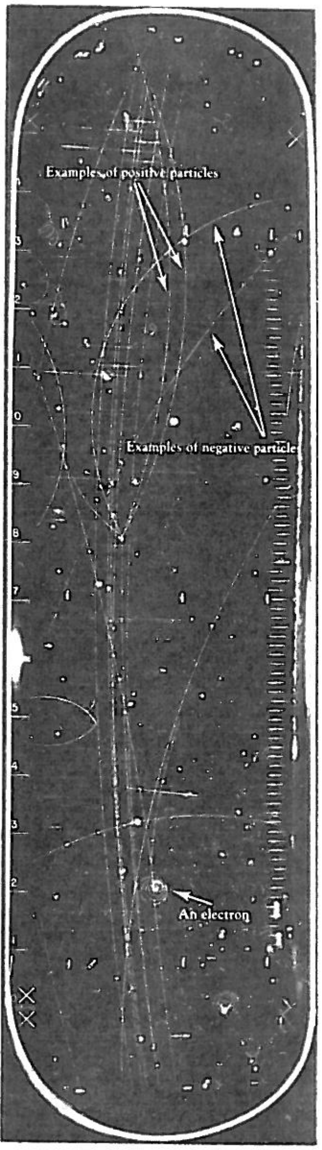


Photo by Lawrence Berkeley Laboratory

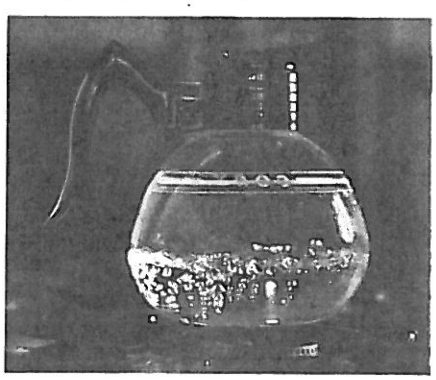
The bubble chamber, a device used to reveal the paths followed by atomic particles, takes advantage of the properties of boiling liquids and bubbles. This bubble chamber is filled with very cold liquid hydrogen under pressure. The pressure is great enough to keep the liquid hydrogen from boiling, but the temperature is such that the liquid would boil if the pressure were reduced slightly or the temperature were increased slightly in any part of the liquid.

A high-speed subatomic particle, fired from a linear accelerator into the bubble chamber, collides with hydrogen atoms along its path, knocking off electrons and producing a trail of local heating. The heat generated by the particle's passage is enough to make the liquid hydrogen boil and produce bubbles—but only in the thin line along the particle's trail. A photo of the chamber shows the bubble trail left by the original particle, as well as the trails left by any particles produced by collisions with hydrogen atoms and nuclei. The chamber is surrounded by a magnetic field, which causes the charged particles to follow a curving path rather than a straight one.

bubble emerges at the surface, the puff of gas emerging from the liquid creates a film bubble—a thin layer of liquid surrounding a pocket of carbon dioxide.

The vapor bubbles in a pot of boiling water are a different breed than the bubbles in a soft drink. In the soft drink, dissolved gas leaves solution. In boiling water, molecules make the transition from liquid to gas within the solution. At room temperature, water makes the transition from liquid to gas only from the surface of the water. When the water boils, vapor bubbles form within the water, overcoming surface tension and pressure to do so.

As you heat cold tap water in an open pot, the first bubbles that form on the sides and bottom of the pot are bubbles of dissolved air coming out of solution. You can distinguish between air bubbles and vapor bubbles by their behavior: an air bubble remains stable until it breaks free and rises; vapor bubbles form and collapse and reform repeatedly. Vapor bubbles form on the pot's bottom, where the water is hottest, and collapse when they leave the bottom and encounter cooler water. At temperatures below the boiling point, the pressure of the water squeezes the vapor bubbles out of existence. The familiar rumble of heating water comes from the sound made by these collapsing vapor bubbles.



As the water continues to heat, the water throughout the pot becomes hotter and the water molecules become increasingly agitated. At the boiling point, the agitation of the water molecules is sufficient to overcome the pressure, and pockets of vapor form within the water. If atmospheric pressure were reduced—if your kitchen were on a mountaintop, for example—the water would boil at a lower temperature. If the pressure were increased—as it is inside a pressure cooker—the water would boil at a higher temperature. ○

Tough Old Bubbles

Shakespeare wrote of the soldier "Seeking the bubble reputation/Even in the cannon's mouth." Poets have long used bubbles in describing things that are delicate, transient, insubstantial and frivolous, a metaphoric usage that betrays a rather narrow view of bubbles and neglects the variety of bubbles to be found in solids —from swiss cheese to cinder blocks.

Bubbles can be quite resilient. Foam rubber owes its bounce to its squashable bubbles.

Bubbles can be durable. A glass blower creates bubbles of molten glass, which harden as they cool to become petrified bubbles. Molten rock can capture pockets of air, bubbles that remain trapped as the rock cools and becomes solid. These ancient bubbles are capsules of history, containing samples of gas and sometimes liquid that may be tens of millions of years old.

And bubbles are often essential to the character of a thing, and therefore not frivolous at all. There are bubbles in bread (pockets of carbon dioxide produced by the same yeast that creates the bubbles in champagne), bubbles in lemon meringue (air captured in a matrix of proteins), bubbles in sponge cake (pockets of carbon dioxide created by a chemical reaction of baking soda and acid).

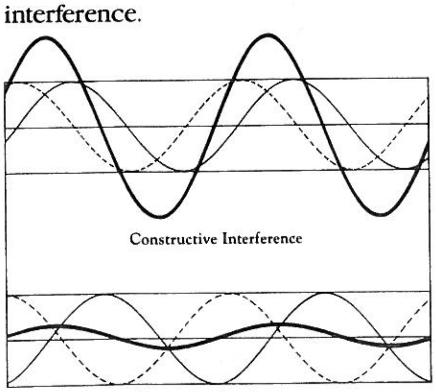
Consider—and encourage your class to consider—the variety of bubbles. Think about various bubble products: are the bubbles added on purpose? You may want to try making a few simple bubble products—such as bread or root beer—to learn a little more about how the bubbles become a part of the product.

Bubble Colors

What color is a soap bubble? Describing the iridescent and shifting color of a bubble is close to impossible. Like a rainbow, the soap film of a bubble reveals the hidden colors of white light. And by revealing the colors of light, it also shows something about its own nature: the color of a bubble film betrays the film's thickness.

