

CHEMISTRY IN THE TOY STORE™

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A look at some toys which utilize chemicals, chemical reactions or unique properties of materials which can be found in toy, magic or novelty stores.

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SOAP BUBBLES

One of the most common items found in toy stores are soap bubbles. These are usually accompanied by small plastic wands, a bubble pipe, or more complicated type of apparatus such as bubble trumpets, bubble airplanes, bubble lawn mowers, and more. Some companies have been producing large bubble loops with many smaller loops inside or one large loop or concentric loops for making small bubbles in a larger bubble. A large bubble loop can easily be made by threading string through two plastic soda straws (see Figure 1) or by bending a wire coat hanger into a loop. (Note: Plastic coated coat hangers will not rust as rapidly as regular metal coat hangers.) Wrapping some string around the wire hanger will allow it to hold more soap solution, making larger bubbles.

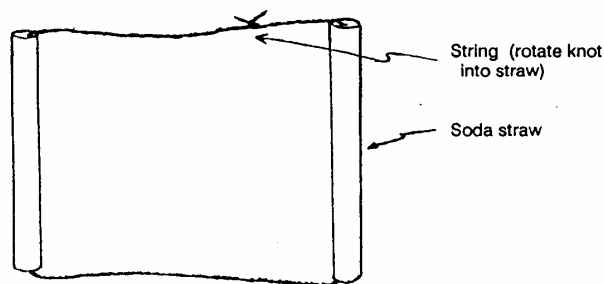


Figure 1. A bubble loop constructed from string and soda straws.

The bubble solutions commonly available in the toy store are dilute soap or detergent solutions that are good for making small bubbles, but not particularly effective for producing strong soap films or large bubbles. A better solution can be made at home.

There are many recipes for preparing soap solutions. A simple solution for making soap bubbles or films can easily be prepared by mixing a soap such as Ivory® or Ivory® powdered detergent or a detergent such as Tide® in some distilled or deionized water. A general purpose solution using liquid dishwashing detergent is:

5% liquid dishwashing detergent such as Dawn[®] or Joy[®], by volume.
92% water (distilled or deionized)
3% glycerin (available at drug stores)
(Note: If an "ultra" detergent is used, decrease the amount to 3% and increase the water to 95%)

The soap mixture should always be stirred, not shaken, otherwise excessive amounts of suds are produced. Do not use a low suds or "controlled suds" detergent and, also, avoid detergents containing bleach and fabric softeners.

Stronger bubbles are made by increasing the amount of detergent and/or glycerin in small amounts. A solution that is good for making stronger, longer lasting bubbles consists of:

10% liquid dishwashing detergent such as Dawn[®] or Joy[®], by volume.
84% water (distilled or deionized)
6% glycerin (available at drug stores)
(Note: If an "ultra" detergent is used, decrease the amount to 7% and increase the water to 87%)

Generally, it was found that when the detergent concentration exceeds 12% (by volume) the bubbles do not last as long. Also, a greater concentration of glycerin will not usually make longer lasting bubbles.

The glycerin is used to strengthen the soap film. Sugar can also be added but it is best to use it in the form of a sugar syrup, made by heating equal volumes of sugar and water, since solid sugar does not dissolve readily. White Karo syrup (corn syrup or dextrose syrup) also works well. If you intend to store the soap solution for a long period of time, generally, it is best to use glycerin as solutions containing sugar or Karo syrup may become moldy.

A recipe for "super bubbles" (supplied by Fred Juergens, Dept. of Chemistry, University of Wisconsin-Madison) calls for:

4 parts glycerin by volume
2 parts liquid Joy[®]
1 part white Karo[®] Syrup.

All parts are measured by volume. There is no water added to this solution. This produces a thick solution that will be difficult to clean up. These "super bubbles" should only be used outdoors.

Variables will depend on the purity of materials as well as the brand of soap or detergent used. Distilled water is essential to prevent interference from dissolved metal ions, although detergents will not be affected as much as a soap such as Ivory[®] (Metal ions in the water are responsible for producing the soap "scum" that forms a ring around the tub.). If the solution does not seem to work well, let it sit for a few days to a week. Aging improves the characteristics of soap solutions. Super-bubbles may even bounce on a clean, smooth floor. A note of caution, these bubbles break with a fair amount of force, keep them away from your face. Also, the solutions will make the floor or ground slippery, wear rubber soled shoes or sneakers and be careful to avoid falling. Indoors, a piece of indoor/outdoor carpet protects the floor and can prevent slipping.

A soap or detergent molecule consists of a long slender nonpolar hydrocarbon chain (consisting of hydrogen and carbon) with a highly polar oxygen-rich group attached to one end (see Figure 2). Water molecules, consisting of hydrogen and oxygen arranged in a bent or angular arrangement (see Figure 4), are polar (think of a polar substance acting like a little magnet). In a soap, the nonpolar hydrocarbon end is hydrophobic, which means it moves away or separates from water like the salad oil in a vinegar and oil salad dressing. The polar oxygen-rich end is hydrophilic, which means it is attracted to water and will try to dissolve in it. When soap molecules are added to water, some form clusters, called micelles, in the body of the solution where the nonpolar ends are in the middle of the cluster and the polar ends are on the outside. (See Figure 5) These micelles are important to the cleaning properties of soaps and detergents. Many of the soap molecules tend to migrate to the surface and orient themselves so that their polar ends are pointed toward the water and the nonpolar ends are sticking out. The surface of the water is covered with a nonpolar layer which drastically reduces the surface tension of the water and adds

stabilizing elastic properties to the liquid surface along with an increase in total surface area. (The total surface area is increased as a result of the non-polar ends of the soap molecules sticking out of the surface.) This is accompanied by an increase in the surface energy (or surface tension) of the solution (but still less than the surface tension of pure water – see Experiment 2). These surface molecules are important in making soap bubbles. When a plastic or wire loop or frame is placed in the solution and then withdrawn, the water tends to drain from the inside of the raised surface, making the surface begin to collapse on itself forming a multilayered film that forms a soap bubble. (In essence, the ends of the soap molecules fall over and become tangled like pieces of spaghetti to form the surface film. The layers consist of soap molecules on the inner and outer surfaces with a water and/or water-glycerin layer in the middle. See the soap bubble diagram in Figure 7.) The soap limits the minimum thickness of the soap film to the length of two soap molecules stacked end to end. Moderately thick films, such as these, are self-healing with respect to small punctures. That is, escaping air bubbles that burst through the surface do not cause the film to break. Also, small objects may pierce a soap film and be removed without it breaking, as long as the objects have a coating of water or soap solution and are not totally dry.

Experiment 1. Determining the Best Formula for a Soap Bubble Solution

Materials needed

Liquid dishwashing detergent
Distilled or deionized water (from grocery or drug store)
Soda straws
Containers to hold soap solutions
Glycerin (available from drug store)
Meter stick or tape measure
Timer, or stopwatch
Table with waterproof top or plastic tablecloth

Procedure

Start with liquid dishwashing detergent and distilled or deionized water. Make a series of solutions such as 2% detergent by volume, 4%, 6%, 8%, and so on up to a maximum value of no more than 20%.

Select one soap solution. Spread some of the solution on a clean waterproof surface such as a Formica tabletop or a table covered with a plastic tablecloth to wet an area about 40 to 50 cm (about 15 to 20 inches) in diameter. Dip a soda straw into the solution, touch it to the wet surface, and gently blow a hemispherical (or dome shaped) bubble. Do this several times to get the largest bubble possible. Use a meter stick or tape measure to measure the size of the largest bubble. (When the bubble breaks, it leaves a ring of suds that is a record of the bubble's diameter.) Record the size of the bubble. Repeat this process several times and determine the average size of the bubbles you could blow from that particular solution.

Repeat the bubble blowing procedure for each soap solution you prepared.

You want to use the concentration of detergent that consistently makes the largest bubbles.

Once you find the concentration of detergent that makes the largest bubble, make several solutions adding glycerin in the concentrations of 2% by volume, 4%, 6%, and so on up to a maximum value of no more than 12 to 15%.

Repeat the bubble blowing procedure that you used for the detergent solutions, but this time, try to blow large bubbles approximately the same size each time. Use a watch with a second hand, a stopwatch, or a timer to determine how long the bubble lasts. You want to determine the concentration of glycerin that produces the longest lasting bubbles.

The best solution produces the largest and longest lasting bubbles.

Experiment 2. Comparing the Surface Tension of Water vs. a Soap Solution

Materials needed

Two pennies or other small coins
 Eyedropper
 Water
 Dishwashing detergent

Procedure

Obtain two clean pennies, an eyedropper, some water and some dishwashing detergent.