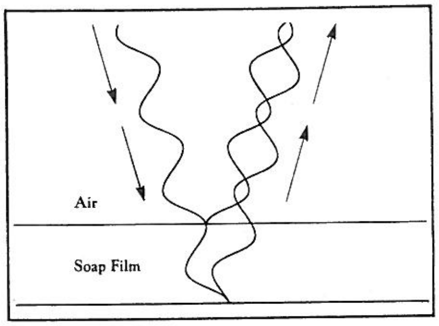
Light travels in waves. Like any wave, a light wave has a wavelength, the distance from one wavecrest to another. The wavelength of light determines its color: red light has the longest wavelength and violet has the shortest.

Waves—whether they are ocean waves or light waves—have their ups and downs, their crests and troughs. When two waves meet, their crests—the upward vibrations—can coincide so that the waves add up and reinforce one another, an interaction known as **constructive interference**. On the other hand, two waves can meet crest to trough, so that the crest or upward vibration of one wave cancels the trough or downward vibration of the other, an interaction known as **destructive interference**. When light waves of equal wavelength interfere destructively, they can cancel each other completely, leaving darkness where once there was light. The colors of abalone shells, the iridescence of dragonfly wings, and the swirling colors of an oil slick all result from this cancellation due to **interference**.



If the crests of two waves are in step, or almost in step, they combine. This combination of waves is called constructive interference. If the crest of one wave meets the valley of another, the two waves cancel. This is called destructive interference. When two light waves interfere destructively, the result is darkness.

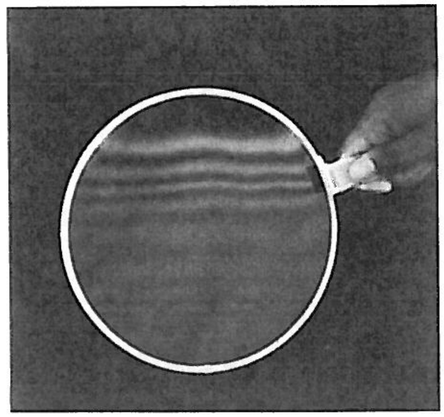
Since white light is made up of all colors, subtracting one color (one wavelength) from the rest leaves the other colors, the complement of the missing color. For example, if blue light is subtracted from white light, the red light and green light remains, combining to make yellow. (Remember that colored lights mix differently than colored paints: red and green make yellow.) The bubble film reflects complementary colors, produced by the destructive interference of light of various wavelengths.



Light reflects from both the outer surface and the inner surface of a bubble film. The light waves reflected from the inner surface must travel through the film and back before they meet the light waves reflected by the outer surface. When the two light waves meet again, they may cancel each other. If they do, the color that they represent is subtracted from the spectrum. If you subtract one color from white light, you see the complement of that color.

Light reflects from a bubble film at two locations: once from the outside surface of the film and once from the inside surface of the film. The light waves that reflect from the outside surface of the film are meeting a water surface and the direction of vibration of the wave is reversed in the reflected wave: up becomes down and down becomes up. (You can see this kind of wave reflection by tying a rope to a doorknob. When you send a pulse down the rope, a reversed pulse reflects and returns.) The light waves that reflect from the inside surface of the film (where water meets air) are not reversed. The light that reflects from the inside surface passes through the film and back, traveling farther than the light that reflects from the outside surface by twice the thickness of the film.

When the two reflected rays of light meet again, they may interfere destructively. The thickness of the bubble film—and therefore the distance that the light reflecting from the inside surface must travel—determines which wavelength of light will interfere destructively.



The bands of light and dark in this photo are really bands of colored light reflecting from a soap film. White light contains all the colors of the rainbow. The light waves that reflect from a soap film interact to reveal these colors. The thickness of the film determines what colors reflect. At the top of the photo, where the soap film is thinnest, no light reflects and the film is black.

When you are observing bubble colors, remember that these colors are the result of reflected light, not transmitted light. Only about eight percent of the light shining on the bubble reflects; the rest shines through the bubble. You will see the colors best in a bubble on a black background, lit by the reflection of white light from a wall or some broad expanse of white.

If you observe a bubble film as it grows thinner and thinner (see *Doing Science* #2 activity), you see the color change as different wavelengths of light cancel. If the bubble wall is relatively thick, only the longest wavelengths, the red light, will cancel, leaving the complementary color: blue-green. As the bubble film grows thinner, the yellow light cancels, leaving the complementary color: blue. As the film grows still thinner, the green light cancels, leaving magenta. Finally, the blue wavelengths cancel, leaving yellow-white. Eventually, the bubble becomes so thin that all wavelengths cancel, leaving a film that appears black. Why black? Because with the thinnest film, the light reflecting from the inside surface meets and cancels all the light reflecting with reversed vibrations from the outside surface. A black film is less than one-quarter of a wavelength of light thick, less than one millionth of an inch thick. When you see black, you know the bubble film is getting thin, thinner, thinnest, until... POP! ○

Annotated Bibliography

- Boys, C.V. *Soap Bubbles and the Forces Which Mould Them.* New York: Doubleday & Company, Inc., 1959.

  This brief book is a classic of scientific literature. It contains three lectures that Boys delivered before a juvenile audience in 1889 and 1890. Boys describes a number of experiments that anyone can use to demonstrate the effects of surface tension.

- The Exploratorium, *The Exploratorium Magazine: Bubbles.* Winter 1982.

  This issue of *The Exploratorium Magazine* deals exclusively with bubbles: in liquids, rocks, boiling water, soap solution, bubble chambers, bread and the blood of whales. Copies of this issue are available for $2.50 from The Exploratorium, 3601 Lyon St., San Francisco, CA 94123.

- Walker, Jearl. "Amateur Scientist: Reflections on the rising bubbles in a bottle of beer." *Scientific American*, December 1981.

  In an engaging style, Walker discusses the bubbles in beverages: their formation, the forces that control them, the tensions that lead to their demise.

- Walker, Jearl. "Amateur Scientist: What happens when water boils is a lot more complicated than you might think." *Scientific American*, December 1982.

  Walker makes the complicated events that take place when water boils simple to understand. He describes the circulation of water being warmed in a pot, the formation of bubbles in boiling water, his own home experiments and observations of boiling, and he ends with a discussion on whether adding salt to the cooking water changes the cooking time for pasta.

- Zubrowski, Bernie. *Bubbles: A Children's Museum Activity Book.* Boston: Little, Brown and Company, 1979.

  Zubrowski is an enthusiastic proponent of using bubbles as teaching aids. The book describes numerous bubble film activities and includes techniques for blowing bubbles and making gigantic bubbles, bubble sculptures, bubbles under glass, and other unusual bubbles.

- Zubrowski, Bernie. "Memoirs of a Bubble Blower." *Technology Review*, November/December 1982.

  Zubrowski describes how he has used bubbles in teaching and discusses the importance of exploring natural phenomena and encouraging a sense of meaningful play in the classroom.