Count the number of drops of water you can place on a penny.

Add a drop of the dishwashing detergent to the water and stir gently to mix. Count the number or drops of the soap solution you can place on a penny.

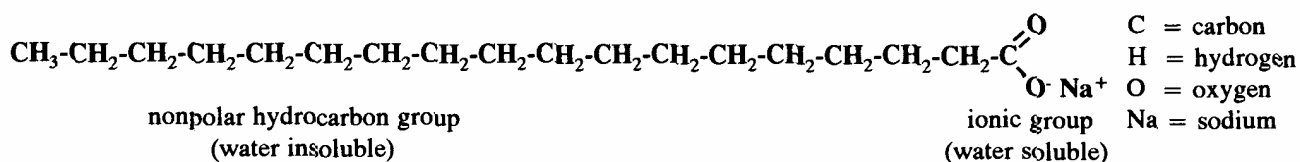


Figure 2. Sodium stearate, a typical soap

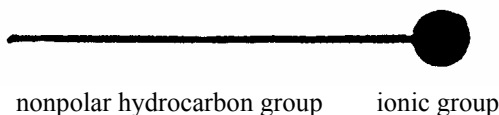


Figure 3. A shorthand notation for a soap molecule.

Soap films can come together at only two angles. If there are three films that meet along a common edge, the angles between them are 120° . If there are four films that meet at a point, the angles between them are 109° (see Figure 6). If there are more soap films, then they will rearrange themselves so that there are never more than three films in contact along an edge or four films in contact at any one point. (See Experiment 3)

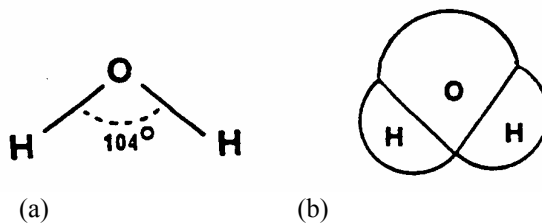


Figure 4. A water molecule showing (a) arrangement of the atoms and (b) the shape of a water molecule

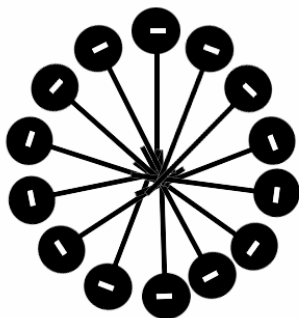


Figure 5. A micelle

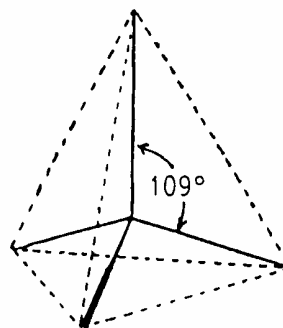
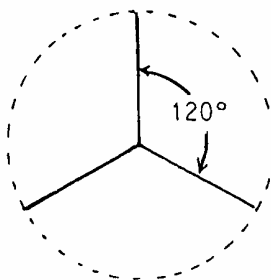


Figure 6. Angles formed by soap films.

Experiment 3. Observing the Angles formed by Soap Films

Materials needed

- Wire frames: a triangular prism and a tetrahedron
- Soap bubble solution
- Bucket or container to hold bubble solution and allow dipping of frames

Procedure

Obtain two wire frames, a triangular prism and a tetrahedron (See Figure 9) and a container of soap bubble solution large enough to hold the frames. (Frames can be made from copper wire by twisting or soldering them together at the angles.) Dip each frame into the soap solution and withdraw it. Observe the angles between the soap films in the frames.

A soap bubble is round (or spherical) since the surface of the soap film which forms it will try to contract to take up the smallest surface area. In nature, the volume with the smallest surface area is a sphere. (See Experiment 4)

Experiment 4. Observing Surface Tension in a Soap Film or Understanding Why a Soap Bubble is Spherical.

Materials needed

- Bubble loop made from string and soda straws
- Soap bubble solution
- Container for soap bubble solution

Procedure

Obtain a bubble loop made from string and soda straws (See Figure 1). Hold it by one straw so that the soda straws are positioned horizontal to the ground and the string forms the left and right sides of the square or rectangle. Note the shape of the bubble loop.

Dip the loop into some soap solution and hold it up the same way as before. How does the soap film in the loop affect its shape? What happens when you break the soap film?

Experiment 5. Observing Surface Tension in a Soap Bubble

Materials needed

Soap bubble wand
Soap bubble solution

Procedure

Obtain a small bubble wand with a loop on one end. Dip the wand into some soap solution and blow a medium to large bubble. Catch the bubble on the loop of the wand. Insert a dry finger into the loop to poke a hole in the soap film. What happens to the soap bubble?

One reason a bubble breaks is that it hits something dry. The other reason is a result of the water in the walls of the bubble draining to the bottom of the bubble. The water, in the bottom of the bubble produces a small bump on the bottom and will drip from the bubble. (see Figure 6). One can observe water dripping from the bottom of a large bubble. (See Experiment 6) When the top of the bubble becomes too thin to support the total mass of the bubble, it breaks. The addition of glycerin, or other viscous material like Karo[®] syrup, adds strength to a bubble since this material does not drain out of the soap film readily making the upper part of the soap bubble stronger.

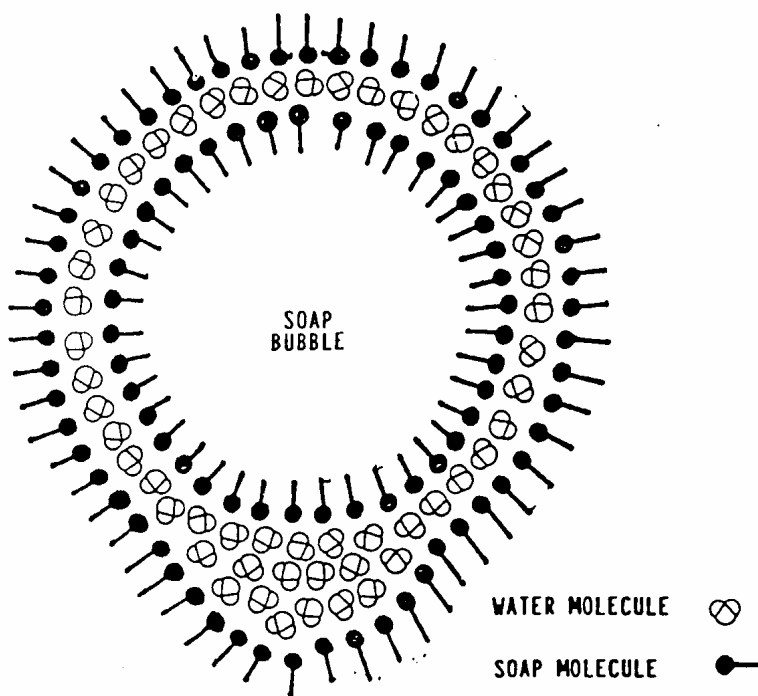


Figure 7. Schematic diagram of a soap bubble

Experiment 6. Observing the Water Draining From a Soap Bubble

Materials needed

Large bubble loop 15 to 20 cm (6 to 8 inches) in diameter
Soap bubble solution

Procedure

Obtain a large bubble loop, approximately 15 to 20 cm (6 to 8 inches) in diameter. Dip it in soap solution and make a large bubble. Observe the shape of the bubble as it falls through the air. Does water drip from the bottom of the bubble?

The swirling colors observed in a soap bubble are a result of thin film interference and the changing thickness of the film due to the draining liquid. (See Figure 8) The color is not affected by the addition of coloring agents, such as food colors, when used in normal concentrations. Although a bubble is transparent, like glass, some light is reflected off the outside surface of the soap film. Some light is also reflected off the inside surface of the film. When the two reflected light waves meet, they may be in phase (the waves aligned peak to peak and trough to trough) or out of phase (not aligned). In phase light waves produce the same color as the incoming light (e.g., white light) making the color appear brighter. This is called constructive interference. Out of phase light waves produce interference effects which we see as color. If the light wave are out of phase so that the peak of one wave is aligned with the trough of the reflected wave, then the light cancels itself out and no color is seen. This is called destructive interference. As the thickness of the soap film changes, the distance the light travels changes, and the different interference effects give different colors. When just about all the water is drained out of the upper part of the soap bubble, the wall becomes so thin that the light reflected from the top surface cancels itself out (when light is reflected, all peaks become troughs) and dark spots appear in the soap film. The swirling effects are a result of the uneven thickness in the soap film as the water drains out. (See Experiment 7)

Experiment 7. Observing Colors in a Soap Bubble

Spread some soap solution on a clean waterproof surface, such as a Formica tabletop or a table covered with a plastic tablecloth, to wet an area about 20 to 30 cm (about 8 to 12 inches) in diameter.

Dip a soda straw into the soap solution, touch it to the wet surface, and gently blow a hemispherical (or dome shaped) bubble.

Watch the soap bubble as the water drains toward the bottom of the bubble. How do the colors change? Do the colors stabilize?

Watch the top of the bubble. When the top of the soap film is close to its minimum thickness, it will be some multiple of half the wavelength of the reflected light. The light from the two surfaces, the inside and the outside, will cancel (destructive interference) making parts of the bubble film look black.

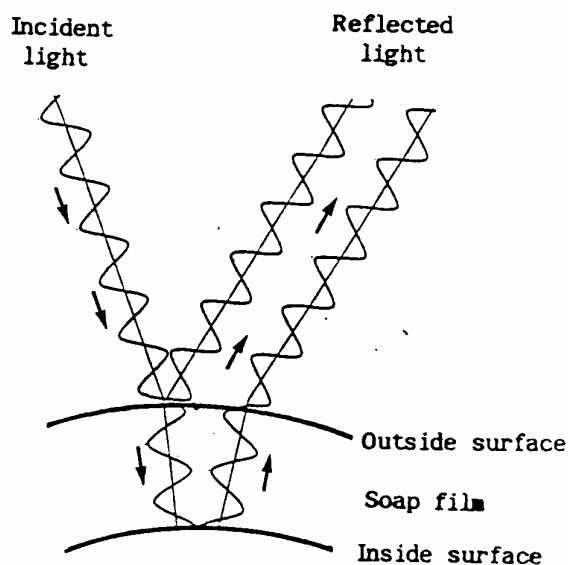


Figure 8. Interference between light waves reflected from the outside and inside surfaces of a soap film.

Soap Bubble Activities

There are many activities that can be performed with soap bubbles. The simplest is making bubbles with a loop, wand, or home-made frame. You can buy a bubble trumpet, or use a household funnel. A soda straw, or an empty cardboard tube from toilet tissue, paper towels, aluminum foil, or plastic wrap can be used to blow bubbles, although the cardboard tubes tend to disintegrate after they become wet. You can even blow bubbles from your hand by making a circle from your thumb and forefinger. See what household items you can use to blow bubbles.

Catch a Bubble

You can catch a bubble or put your finger, hand, or even an arm through a soap film without breaking it by first spreading the soap solution over the skin surface. As long as a surface or your skin is wet, even with water, soap bubbles generally will not break when they contact that surface.

Bouncing Bubbles

You can bounce a bubble off your shirt sleeve once the shirt has been washed in detergent. There will be small amounts of detergent that remain in your clothing that will prevent the bubble from breaking.

Putting Objects Through or Inside a Soap Bubble

When using a large bubble loop, one can easily put a bubble around an object or a person. If soap solution is spread over the skin surface, a person can place a finger, hand or even an arm through a soap film or soap bubble without breaking it. With a big enough loop, and enough soap solution, one could walk through a soap film and stand inside a large bubble. (See Experiments 10 and 11)

Experiment 8. Demonstrating that soap or detergent is in your clothes

Materials needed

Ultraviolet lamp, long wave
Container of detergent

Procedure

In a darkened room, place an ultraviolet lamp near your clothes (light colors or whites work best). Note how your clothes fluoresce (i.e., glow with a blue color). The fluorescence is due to optical brighteners from the laundry detergent. Do you recall the TV commercials stating that detergents make your clothes “whiter and brighter”? What you are seeing is the “brighter” aspect of the detergent. Although detergents clean your clothes, they leave a residue behind that may give the clothes a yellow or gray color. Before the use of optical brighteners, people used a material called laundry bluing. Laundry bluing was a solution of Prussian Blue, a blue dye that covered up the yellow or gray from the detergent residue. The problem was that laundry bluing had to be added to the rinse cycle and one had to watch the washing machine for that cycle to start. Also, if spilled, laundry bluing would leave permanent stains. Optical brighteners were a welcome improvement to the detergents. In sunlight or under fluorescent lights, both sources of ultraviolet light, the brightener in the clothes is glowing. You do not see it consciously, but are aware of it subconsciously and your clothes appear to be brighter. Thus, if there is optical brightener in your clothes, there is also some detergent residue.

Place the ultraviolet lamp near the detergent. It also fluoresces.

Place the ultraviolet lamp next to the label of the detergent container. Does the label, or parts of it fluoresce? What you are seeing is some subliminal advertising. That is, the label glows to your subconscious under the fluorescent lights in the market making you notice that detergent and, hopefully, to the manufacturer, you will pick up that container and purchase the detergent.

Experiment 9. Bounce a bubble off your shirt sleeve

Materials needed

Small bubble loop
Soap bubble solution

Procedure

Blow some bubbles using the bubble loop. Gently bring your arm up to the bubbles and give them a gentle push. If your shirt has been washed in detergent, the bubbles should bounce off your shirt sleeve.

Experiment 10. Put your hand through a soap film

Use a large bubble loop or the string and soda straw shown in Figure 1.

Dip the loop in soap solution and hold it in a vertical position.

Dip your finger, or hand, in soap solution. Stick your finger, or hand through the soap film. What happens? How far can you insert your finger or hand through the film? What happens if your finger or hand is wet with water only?

Experiment 11. Put someone inside a soap bubble

Construct a large bubble loop approximately 30 inches (76 cm) in diameter. The loop can be made from different materials such as curved plastic pipe or 3/8 inch diameter copper tubing. (Copper tubing is preferred by the author.)

To make a 30 inch loop from the copper tubing. Solder the loop together using a T-fitting. Fashion a handle from 1/2 inch copper tubing and connect it to the T-fitting using a 3/8 to 1/2 inch adapter. Solder all joints. Wrap the handle with plastic or foam tape so it does not become too slippery to hold when it gets wet.

Wrap string around the large bubble loop. This will allow it to hold more soap solution for large bubbles.

For the bubble pool, you can use a small wading pool, or make a pool by making a square frame from 4 36-inch pieces of 2 x 4 inch wood and placing 4 or 6 mil heavy plastic sheeting inside the frame. (The plastic sheeting is available from hardware stores and home centers.) Tuck the ends of the plastic under the frame. It is recommended that the bubble pool be set up on a large piece of indoor-outdoor type carpeting as the area around the bubble pool will become very slippery due to a coating of soap from bursting bubbles.

Provide a stand to place in the center of the pool. Make sure it is strong enough to hold an adult and that it has no sharp edges that can cut into the bubble pool. Small utility stands (one step high) can be found in home centers, or use a heavy plastic milk crate.

Add soap bubble solution (use the solution described on page 2: 10% liquid dishwashing detergent such as Dawn[®] or Joy[®], 84% water, and 6% glycerin, or the adjusted version for ultra-type detergent) to the pool and place the stand in the center. Put the loop in the pool. Help someone to step SLOWLY onto the stand as the stand can slide across the pool.

Lift the loop around the person. Practice will help you determine the proper method and speed.

Indoor Activities with Soap Bubbles

Although bubbles are mainly an outdoors activity, there are many activities that can be done indoors.

Tabletop Bubbles

To do this you will need a table with a Formica or plastic laminate top. You can substitute vinyl floor tiles, taped together with a waterproof tape from the back side or cover a table with a plastic sheet or tablecloth. Put newspapers around the work area in case of spills.

To make tabletop bubbles, spread some bubble solution onto the table to wet an area about 35 to 50 cm (about 15 to 20 inches) in diameter. Take a straw, dip it into some soap solution, then touch the straw to the soapy surface and gently blow a hemispherical (or dome shaped) bubble. You can blow bubbles of different sizes, bubbles inside of bubbles, bubble colonies, and more.

If you want to see how large a bubble you can blow, continue to blow a tabletop bubble until it pops. You will observe that there is a ring of soap suds left by the bubble. You can use a meter stick, or other measuring device, to measure the diameter of the ring. This is the size of the bubble. Record the sizes of the bubbles and determine the average sized bubble. (Soap bubbles are an excellent means of teaching measurement skills. See Experiment 12)

Try mixing up different concentrations of soap solutions (as described in Experiment 1). Make up small batches of soap solutions with soap concentrations such as 2%, 4%, 6%, 8%, 10%, 12%, etc. Record the sizes of the bubbles and determine the average size bubble blown from each solution. Construct a graph of average bubble size versus soap concentration. Which concentration of soap makes the largest bubbles?