- Rogers, Eric M. "Chapter Six—Surface Tension: Drops and Molecules" in *Physics for an Inquiring Mind.* Princeton, New Jersey: Princeton University Press, 1960.

  This readable book discusses surface tension, capillarity, soaps and wetting agents, and waterproofing.

- Chapter Thirteen, *Project Physics*. New York: Holt, Rinehart and Winston, 1970, 1975.

Science Resources for Schools is published by the **American Association for the Advancement of Science** (1776 Massachusetts Ave. N.W., Washington D.C. 20036), with grant funds provided by **Standard Oil Company (Ohio)**.

This issue of *Ideas in Science*, the accompanying *Poster Plus*, and *Doing Science* sheets #3, #4, #5 were produced by the staff of the **Exploratorium**, San Francisco's museum of science, art, and human perception.

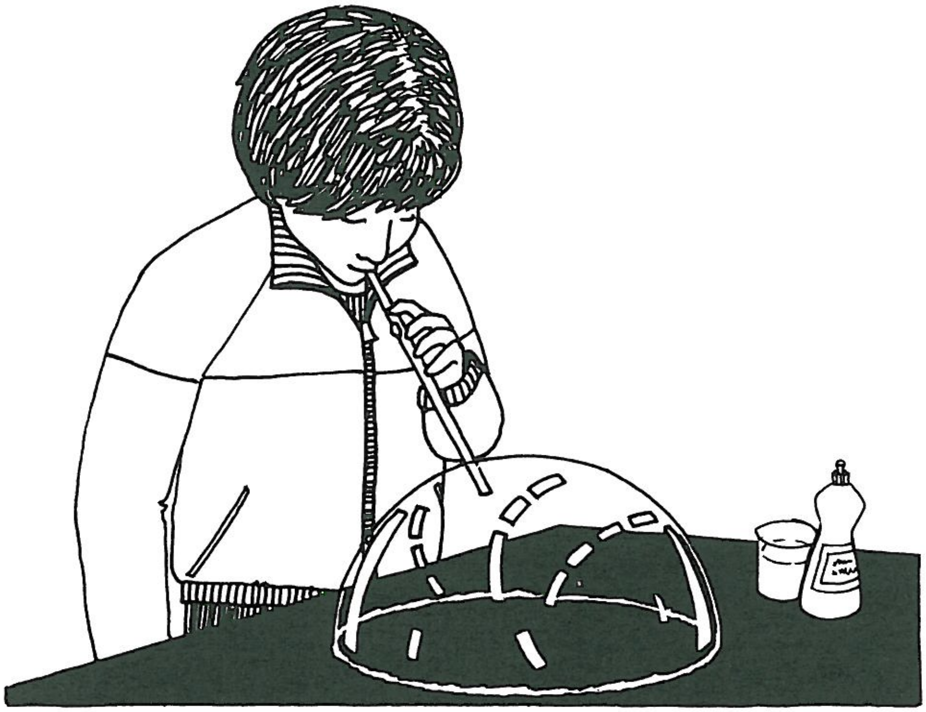
Director: Frank Oppenheimer
Associate Director/Project Coordinator: Rob Semper
Writer/Editor: Pat Murphy
Art Director: Jad King
Illustrations, Design, and Layout of *Ideas in Science*: Joni Venticinque
Poster Design and Layout: David Barker
Photographer: Susan Schwartzenberg
Additional Photos by Nancy Rodger
Illustrations, Design, and Layout of *Doing Science* #3, #4, #5: Joni Venticinque

Doing Science sheets #1 and #2 were produced by **Lawrence Hall of Science, Berkeley**.

Directors: Alan Friedman, Jennifer White, Cary Sneider
Project Coordinator: Susan Jagoda
Writers: Jacquey Barber, Cary Sneider
Editor: Kay Fairwell
Art Director: Wendy Kitamata-Pulaski

DOING SCIENCE

Bubble Solutions



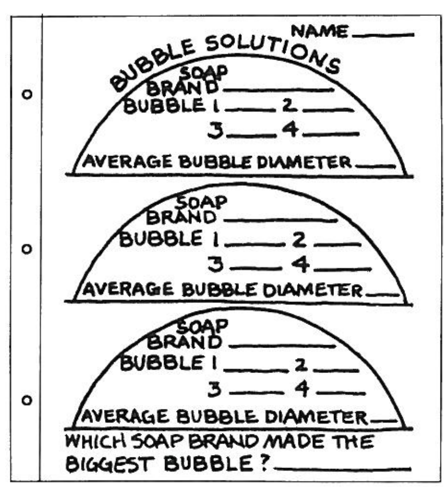
Science Themes
substances, chemicals, solutions, properties

Science Skills
measuring, recording data, conducting experiments, calculating averages, drawing conclusions

Time Frame
two class periods

Materials
For the class:
- ☐ *3 brands of dishwashing liquid (include one cheap and one expensive)*
- ☐ *eyedropper*
- ☐ *water*
- ☐ *measuring cup and teaspoon, or graduated cylinder*
- ☐ *masking tape*
- ☐ *3 one-gallon containers for mixing bubble solutions*
- ☐ *15 to 20 one-pint containers*
- ☐ *paper towels*
- ☐ *vinegar*
- ☐ *squeegie (optional)*
- ☐ *glycerin (optional - available at drug stores)*
- ☐ *calculators (optional)*

For each pair of students:
- ☐ *1 meter or yard stick*
- ☐ *2 plastic drinking straws*
- ☐ *1 data sheet*

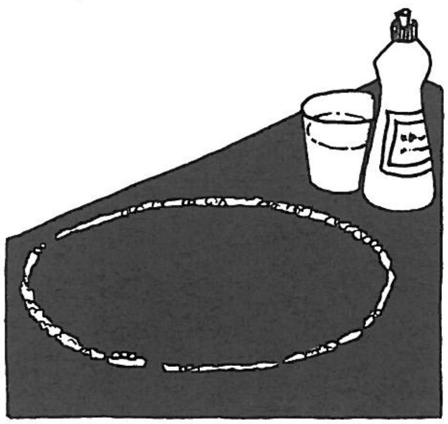


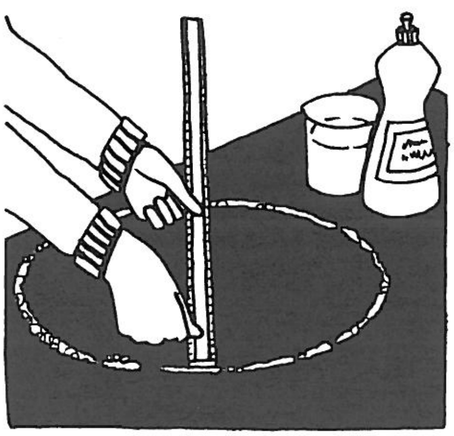
Introduction
Watching a puddle of soap solution turn into a beautiful, fragile, multicolored sphere is captivating. An enormous variety of substances in nature form bubbles. Cream, but not milk, will form bubbles when whipped. Siamese fighting fish use bubbles of saliva to float their eggs on the surface of water. In each case, whether or not bubbles form depends on the *chemical composition* of the substance. This activity uses soap bubbles to introduce the procedures that chemists use to alter the composition of a substance in order to achieve desirable properties.