Repeat your studies of the largest soap bubble with different brands of soap. Record your results. Construct a graph of average bubble size versus the brand of soap used. Determine which brand makes the largest bubbles.

If you want to make long lasting bubbles, try varying the concentration of glycerin in your soap solution. Make small batches of soap solutions containing 2%, 4%, 6%, etc... glycerin, up to a concentration equal to that of the soap. Try to blow large bubbles approximately the same size bubble each time. Use a watch with a second hand, a stopwatch, or timer to see how long the bubble lasts. Record your results. Construct a graph of average time the bubble lasts versus the amount of glycerin used. Which solution makes the longest lasting bubbles?

Other bubble solutions for making long lasting bubbles can be made by adding gelatin (use unflavored gelatin) or agar to the mixture. Addition of a polyvinyl alcohol solution can also prolong the life of a bubble. Try concentrations of 2%, 4%, 6% and 8%. (Above about 8% concentration, polyvinyl alcohol solutions can be very thick.)

To see the color fringes in a bubble, blow a tabletop bubble in a brightly lit area and watch it as the water drains to the lower portion of the bubble. How many rings of color do you observe? What is the order of the rings of color? Are the colors always in the same order? Does the top of the bubble become colorless? Does it become black?

To see different bubble shapes, blow clusters of bubbles. Look at the shapes of the bubbles that are located between other bubbles.

To put an object into a tabletop bubble, wet the object with some soap solution and place it inside the bubble. For example, take a small plastic car, dip it in bubble solution and the roll it into the bubble.

Experiment 12. Using soap bubbles to teach measurement skills

You can teach measurement skills to youngsters as long as they can count simple objects.

Instead of using a meter stick or other “standard” measuring device, the diameter of the soap bubble can be measured using a string of pop beads, unifix cubes, or similar objects. It is best to make the string of beads alternating colors to minimize counting errors.

After the soap bubble breaks, just lay the string of beads across the circle of soap suds and have the youngster count the number of beads. The only difference between using a standard measuring device and a string of beads is that the units of measurement are beads instead of centimeters or inches.

Youngsters may not understand how to calculate an average value, however, if all the measured diameters of the soap bubbles are recorded on a chalkboard or sheet of paper and placed in numerical order, a central, or average, value can be determined.

Experiment 13. Color fringes in an illuminated soap bubble

Materials needed

Plastic bucket with a smooth top edge
Waterproof lantern or flashlight
Soap bubble solution
Cloth large enough to span the top of the bucket
Water
Dry ice

Safety Precautions

Dry ice (solid carbon dioxide) is very cold (-78.5°C) and can cause burns to the skin which are similar to frostbite. Wear heavy gloves and handle dry ice with tongs. In the event of a burn, obtain medical assistance.

Procedure

Add water to the bucket to a depth of about 2.5 cm (1 inch). Turn on the lantern or flashlight and stand it in the bucket with the light shining up. Place a few chunks of dry ice into the bucket. Note that a fog forms in the bucket.

Roll or fold the cloth into a narrow strip. Dip the cloth in some bubble solution. Pull the cloth over the top of the bucket to make a soap film over the entire top of the bucket. Dim the room lights and watch the bubble. Look for the colored rings in the bubble.

This procedure can be repeated several times until soap solution, which drips into the water, will start producing lots of soap suds, filling the bucket.

Experiment 14. Floating Soap Bubbles

Materials Needed

Large aquarium or plastic cube (Plexiglas or similar) with clear cover (plastic recommended). (Note: The author utilizes a 24-inch cube, constructed from Plexiglas, with an 8-inch square cut-out, centered at the top of one side, and a Plexiglas cover.)

Soap bubble solution

Foam insulation sheets (expanded polystyrene or equivalent) to cover bottom of container.

Soap bubble loop

Dry ice

Optional: Vermiculite

Safety Precautions

Dry ice (solid carbon dioxide) is very cold (-78.5° C) and can cause burns to the skin which are similar to frostbite. Wear heavy gloves and handle dry ice with tongs. In the event of a burn, obtain medical assistance.

Procedure

Cover the bottom of the aquarium or plastic cube with foam insulation sheets.

Add chunks of dry ice to the container. If desired, the dry ice can be hidden by covering it with vermiculite. Cover the container and allow it to sit for about 5 minutes to build up a concentration of carbon dioxide gas.

Blow bubbles into the container. (If it is a large bubble cube, blow bubbles through the cut-out. If it is an aquarium, partially remove the cover.)

What happens to the bubbles in the container?

Watch the bubbles in the container. Do they change in any way?

Do any of the bubbles freeze?

Observations/Explanations

Carbon dioxide is heavier than air. As a result, in a closed container, there will be a layer of carbon dioxide at the bottom of the container. When a soap bubble is blown into the container, it is filled with air, and, as a result, it will float on the carbon dioxide.

The floating bubbles will slowly increase in size as carbon dioxide diffuses through the bubble film into the bubble. This makes the bubble heavier and it will slowly settle toward the bottom of the container.

Some bubbles will freeze and may settle on the surface of a dry ice chunk. Sometimes the frozen bubbles collapse leaving a frozen hemisphere.

Did you observe any floating bubbles with no top half? Occasionally, most of the water in a floating bubble will drain from the top of the bubble to the bottom without the bubble breaking. The top half of the bubble becomes so thin, it may be difficult to see in certain light conditions. Look closely, from several different angles to observe the upper half of the bubble.

Investigations with Soap Films and Frames

Some experiments with soap solutions, other than blowing bubbles, can be performed with different shaped wire frames dipped into soap solution. These frames can be purchased in kits, ready made, or they can be made by bending and twisting together stiff wire, such as a heavy gauge copper wire. (Stiff pipe cleaners can be used, but some tested by the author tended to sag when wet with the soap solution.) More permanent frames are made by soldering the wire together. Some shapes that can be used are shown in Figure 9.

To demonstrate the surface tension of a soap film (in addition to the method in Experiments 4 and 5, take a piece of thin string or thread, tie it into a loop, dip it in soap solution, and gently lay it on a soap film on a large simple loop. Using a dry toothpick, touch the soap film in the center of the string loop. What happens?

Using a loop within a loop, dip it into a soap solution to get a soap film in both loops. Use a dry toothpick or a dry finger and touch the soap film inside the center loop. What happens?

Using a planar rectangle with a movable side, slide the side close to the bottom and dip it into a soap solution. Make sure your hands are soapy. Can you move the side up and down stretching and compressing the soap film? How much can the soap film be stretched?

Dip a cubic frame into a soap solution. What happens to the soap films on the cube? How many soap films are in contact at any one point? Can you measure the angles between the films? Dip the cube about half way into the soap solution and withdraw it to put a bubble into the middle of the frame. Describe the bubble in the center of the frame.