Preparation
1. Using the drawing on this page as a model, draw a data sheet and make one copy for every pair of students.
2. Label one large and several small containers with the name of each dishwashing liquid.
3. Prepare a bubble solution from each brand of liquid in each of the large containers:
5 tsp. (25 ml) dishwashing liquid
2 cups (480 ml) water
7 drops glycerin
4. Set up one test station for each pair of students on a flat surface, about 30′′ (75 cm) in diameter with a small container of *one* type of solution and a meter stick.
5. See "Films, Foams, and Fizz," included with this packet, for an excellent description of bubble chemistry.

The Activity (30-45 minutes)

1. Introduce this activity to the students. Explain that the specific challenge for today is to compare brands of dishwashing liquids to find out which chemical solution can make the biggest bubble.
2. Demonstrate the following procedure: (a) Dip your hand in the solution and wet the table surface. (b) Dip a straw into the solution. (c) With the straw just touching the soapy surface of the table, gently blow through the straw to form a bubble dome, and continue blowing until it pops. (d) With a meter stick, show the students how to measure the diameter of the ring of soap suds left by the bubble dome.





3. Set the students working in pairs to measure bubbles from all three solutions. Suggest that they alternate blowing the bubbles to reduce the chance of hyperventilation. Instruct each pair of students to measure four bubbles and average their results before moving on to the next station.

Discussing the Results (20-30 minutes)

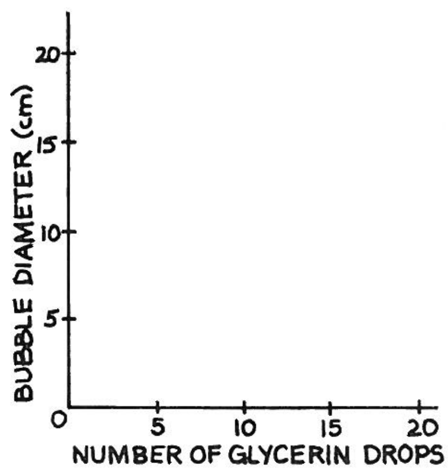
1. Reconvene the class so that everyone can see the chalkboard. Write the names of the dishwashing liquids across the top of the board and record the students' averages under each column. Calculate the grand average for each brand of soap solution. Have the students rank the brands of soap from biggest to smallest bubblemaker.
2. Ask the students if this has been a "fair test." What were the *uncontrolled variables* (e.g., some experimenters are better bubble-blowers)? How could the experiment be improved?
3. Ask your students how a commercial bubble solution manufacturer might test the effects of: a) different amounts of soap, water, or glycerin; or b) the addition of sugar, white glue, corn syrup, or other substances. Refer to Going Further for more details about these experiments.

Cleanup

First, use a squeegie or paper towels to remove excess bubble solution. Do *not* add water. Then sprinkle vinegar on the area to cut the soap film. Wipe dry with paper towels.

Going Further

- Challenge the students to devise ways to test qualities other than size (e.g. lifespan, durability).
- Challenge the students to calculate the volume of a bubble dome.
- Challenge your students to design an experiment that tests the effect the amount of glycerin in the bubble solution has on the size of the bubbles formed. Discuss which ingredients in the solution should be controlled (the water and dishwashing liquid) and a plan for varying the amount of glycerin (e.g. 0 drops in Solution #1, 5 drops in Solution #2, 10 drops in Solution #3, etc.) Ask them to graph the results of their experiments on a graph similar to the one illustrated here. Is there an *optimum* amount of glycerin for making the biggest bubbles?



Resources

- *Bubbles*, by Bernie Zubrowski, Little, Brown and Co., 1979. Though illustrated for elementary age children, this book is filled with good activities and questions.
- Refer to *"Films, Foams, and Fizz,"* included with this packet, for an annotated resource list.

Part of Science Resources for Schools
Sponsored by the **American Association for the Advancement of Science**
1776 Massachusetts Avenue, N.W.
Washington D.C. 20036

This Doing Science was produced by staff of
The Lawrence Hall of Science
University of California, Berkeley CA 94720
Project Co-ordinator: Susan K. Jagoda

Science Resources for Schools
is made possible by a grant from
the **Standard Oil Company (Ohio)**

Predict a Pop

Science Themes
patterns, light and color, technology

Science Skills
observing, recording and interpreting data

Time Frame
one or two class periods

Materials
For each pair of students:
- ☐ *1 container of bubble solution*
  - 5 tsp. (25 ml) dishwashing liquid
  - 2 cups (480 ml) water
  - 7 drops glycerin
- ☐ *2 plastic straws*
- ☐ *5 8-1/2″ × 11″ sheets of white paper*
- ☐ *masking tape*

Introduction

Here's a challenge. Blow a soap bubble. Now, can you tell when it will pop? If you and your students play with bubbles long enough you probably will find that color is the clue. That color is the key to survival is curious, since we usually think of the color of an object as mere decoration. But the colors of soap bubbles are due to a complex interaction between light and matter called *interference*.

This activity is a playful introduction to this important phenomenon in the history of physics and in modern industry. Your students will enjoy discovering how to count down the last few seconds of a bubble's existence . . . 3 . . . 2 . . . 1 . . . POP!!!

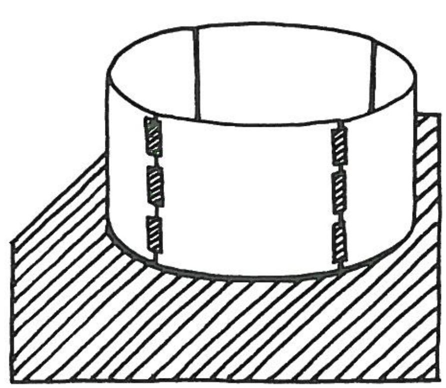
Preparation

1. We recommend that you first have your students do the Bubble Solutions activity, or blow bubbles in an unstructured situation so that "wild bubble blowing" is out of their systems. Tell your students to watch for clues that could tell them the moment just before a bubble will pop.

2. Clear off enough *flat*, *dark* surfaces in your classroom for each pair of students to have an area about 18″ (45 cm) in diameter. Black construction paper on cafeteria trays may be used.