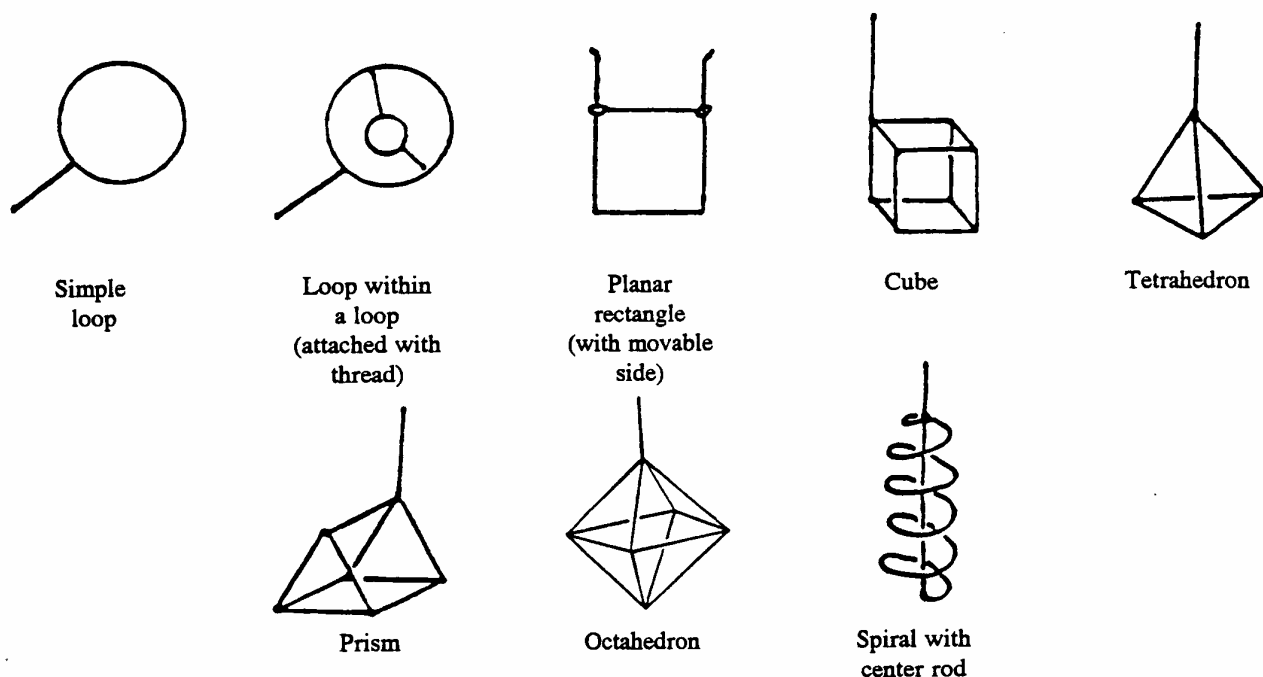


Figure 9. Different shaped wire frames for experimenting with soap films.

Dip a tetrahedral frame into a soap solution. What happens to the soap films on the tetrahedron? How many soap films are in contact at any one point? Can you measure the angles between the films? Dip the tetrahedron about half way into the soap solution and withdraw it to put a bubble into the middle of the frame. Describe the bubble.

Dip a triangular prism frame into a soap solution. What happens to the soap films on the prism? How many soap films are in contact at any one point? Can you measure the angles between the films? Dip the prism about half way into the soap solution and withdraw it to put a bubble into the middle of the frame. Describe the bubble.

Dip an octahedron frame into a soap solution. What happens to the soap films on the octahedron? How many soap films are in contact at any one point? Can you measure the angles between the films? Dip the octahedron about half way into the soap solution and withdraw it to put a bubble into the middle of the frame. Describe any bubbles that form in the center of the octahedron. Repeat your investigations putting bubbles inside the octahedron.

Dip a spiral frame into a soap solution. Describe the soap film that forms.

You can do further investigations by constructing different shaped frames using stiff wire. Use your imagination to come up with different shaped frames.

If you want to make frames more complex than those shown in Figure 9, then a different construction set is needed. One such set, tested by the author, is Zome System. This is a set of small spherical connectors, called nodes, and connecting rods that allows one to construct many geometric shapes from cubes to octahedrons, decahedrons, dodecahedrons, and more. Shapes which, in the past, were too tedious to construct by joining and welding heavy wire are now possible with this construction system.

Cleaning Up

Soap solution can be reused if it is not dirty or contaminated with any metal ions, particularly iron (or rust). It gets better with age. Save the soap solution in an air tight plastic bottle or container. The 2-Liter bottles from soft drinks work well, so do 2 ½ gallon plastic gasoline containers. (5 gallon containers get too heavy) Remember to remove any labels from the containers and put a new label on the container that says "Soap Solution". You may also want to put the formula used to make the soap solution on the label along with the date it was made.

Remove excess bubble solution from the surface by using a squeegee to scrape it into a bucket or tray. (A squeegee works best, but paper towels will also work.) Do not add water. Then sprinkle a small amount of vinegar on the area to cut any remaining soap film. Wipe the surface dry with paper towels. If the surface is still soapy, repeat the procedure.

Bubbles Bibliography

Books

Barber, Jacqueline, **Bubble-ology**, Great Explorations in Math and Science (GEMS), Lawrence Hall of Science, University of California, Berkeley, 1986.

A teacher's guide of activities with bubbles for grades 6-9. Devise bubble blowing devices, test to see which soap makes the best bubbles, and make long lasting bubbles. Each activity lists all materials needed, skills developed, themes, and complete directions from preparation to clean-up.

Boys, C. V., **Soap Bubbles**, Dover, 1959.

A reprint of the 1911 edition. Everything you wanted to know about soap bubbles and surface tension. Many simple experiments and demonstrations are explained along with excellent engravings.

- Cassidy, John, with Stein, David, **The Unbelievable Bubble Book**, Klutz Press, 1987.
This book accompanies David Stein's *Bubble Thing*. Includes recipes for bubbles, methods for making large bubbles, troubleshooting, homemade bubble machines, and additional bubble lore. Also included are articles on Bubble People.
- Faverty, Richard, with Javna, John, **Professor Bubbles' Official Bubble Handbook**, Greenleaf Publishers, 1987.
Information about bubbles, bubble wands, and other bubble toys. Includes recipes for bubble solutions and instructions for all kinds of bubble tricks.
- Isenberg, Cyril, **The Science of Soap Films and Soap Bubbles**, Dover, 1992.
Good discussions of the molecular basis for soap bubbles. A more mathematical treatment of soap bubbles and films than Boys' book with some excellent color plates.
- Noddy, Tom, **Tom Noddy's Bubble Magic**, Running Press, 1988.
Using commercial "bubble juice", Tom Noddy explains how to do many bubble tricks such as caterpillar bubbles, a bubble carousel, and more. Brief explanations of what bubbles are and why they behave as they do.
- Rämme, Göram, **Soap Bubbles in Art and Education**, Science Culture Technology Publishing, Singapore, 1998.
A well illustrated book, with many excellent photographs, which is a collection of papers published by the author. Covers topics such as bursting bubbles, colors of soap films, soap film models, modeling the atom with soap bubbles, and more.
- Stevens, Peter S., **Patterns in Nature**, Little, Brown and Co., 1974.
Chapter 7 of this book examines the mathematics of soap bubbles. Well illustrated and readable.
- Zubrowski, Bernie, **Bubbles**, Little, Brown and Company, 1979.
Activities with bubbles including very big bubbles, soap-film curves, geometric shapes, domes, bubble building blocks, and more. Does not give specific recipes, but encourages experimenting with making bubble solutions.

Articles

- Almgren, Frederick J. Jr. and Taylor, Jean E., "*The Geometry of Soap Films and Soap Bubbles*", **Scientific American**, **235**, 82 (July 1976).
A semi-technical article on the mathematics of bubbles. Well illustrated.
- Katz, David A., "*Chemistry in the Toy Store*", **1988 Yearbook of Science and the Future**, **Encyclopedia Britannica**, **1988**, 154.
Soap bubbles lead off this article on the science behind many toys.
- Kuehner, A. L., "*Long-Lived Soap Bubbles*", **Journal of Chemical Education**, **35**, 337 (July 1958).
A recipe for making a soap that will produce soap bubbles that can last for many months in a jar or other closed environment. This recipe requires handling some hazardous material. A chemistry laboratory is required.
- Strong, C. L., "*How to blow soap bubbles that last for months and even years*" in *The Amateur Scientist*, **Scientific American**, **220**, 128 (May 1969).
A discussion of the work of Dr. A. V. Grosse and his long lived bubbles. A laboratory is needed to prepare some of his solutions.

Bubble Materials

Your local toy store, science and nature stores, and also Science Museum shops are resources for bubble materials. These items are seasonal, that is, any of them may not be available in your area during colder months. You will find many items such as bubble guns, bubble mowers, a bubble bee, bubble airplanes, and more. These items change from year to year. Use discretion in purchasing bubble items, most items do not make large bubbles and do not work as they are expected.

Some items that can be used to make large bubbles are:

A set of two 18 cm diameter bubble wands consisting of a large single loop and one filled with smaller loops and a small plastic pan is available under the name Mickey's (Mouse) Million Giant Bubbles, manufactured by Chemtoy Corp. A variation of that set includes a large loop filled with smaller heart shaped loops

A concentric loop for making bubbles in a bubble is available under the name Giant Bubbles, manufactured by Hedstrom

David Stein's Bubble Thing[®] for giant bubbles six feet long or larger. It should come with Cassidy's **The Unbelievable Bubble Book**.

The Bubble Trumpet which is a long narrow funnel. Good for making a chain or medium-large bubbles.

Kubic Bubbles. Some years ago, this author obtained a set of plastic coated, wire bubble frames consisting of a cube, tetrahedron, octahedron, triangular prism, and helix (screw thread), sold under the name Kubic Bubbles, from The Exploratorium Store in San Francisco, CA . The price for the set was \$30.00 (U.S.). It appears that this well made and sturdy set is no longer available. Currently, the Kubic Bubbles set consisting of plastic tubes and angle fittings which allows one to construct four geometric bubble frames is available from some scientific supply companies under the name Kubic Bubbles.