3. Prepare one "white collar" by taping four sheets of white paper together so they form a cylinder 8-1/2″ high. The white collar reduces air currents and reflects light onto the bubble so its colors can be clearly seen.

4. See "Films, Foams, and Fizz," included in this packet, for an excellent description of bubble colors.



The Activity (30-40 minutes)

1. Gather the students around you. Blow a bubble dome as follows: (a) Dip your hand in the soap solution and wet an area of table. (b) Place the white collar around the soapy area. (c) Dip a straw into the soap solution. (d) With the straw just touching the surface of the table, gently blow through the straw to form a bubble dome. (e) Remove the straw.

2. Explain that the challenge for the day is to use color to recognize the moment just before a bubble pops. Instruct each pair of students to make a collar, blow a bubble dome, and observe the changing colors on top of the bubble. They should record the sequence of colors they see for three or four bubbles.

3. Gather the students and have several of the teams report their findings. Write these on the board. The students will probably discover a repeating sequence something like this: green - blue - magenta - yellow - green . . . (sequence repeats more than once) . . . and finally white - white with black spots - black - POP!!! Not all students will agree fully on this typical pattern. Explain that the colors on the surface of a bubble change as the bubble becomes thinner and thinner.

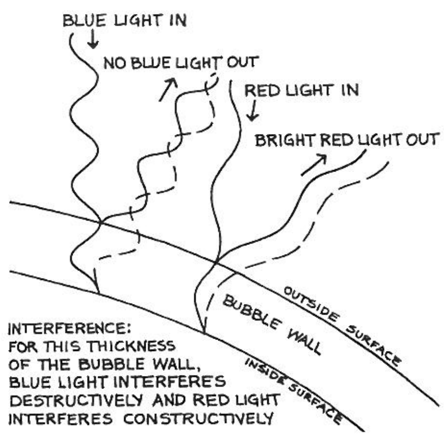
4. Now challenge the students to apply what they learned to invent a strategy for counting down, to the second, when their bubbles will pop.

Explanations

After your students have had some success, discuss with them the following explanations.

1. Where do the colors in a bubble come from?

The colors in a bubble come from the reflection of white light that shines on it. White light contains waves of all different colors. The length of a wave, from crest to crest, determines its color. When light bounces off a bubble, some of each wave is reflected from the outer surface of the bubble wall, and some passes through to be reflected by the inner surface.



When the thickness of the wall is such that the two reflected parts of the wave leave the bubble in step, crest to crest (as illustrated by red light in the diagram), that color appears brighter, ("constructive interference"). Some colors of light will emerge crest to trough (as illustrated by blue light in the diagram); and will cancel ("destructive interference"). As the wall gets thinner, the colors that interfere constructively and destructively will change too.

2. Why does the bubble appear white with growing black spots just before the bubble pops?

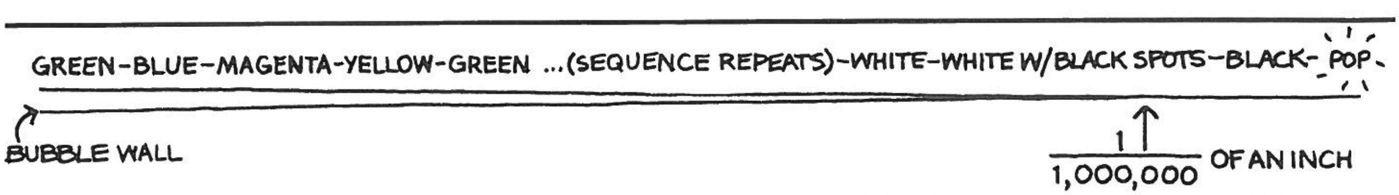
When the wall is less than a quarter wavelength thick for any color, none of the colors are completely canceled, so the bubble appears white. Black spots appear when the wall is super thin (about one millionth of an inch). This occurs because light reflected from the top surface is always reversed (all troughs become crests) but the light reflected from the back surface is not reversed. Thus, when the wall is super thin every light wave will cancel itself.

Going Further

- Dip a dark cup or wire loop into the bubble solution and hold vertically. Challenge your students to explain the sequences of colors and black area at the top of the soap film.
- Assign students to look up the name "Thomas Young" and the concept of "Interference." They will find out about the controversy surrounding wave and particle theories of light and modern applications of interference phenomena such as anti-reflection coatings on binoculars.

Resources

- *Project Physics*, chapter 13, Holt, Rinehart and Winston, 1970, 1975. This high school text offers clear explanations and historical information.
- *Soap Bubbles: Their Colors and Forces Which Mold Them*, by C.V. Boys, Dover Publications, 1959. This classic bubble science text is for those who want to go right to "the source."
- *Bubbles*, by Bernie Zubrowski, Little, Brown and Co., 1979. Though illustrated for elementary age children, this book is filled with good activities and questions.
- Refer to *"Films, Foams, and Fizz,"* included with this packet, for an annotated resource list.



Part of Science Resources for Schools
Sponsored by the **American Association for the Advancement of Science**
1776 Massachusetts Avenue, N.W.
Washington D.C. 20036

This Doing Science was produced by staff of
The Lawrence Hall of Science
University of California, Berkeley CA 94720
Project Co-ordinator: Susan K. Jagoda

Science Resources for Schools
is made possible by a grant from
the **Standard Oil Company (Ohio)**

Observing the stickiness of water

Water is fine for drinking, but it is not much good for blowing bubbles. To make a bubble that lasts for more than an instant, you need to add soap. Water—plain, ordinary water—is a very sticky liquid. Water molecules tend to stick together; they are unwilling to spread out to form a bubble film. This attraction between molecules makes the water's surface act as if it were covered with a thin skin.

The stations described here can give your students a chance to observe the stickiness of water and to notice how soap affects this stickiness.

Science Themes
Substances, chemical properties

Science Skills
Observing, experimenting

Time Frame
One class period

Background

You will find a detailed discussion of the stickiness of water in the accompanying *Ideas in Science #1.* Briefly, the stickiness of water results from weak chemical bonds between water molecules. The pull of these bonds makes the water molecules at the surface behave like a stretchy skin, a phenomenon known as **surface tension.**

The addition of soap to water decreases the surface tension to about one-third that of plain water. Bubbles are one consequence of this reduction in surface tension.

Adding alcohol to water also decreases water's surface tension. Unlike soap, alcohol evaporates readily. The evaporation of the alcohol—and the resulting inequalities in surface tension between areas with more alcohol and areas with less—can cause dramatic swirling motions in a mixture of water and alcohol.