Zome System, a set of spherical connectors, called nodes, and connecting rods that allow one to construct almost any geometric shaped frame. The company maintains lesson plans for teachers and families on their web site: www.zomesystem.com

BALLOONS/RUBBER

Another common item in toy stores are balloons. They are usually composed of rubber and come in a multitude of colors, shapes, and sizes. Natural rubber is a polymer of isoprene (2-methyl-1,3-butadiene) in the form of folded polymeric chains which are joined in a network structure (see Figure 6) and have a high degree of flexibility. Upon application of a stress to the balloon material, such as inflating it, the polymer chain, which is randomly oriented, undergoes bond rotations allowing the chain to be extended or elongated (see Figure 7). Upon removal of the stress, the chain will fold up to its previous configuration. The fact that the chains are joined in a network allows for elastomeric recoverability since the cross-linked chains cannot irreversibly slide over one another. That is, the rubber returns to its previous shape. The changes in arrangement are not constrained by chain rigidity due to crystallization or high viscosity due to a glassy state. Also, the polymeric material that makes up the balloon is porous, as evidenced by the balloon deflating over a period of time.

An interesting demonstration of some of the properties of the rubber material that composes the balloon is the needle-through-the-balloon trick. For this, one needs a large needle about 35-50 cm long (Needles about 45 cm [18 inches] long are available from magicians' supply stores or from an upholstery shop.) and some good quality balloons. The balloon should be inflated to about two-thirds its maximum size, and the end tied in a knot. Wipe the needle with a cloth containing a small amount of oil, allowing the needle to slide through the rubber easier. Starting at the end of the balloon, where the rubber is thicker and under less stress, slowly push the needle into the balloon. If the needle is sufficiently sharp and smooth, it will not tear the rubber, but will slide between the polymer chains, allowing them to stretch around the needle. The needle should then be pushed through the balloon until it comes through the other side near the knotted end. The needle can then be withdrawn or pushed completely through the balloon leaving two small holes where it passed through. (The rubber does not make a perfect seal in those spots.) After showing that the balloon is intact, the balloon is tossed into the air and popped with the needle to hide the small holes from the audience.

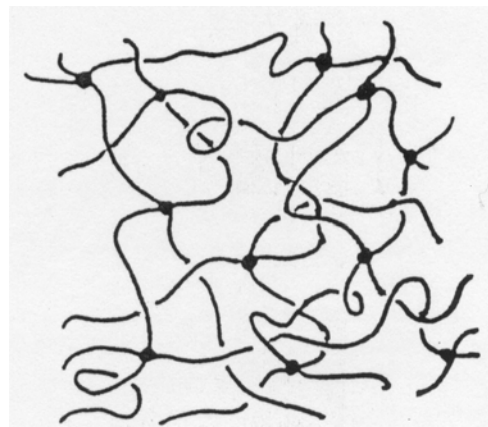


Figure 10. Schematic sketch of a typical elastomeric network

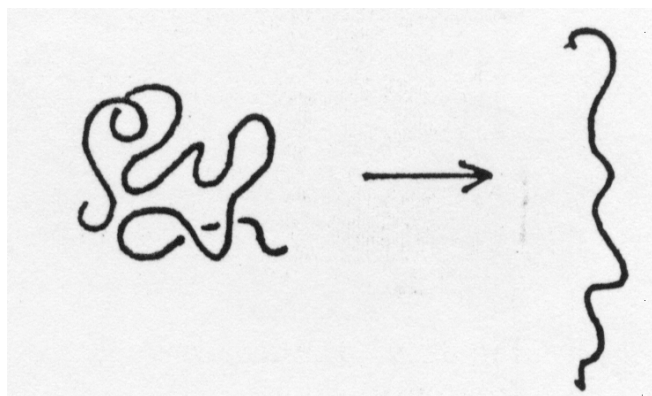


Figure 11. Elastic deformation of a rubber chain.

Rubber latex, available at craft stores, hobby shops, or from Flinn Scientific, Inc., can be used to make a rubber ball. Dilute 20 mL of latex with 20 mL water, stir and add 20 mL of vinegar. Wash the rubber mass under water in a small bucket, squeezing and turning it to shape it into a ball.

A novel application of rubber is in Stretch Armstrong™ marketed by Cap Toys (originally manufactured by Kenner Toys) (See Figure 12) and Drastic Elastic™ from Just Toys, Inc. These consist of action figures approximately 15 inches high that can be stretched up to four or five feet in length. According to a representative from Cap Toys, the skin of the Stretch Armstrong™ figure is composed of rubber latex. The body is filled with a material made from a boiled corn syrup with some moisture removed so that it forms a gel with some flow characteristics and with some

memory properties. Thus, when stretched and released, the figure returns to its original shape by elastomeric recovery of the rubber skin.

Other variations of Stretch Armstrong™ are Vac-Man™, marketed by Cap Toys, and Electronic Stretch Screamers!™ marketed by Manley Toy Quest. Vac-Man™ is a stretchable figure with a tough rubber body filled with ground up corn cobs. Vac-Man™ comes with a hand operated vacuum pump and has a valve in one ear where the pump connects. While stretching Vac-Man™, one can pump the air out of the inside of its body effectively “freezing” it in its stretched position. A release valve allows air to reenter Vac-Man’s™ body. An Electronic Stretch Screamers!™ is similar to Stretch Armstrong™ and Vac-Man™, but only the upper torso of the body stretches. That section of the body is filled with solid particle-type filler and an electronic “voice box”. When stretched, a Electronic Stretch Screamers!™ will scream or speak a message.



Figure 12. A Stretch Armstrong™ action figure.

SHRINKY DINKS*

Shrinky Dinks* consist of sheets of plastic, usually with pictures of cartoon characters, dolls, or designs printed on them. They have also been available in 8 inch by 10 inch blank sheets. Colored pencils or permanent markers are used to color the preprinted pictures or to draw pictures or diagrams on the blank sheets and then the pictures can be cut out or cut into any desired shape. The material is placed in a 163°C (325°F) oven and within 4 minutes will shrink to about 1/3 its size with all dimensions in the same ratio as the unshrunk piece.

Shrinky Dinks* is a bioriented polystyrene film (See Figure 13) that has been extruded under stress. Upon heating to 163°C (325°F), the film exhibits what is called a “memory effect”, softening and shrinking to its original pre-stressed size. The material will shrink to 1/3 its size and will become about 9 times thicker.

Shrinky Dinks* sheets are available in both frosted and clear sheets. Both are composed of the same material. Frosting is accomplished by rubbing the sheet with fine sandpaper. This makes the surface suitable for writing or drawing on it with colored pencils. The newest version of Shrinky Dinks® comes with its own oven for shrinking the plastic sheet.

Other versions of shrinking plastic sheets now includes a shrinking sheet that can go through a Laser or InkJet printer. This material is sold by Flinn Scientific.

Many plastic items that have been softened and stretched or blown into other shapes also exhibit a memory effect. Some examples are 2-Liter plastic soda bottles, and some plastic lids used on containers for deli-style foods in the markets.

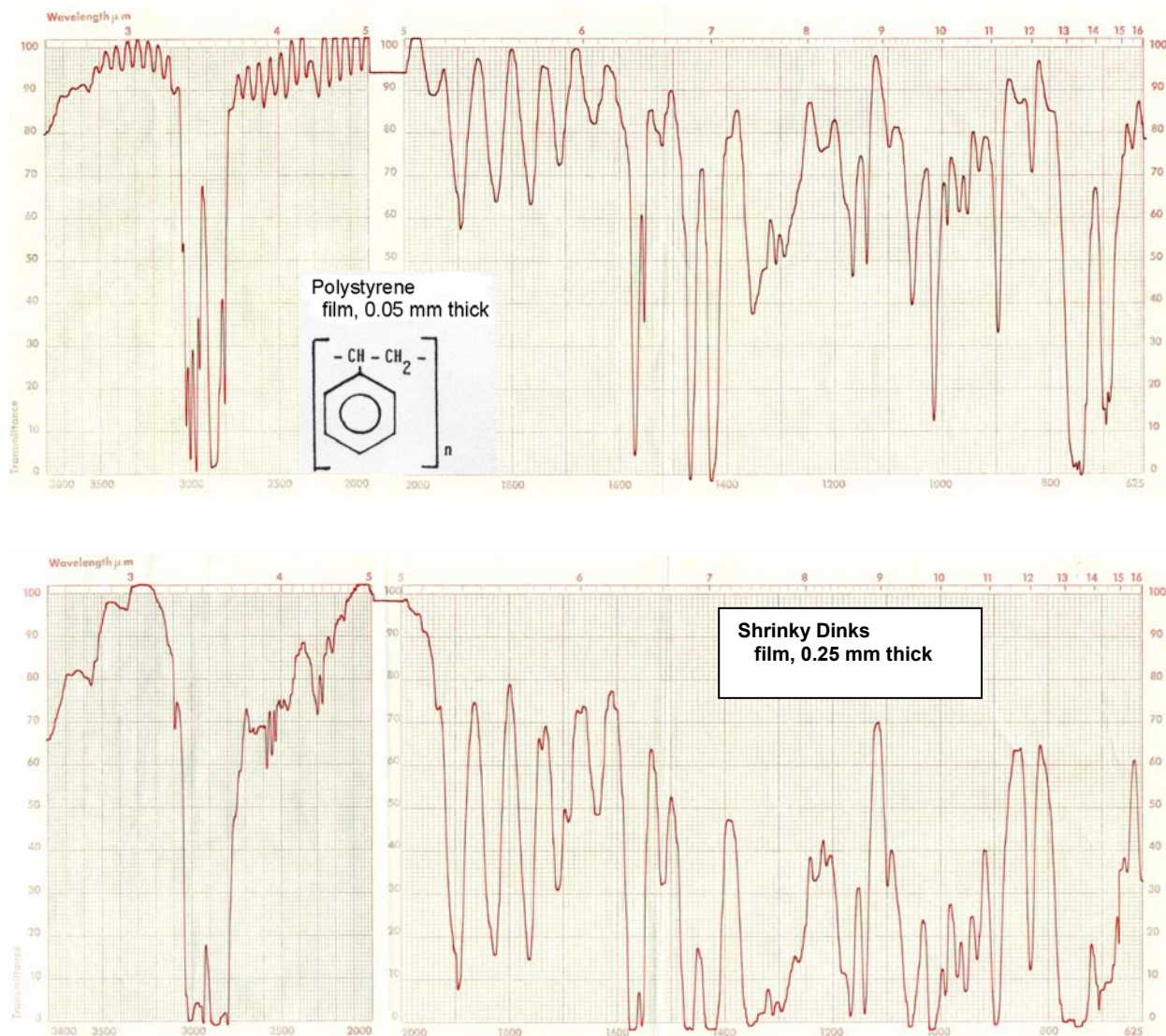
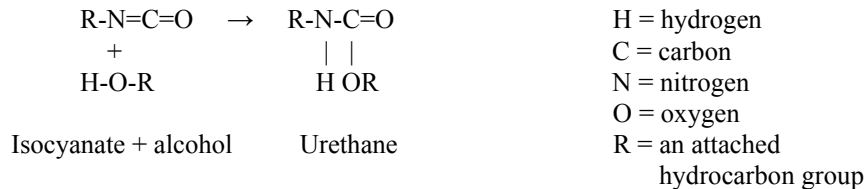


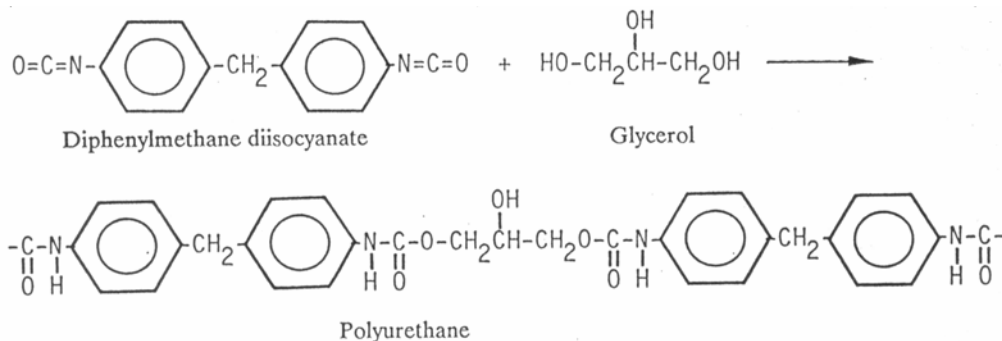
Figure 13. The infrared spectrum of polystyrene film (top). The infrared spectrum of Shrinky Dinks* (bottom). All infrared spectra were run on a Pye Unicam SP1000 Infrared Spectrophotometer.

CRAFT CAST* (POLYURETHANE FOAM)

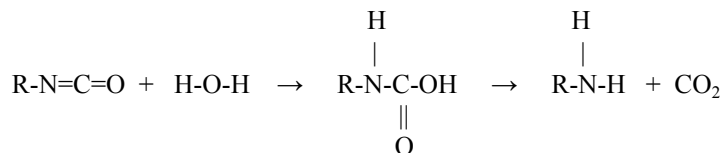
Craft Cast* is a two-part liquid material that, when mixed in equal amounts, produces a rigid polyurethane foam that can be used to make mushrooms, castings of objects, for insulating and soundproofing, or other craft uses. Part A consists of a polymeric diol or triol (glycerin is usually used), a blowing agent, a silicone surfactant, a catalyst, and a Freon (trichlorofluoromethane). Part B contains a polyisocyanate (diphenylmethane diisocyanate). Upon mixing, a polymerization reaction occurs in three directions leading to a large molecule that is rigidly held into a three-dimensional structure. At the same time, the small amount of water present causes a decomposition of some of the isocyanate and the evolution of carbon dioxide which results in the foaming. The freon, which boils at 23.7°C (75°F), is vaporized by the heat of the reaction and also contributes to the foaming. The carbon dioxide and Freon bubbles create pores in the viscous mixture as the foam sets into a rigid mass. The cell size and structure of the foam is controlled by the silicone surfactant. A generalized reaction scheme is:



The actual reaction of the diphenylmethane diisocyanate to form polyurethane with glycerol is:



The generalized reaction forming the carbon dioxide is:



Part B, which contains diphenylmethane diisocyanate (MDI), is toxic as well as an irritant to the skin and eyes. It may also cause an allergic response. This material should only be used with good ventilation.

A variation of the polyurethane foam is a product called String Confetti manufactured in France. This is an aerosol spray producing instant streamers of colored foam that utilizes a propellant as a blowing agent. The String Confetti material becomes hardened on exposure to air.

SILLY PUTTY®

Silly Putty® is a silicone polymer that comes packaged in small egg-shaped containers and is usually pink in color. Some forms of Silly Putty® contain phosphorescent material (usually zinc sulfide) that will allow it to glow in the dark. Silly Putty is also available in a range of fluorescent colors.

Silly Putty® was first made in 1941, by chemists working for General Electric, as an unsuccessful attempt to prepare a synthetic rubber based on silicon, the element present in sand (silicon dioxide). Although this “bouncing putty” had no industrial value, a salesman who frequented the laboratory would give out samples of this unusual material to his clients. Eventually, Silly Putty® was marketed as a toy.

Silly Putty® is a non-Newtonian fluid which has dilatant properties. That is, instead of its viscosity (measured resistance to flow) being dependent only on temperature, as described by Sir Isaac Newton in his Law of Fluid Friction, the viscosity can be altered by shearing it through stirring, pouring, or spreading. Thus, Silly Putty® tends to dilate (or expand) when sheared resulting in an increased viscosity under stress. Some other examples of stress-thickening fluids are quicksand, wet sand on the beach, some printers’ inks, starch suspensions, and Slime®.

Silly Putty® has some unique properties:

- Under low stress, such as slowly pulling the Silly Putty® apart, the putty flows forming thin strands.
- Under high stress, such as a sharp pull, the putty breaks.
- If rolled into a ball and dropped, the putty will bounce.
- If the ball of putty is placed on a table top and hit with the hand, the ball will hardly be deformed. If hit with a hammer, the putty will shatter. Yet, if it is squeezed gently, the ball will flatten.
- If the putty is stuffed through a tube, it will swell as it emerges from the open end. This is known as die-swell. (This works well with freshly prepared putty as the putty tends to harden with age.)

When Silly Putty® is prepared in the laboratory, initially, it is a clear, colorless to slightly yellow material. Within one week it cures to a white solid with properties closer to the commercial Silly Putty® which contains fillers to make it stiff. As it is used, it will pick up foreign matter and become gray in color slowly improving its properties.