Water not only sticks to itself; it also sticks to clean glass. The curve or meniscus at the place where water meets glass results from an equilibrium among surface tension, the attraction of water to glass, and the pull of gravity.

Preparations

Set up the activity stations, including a sheet of instructions at each location. Have the students visit each station and investigate on their own. When all students have had a chance to experiment at each station, discuss their discoveries.

1. Raindrops are Round

Use a medicine dropper to place a drop of water, a drop of alcohol, and a drop of vegetable oil on a piece of wax paper. Take a close look at the three drops. How are they different? You can see that the water drop does not lie flat like a puddle in the street. It looks more like a tiny waterballoon; the water seems to be contained by a stretchy membrane.

Put the wax paper over this page and look at the type through the water drop. The curved surface of the water drop makes it act as a magnifying lens.

Try poking the water drop with a clean dry toothpick. How does it react? Now, poke it with a toothpick that has been dipped in liquid soap or detergent. What happens?

Materials
- ☐ *Three medicine droppers*
- ☐ *Rubbing alcohol (isopropyl alcohol)*
- ☐ *Vegetable oil*
- ☐ *Toothpicks*
- ☐ *Wax paper*
- ☐ *Liquid soap or detergent*

2. Paperclips Float

Fill the bowl with water. If you drop a paperclip into the bowl, the paperclip sinks. But you can make a paperclip float. Use a fork to lower a paperclip gently onto the water's surface. Make sure you choose a relatively flat paperclip. It is important to keep the paperclip parallel to the water's surface and to place it gently on the water. If you have trouble making the paperclip float, rub it with a candle. (The wax helps repel the water and makes it easier to float the paperclip.)

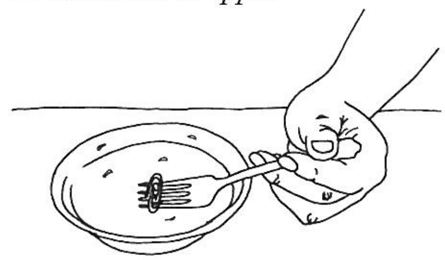
Can you see the shadow of the floating paperclip on the bottom of the bowl? Describe anything unusual about the shadow.

What happens if you push the paperclip below the water's surface? Why do you suppose that the paperclip sinks if you drop it in, and floats if you place it gently on the surface?

Add a touch of liquid soap to the water, using a medicine dropper. What happens to the paperclip?

Empty the bowl and rinse it for the next group of students.

Materials
- ☐ *Paperclips*
- ☐ *Bowl of water*
- ☐ *Candle*
- ☐ *Fork*
- ☐ *Medicine dropper*



3. Duststorms

Sprinkle talcum powder on the surface of a bowl of clean water. Use a medicine dropper to add a drop of rubbing alcohol to the water. Watch what happens. Try it a few times. Can you think of any reasons that the powder would swirl so vigorously? Use the medicine dropper to add a drop of soap to the water. How much soap must you add to make the powder sink?

Empty the bowl and rinse it for the next group of students.

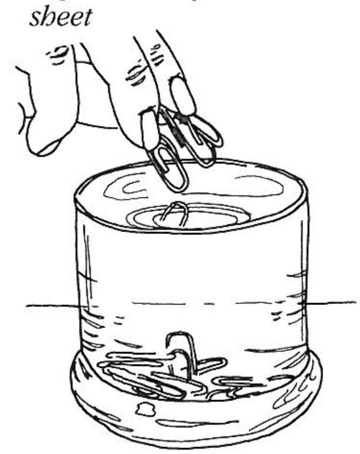
Materials
- ☐ *Bowl of water*
- ☐ *Talcum powder*
- ☐ *Liquid detergent*
- ☐ *Rubbing alcohol*
- ☐ *Medicine dropper*

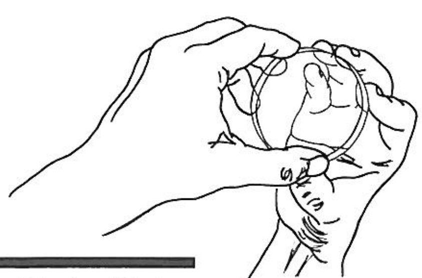
4. Fuller than Full

Fill a glass nearly full with water and place it on the tray. Take a close look at the place where the water's surface meets the glass. The curve where the water sticks to the glass is called the meniscus.

Pour more water very slowly into the glass until it is full to the brim. Look at the surface of the water. Is it even with the edge or does it bulge up over the edge? Estimate how many paperclips you could drop into the glass before it starts to overflow. Try adding paperclips and see how close your estimate was. When the water is bulging over the edge, touch it with a soapy toothpick. What happens?

Materials
- ☐ *Glass*
- ☐ *Bottle of water*
- ☐ *Large supply of paperclips*
- ☐ *Liquid detergent or soap*
- ☐ *Cafeteria tray or cookie sheet*





5. Sticky Water

Wet the two circles of glass by dipping them in the bowl of water. Press them together. Try to pry them apart. The water holds them together. You can slide the two circles apart, but the water holds them together when you try to pry them apart.

Materials
- ☐ *Two flat circles of glass (You can use flashlight lenses, available at hardware stores)*
- ☐ *Bowl of water*

Part of Science Resources for Schools
Sponsored by the **American Association for the Advancement of Science**
1776 Massachusetts Avenue, N.W.
Washington D.C. 20036

This Doing Science was produced by
The Exploratorium
3601 Lyon Street
San Francisco CA 94123

Science Resources for Schools
is made possible by a grant from
the **Standard Oil Company (Ohio)**

Bubble Tools

Tools and Techniques for Making Bubbles

According to one scientist, "If the only tool you have is a hammer, you tend to treat everything like a nail." Limiting yourself to one tool limits your thinking on a subject. The bubble wand that comes with most commercial bubble solutions, a simple hoop that holds a soap film, is only one bubble-blowing tool. In this activity, you and your class will consider other bubble-blowing tools and will experiment to determine what tool or tools will help create the largest bubble.

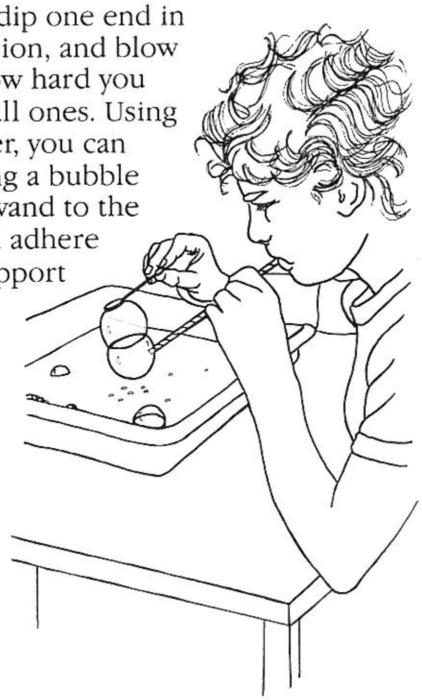
A well-designed tool lets a person overcome the limitations of the human body to perform a certain task. The tool must not only match the task, but also take into account the strengths and weaknesses of the user or users. By finding, making and experimenting with other tools, you open the way for your class to think about tool design, a topic of particular interest to industrial engineers and biotechnicians. (For more information on tool design, see "Bennett's Bend" in *Science 83,* October 1983, page 80.)

Preparation

Practice your bubble-blowing techniques using a bubble wand and a plastic straw. You can blow a large bubble using a bubble wand alone, but it takes a few tries to get the technique down. The size of the bubble depends on how hard you blow and what shape you hold your mouth, two conditions which control the flow of air striking the soap film. A fast stream of air blown through an O-shaped mouth will make many small bubbles. A slower, steady stream of air blown through a relaxed mouth makes a big bubble. When you succeed in blowing a large bubble, seal it off by quickly flipping the wand over to create a soap film across the hoop of the bubble wand.

To blow bubbles with the straw, just dip one end in bubble solution, take it out of the solution, and blow through the dry end. Depending on how hard you blow, you can make big bubbles or small ones. Using the straw and the bubble wand together, you can blow a really big bubble. Begin blowing a bubble with the straw, then touch the bubble wand to the top of the bubble. The bubble film will adhere to the wand and the wand will help support the bubble. Blow through the straw to continue inflating the bubble.

Using the straw and the wand, you may also want to try blowing a bubble cube, as shown in *Doing Science* 5 (Bubble Geometry).



Science Themes

Tool design, technology

Science Skills

Creative invention, observing properties of materials, experimenting

Time Frame

One class period

Materials

- ☐ *Bubble wands or hoops formed of pipe cleaners*
- ☐ *Plastic drinking straws*
- ☐ *String*
- ☐ *Bubble solution (To mix your own bubble solution, mix 2/3 cup liquid detergent, 1 gallon water, 1 tablespoon glycerine.)*
- ☐ *Basins to hold bubble solution in tool testing session*

You will be asking students to bring in bubble-blowing tools, but you may want to have some already on hand. Some common household items that make excellent tools for bubble-blowing are:

- ☐ *A soup can with both ends cut away (or several such cans taped together)*
- ☐ *A bubble trumpet (available in toy stores)*
- ☐ *A funnel*
- ☐ *A plastic bottle with one end cut away*
- ☐ *A hula hoop (blowing bubbles with this takes practice)*

Activity

1. Preliminary experimentation:

Before you begin a discussion of bubble blowing tools, give your class a chance to experiment with bubble-blowing—either through another bubble-blowing activity or through experimentation with the wand and the straw. Ideally, students experiment with bubble-blowing using bubble wands and straws, discuss and collect other bubble-blowing tools, and then test these tools and determine the advantages and disadvantages of each.

2. Class Discussion:

Once your students have had a chance to experiment, begin a discussion on tools. Demonstrate that you can use a bubble wand to blow a large bubble or a swarm of small bubbles. Talk about the conditions that determine bubble size: the speed of the air and the shape of your mouth. Talk about how you might better control the flow of air that strikes the soap film.

Demonstrate to the class that you can also use a drinking straw to blow large and small bubbles. The tube of the straw controls the flow of air, making it less turbulent when it strikes the soap film. But the size of the bubble you can blow with the straw tends to be limited. When the bubble reaches a diameter of about three inches, gravity tugs the bubble free of the straw. Talk about the characteristics of the straw and the bubble wand as bubble-blowing tools. The hoop holds the bubble well, since the soap film has more area to cling to. The straw controls the flow of air.

Demonstrate how you can use the wand and the straw together to blow a larger bubble than you could blow with either tool alone. Ask the students to suggest ways that these tools might be combined into one tool. You need a wide hoop so the bubble can cling and a tube that will control the flow of air.

You can also blow bubbles with a bubble wand by waving it through the air. Ask your students how you could make the wand a better tool for this use. Since you are relying on the wind created by the passage of the wand through the air, the characteristics you need in a tool are different. You could get a bigger bubble if you had a bigger hoop, since the wind of your movement would strike a larger soap film.

Ask each student to bring at least one bubble-blowing tool to class. You may want to list a few possible tools.

3. Testing the Bubble-blowing Tools:

Set up an area outside or in a large room. Bubbles do best in still air, so try to choose a windless day if you work outside. You will need a basin of bubble solution for each group of students. If you plan to use hula hoops, you will need a child's wading pool or other large basin.

In groups of four, have students test their bubble-blowing tools and note which tools consistently blow the largest bubbles. You may also want to have students make bubble hoops by threading string through two plastic drinking straws and tying the string to make a square frame. Point out that students can use their own hands as bubble-blowing tools, forming a hoop with their fingers. Remind students that there may be more than one way to use a tool: you can wave a hoop through the air, blow through it, or hold it up and let the breeze blow a bubble. Encourage students to experiment with different tools and techniques. You may want students to write up a description of the advantages and the disadvantages of each tool.

Hints on Using Hoops

Hoops—made of anything from straws and string to hula hoops—can be used to launch enormous bubbles. The larger the hoop, the more difficult it is to keep the bubble from popping. With a hula hoop, even expert bubble blowers have limited success. 1) Dip the hoop in bubble solution and lift it out carefully so that you have a soap film across the opening. Make sure that your hands are soapy and wet so that the bubble does not pop if it hits your skin. 2) Move the hoop so that the air pushes against the soap film and the film billows out to form a bubble. Experiment with moving the hoop through the air at different speeds. 3) If you are using a frame made of straws and string, you can seal off a bubble by bringing the two straws together. With any hoop, you can seal off the bubble by flipping the hoop as shown.

Part of Science Resources for Schools
Sponsored by the **American Association for the Advancement of Science**
1776 Massachusetts Avenue, N.W.
Washington D.C. 20036

This Doing Science was produced by
The Exploratorium
3601 Lyon Street
San Francisco CA 94123

Science Resources for Schools
is made possible by a grant from
the **Standard Oil Company (Ohio)**

Bubble Geometry

The heaps of bubbles in a sink full of suds may look like a mess—but there's an underlying order to their arrangement. By taking a closer look at soap bubbles, you can discover the patterns that hide within the foam. Clustered bubbles on a flat surface form polygons that fill the surface without overlapping or leaving gaps between bubbles. This kind of close packing is not limited to bubbles; similar patterns can be observed in honeycombs, plant cells, cracking mud. This exercise in observation of bubbles will help make your class more aware of the patterns and the underlying order in nature.

You can also use this activity to arouse students' curiosity in math and geometry. Bubble arrays are one type of tessellation, a repeated use of polygons to fill a plane region without gaps or overlaps. A study of bubbles and other tessellations can provide a fascinating introduction to mathematical concepts. (For more information on tessellations, see *Tessellations: the Geometry of Patterns* by Stanley Bezuszka, Margaret Kenney, and Linda Silvey, published by Creative Publications, P.O. Box 10328, Palo Alto, CA 94303, copyright 1977.)

For a detailed discussion of bubble geometry, read pages 5 to 7 in *Ideas in Science #1*.

Preparation

Practice your bubble-blowing techniques. In the Student Instructions, students are asked to figure how they might create a bubble cube. On page 7 of *Ideas in Science #1*, you'll find a photo of one bubblologist's bubble cube. With about an hour of practice, the average bubble-blower can duplicate this unlikely bubble. To blow a bubble cube:

1. Work inside, out of the wind. You can use either commercial bubble solution or bubble solution made according to the recipe (right).

2. Use a drinking straw to blow a cluster of six bubbles of approximately equal size on a bubble wand. Keep the bubbles relatively small— about an inch and a half in diameter—or they may fall off the wand.

3. Insert the drinking straw into the center of the cluster and blow a seventh bubble. If all goes well, the six bubbles of the cluster will form common walls with the central bubble, forcing it into a cubical shape.

Blowing a bubble cube takes practice. Good luck! After you have mastered the bubble cube, you may want to try to create more difficult bubble shapes, such as a bubble tetrahedron.

Science Themes

Math, geometry, patterns

Science Skills

Calculating averages, observing properties of materials, analyzing problems, recording data

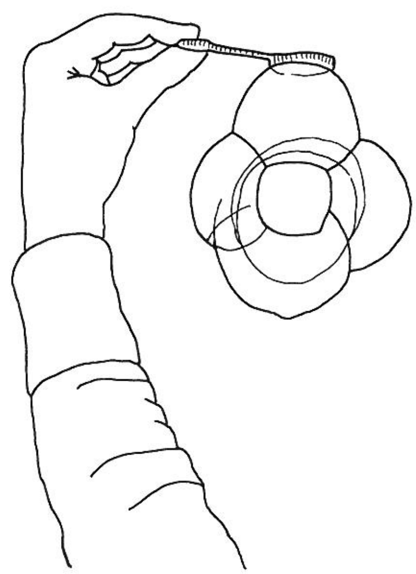
Time Frame

One class period

Materials

For each group of 2 to 4 students, you will need:

- ☐ *One plastic drinking straw for each student*
- ☐ *A cafeteria tray or cookie sheet*
- ☐ *A container to hold bubble solution*
- ☐ *A copy of the instructions for each student*
- ☐ *Bubble solution (To make your own bubble solution, mix 2/3 cup liquid detergent, 1 gallon water, 1 tablespoon glycerine.)*



Student Instruction Sheet

For centuries, mathematicians have been intrigued by bubbles and the shapes that they form. Bubbles cluster together, filling a space without overlapping or leaving gaps. The patterns that you see in a cluster of bubbles may remind you of other patterns you have seen: the cells of a honeycomb, the markings on a turtle shell, the spots on a giraffe.

Procedures

Your lab group should have a plastic drinking straw for each person, a cafeteria tray or cookie sheet, and bubble solution.

1. Pour enough bubble solution into the tray or cookie sheet to cover the bottom. Make sure the bottom of the tray is completely wet; soap bubbles burst when they hit dry surfaces.

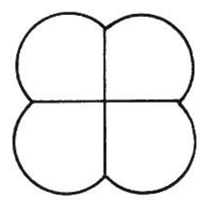
2. Practice blowing bubble domes on the cookie sheet. To blow a dome, dip a straw into the bubble solution. With the end of the straw just touching the bubble solution on the cookie sheet, blow gently through the straw. When the dome is the size you want, remove the straw. Try blowing domes of various sizes.

3. When you blow two bubble domes right near one another, they move together. Try it and see. If nothing happens, move the two domes closer together by blowing on them. Blow two domes of about the same size and let them move together. What does the wall between the two bubble domes look like?

Blow a big dome and a small dome and let them move together. How does the wall between these two bubble domes differ from the wall between bubble domes of the same size?

4. Blow three bubble domes that all join together. Try making other groups of three with bubble domes of different sizes.

Try blowing a fourth bubble that meets the other three. Can you form a cluster that looks like this? What happens when you try?



5. Blow a whole bunch of bubbles of about the same size—about an inch in diameter. (The number of bubbles you can blow will depend partly on the size of your tray.) Notice that the bubbles that are surrounded by other bubbles form polygons: squares, pentagons (five sides), hexagons (six sides), heptagons (seven sides), and octagons (eight sides). What sort of bubble is most common?

Appoint one person in your group to count the number of square bubbles, the number of pentagons, the number of hexagons, the number of heptagons, and the number of octagons. Appoint another person to record the number of each type. Appoint a third person to blow bubbles. You will have to work quickly to finish counting before the bubbles pop. Be sure to count only the bubbles that are surrounded by other bubbles. Use the workspace on the right to figure out the average number of sides of a bubble surrounded by other bubbles.

6. Try blowing more bubbles on top of your layer of bubble domes. Look carefully at the shapes formed when bubbles are squashed between other bubbles.

If you wanted to blow a bubble in the shape of a cube, how would you go about it? Remember that when two bubbles of the same size meet, they form a flat wall. See if you can blow a cubical bubble in the tray.

This workspace will help you figure out the average number of sides of a bubble surrounded by other bubbles:

How many squares? ________

×4=______ Sides.

How many pentagons? ________

×5=______ Sides.

How many hexagons? ________

×6=______ Sides.

How many heptagons? ________

×7=______ Sides.

How many octagons? ________

×8=______ Sides.

What are the total number of bubbles? ____________

What are the total number of sides?____________

Divide the total number of sides by the total number of bubbles. Your answer: ________ is the average number of sides.

According to Joseph Plateau, a Belgian mathematician who studied bubbles and soap films, the common walls between bubbles in groups of three always meet at 120° angles. The sides of a hexagon (six sides) meet at 120° angles. Do your results confirm Plateau's findings?

Part of Science Resources for Schools
Sponsored by the **American Association for the Advancement of Science**
1776 Massachusetts Avenue, N.W.
Washington D.C. 20036

This Doing Science was produced by
The Exploratorium
3601 Lyon Street
San Francisco CA 94123

Science Resources for Schools
is made possible by a grant from
the **Standard Oil Company (Ohio)**