An interesting property of Silly Putty® is that it picks up pictures from many newspapers or the comic sections. This is a function of the older type of ink used in newspapers. The ink is composed of mineral oil and carbon black or colored pigments. These inks do not dry readily as demonstrated by rubbing a finger over them. When Silly Putty® is placed on the newsprint, the pigment is transferred to the excess silicone oil in the putty.

SLIME®

Slime® and Nickelodeon Green Slime, products of the Mattel Toy Corporation, are reversible cross-linking gels made from Guar gum. The cross-linking is accomplished by the addition of sodium borate, $\text{Na}_2\text{B}_4\text{O}_7$, commonly called borax. Like Silly Putty®, Slime® is a non-Newtonian fluid that is dilatant. Its properties are also similar:

- Pull slowly and the Slime® will flow and stretch. If careful, you can form a thin film.
- Pull sharply (high stress) and the Slime® breaks.
- Pour the Slime® from its container then tip the container upward slightly, the gel will self siphon.
- Cut the pouring stream with a scissors.
- Put a small piece of Slime® on a table top and hit it with the hand, there is no splashing or splattering. Throw a small piece onto a hard surface, it will bounce slightly.
- Stuff the Slime® through a tube, die swell occurs as it emerges.

Guar gum, the main component of Slime®, is a vegetable gum from the guar plant, *Cyamopsis tetragonolobus*, a leguminous plant which resembles a soybean plant. It is composed of a straight chain of D-mannose with a D-galactose side chain at approximately every other mannose unit (see Figure 14). The mannose-galactose ratio is about 2:1, and the molecular weight of guar is approximately 220,000-250,000. It is used as a protective colloid, stabilizer, thickening and film forming agent for cheese, salad dressing, ice cream, and soups; as a bind and disintegrating agent in tablet formulations; in suspensions, emulsions, lotions, creams, and toothpastes.

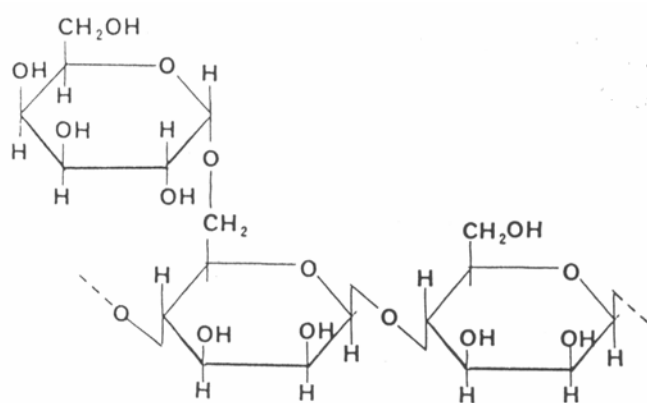


Figure 14. The Structure of guar. The mannose units are β-(1-4) linked and the single D-galactose units are joined to this chain by α-(1-6) linkages

Slime-type materials are also available as Weird Ball Sludge® (in Lucky Yellow, Putrid Purple, and Ghastly Green colors) from Mel Appel Enterprises, Inc., as purple Ecto-Plazm® from Kenner Parker Toys Inc, as Living Nightmare® Body Fluids from Fun World, as Teenage Mutant Ninja Turtles Retromutagen Ooze from Playmates Toys, as Toxic Crusaders™ Toxic Waste™ from Playmate Toys, as Dinosaur Ooze™ from Imperial Toys, and other similar materials.

Slime®, originally sold as a separate toy, was incorporated into a number of toy kits by Mattel. One of these was the Slime Pit® which was used with Masters of the Universe® toy action figures to turn them into Slime monsters. Other variations of this toy include the Teenage Mutant Ninja Turtles Flushomatic™ High-Tech Toilet Torture Trap! and the Hot Wheels Attack Pack™ Slime-inator™ Vehicle. (See Figure 15)

Another application of Slime® was Glow-In-The Dark Alien Blood® in Mattel’s Mad Scientist® Dissect-An-Alien® Kit. This version of Slime® contained a phosphorescent material (zinc sulfide) that glows in the dark after being exposed to light. In the Dissect-An-Alien® Kit, a plastic alien with a clear, colorless body cavity (see Figure 16) is packed with plastic body organs such as a Stumukus, Mad Bladder, Spleenius, and Liverot, among others, and the Alien Blood® is used to fill in open spaces around the organs. Later, when the alien is dissected, body parts are removed dripping in Alien Blood®.

Mattel also marketed Alien Blood® Monster Kits. These were plastic creatures filled will Alien Blood® which oozed from their eyes, mouth, or nose when they were squeezed.

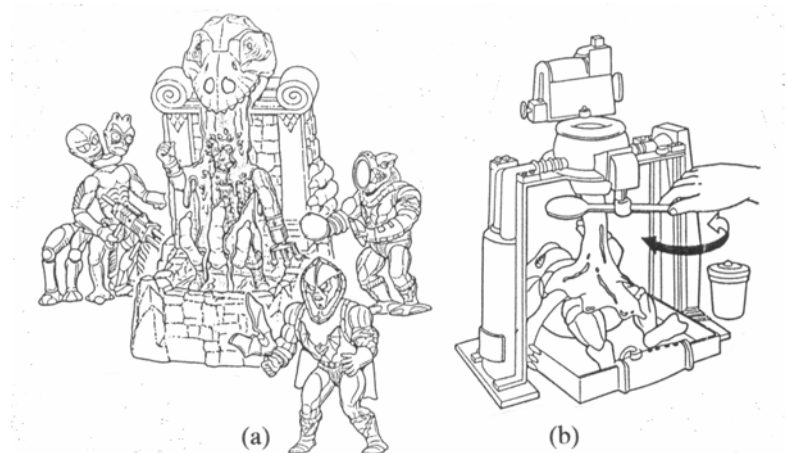


Figure 15. a) A Slime Pit® with Masters of the Universe action figures and b) The Teenage Mutant Ninja Turtles Flushomatic™.



Figure 16. Dissect-An-Alien

Another toy is The Glooper Game® which consists of a gun-type of device that shoots small, single globs of gloop, a Slime-type of material, up to 25 feet (only up to 10 feet in this author’s tests). For this toy, the gloop is contained in non-reloadable cartridges.

A material similar to Slime® can be made from a polyvinyl alcohol solution or water soluble polyvinyl alcohol bags and borax. This material is a colorless reversible cross-linking gel that has the same properties as Slime. This material can be colored by using food coloring. Polyvinyl alcohol is a water soluble polymer. Thin films of polyvinyl alcohol are one of the materials being studied for use as a environmental degradable packaging material.

NICKELODEON™ GAK™ SPLAT

Nickelodeon™ Gak™ Splat, a product of Mattel, Inc., is a non-Newtonian fluid made from guar gum, that has properties between Silly Putty and Slime. Gak™ is thick and will stretch and break like Silly Putty, but it will

flow and is cold to the touch like Slime . The Gak™ can be twisted and squeezed and different colors can be mixed. It is stored in an amoeba shaped plastic container and will make rude noises when stuffed in the Splat.

A variation of Gak™ called Solar Gak™ is available that changes color in light and fades rapidly in the shade. Solar Gak™ is available in blue, green, and purple. The best color change is obtained with direct sunlight as opposed to light from incandescent or fluorescent lamps. At this writing, the identity of the material causing the color change is not known.

There are several Gak™ toys available. A Gak™ Inflator which is used to pump Gak™ up into bubbles and then burst it. A Gak™ Vac which sucks Gak™ up and spits it out. A Gak™ Copier in which Gak™ is used to transfer drawing made with a water soluble felt-tip pen from a small white-board or paper to itself and then to another sheet of paper.

A variation of Gak™, called Flubber™ is available from Cap Toys. Slightly stiffer than Gak™, Flubber™ appears to be marketed specifically for producing loud, gross, anti-social noises when it is pushed into its container.

Gak™ and Flubber™ will dry out during use. To extend the life of these materials, dip them in water before storing them overnight in their air-tight containers.

OOZ BALL™

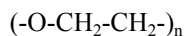
An Ooz Ball®, a product of Ritam International, Ltd., is an elastic non-Newtonian fluid that comes packed in a small plastic pod called The Pod of Intergalactic Ooze®. A representative from Ritam International explained that it was composed of thirteen ingredients using a talcum powder base. There is some polymerization in the Ooz Ball®, but all ingredients are water soluble.

The Ooz Ball®, if pulled slowly, can be stretched to “hundreds of feet” forming thin strands. It can also be stretched to form a thin web. If dropped, an Ooz Ball® will bounce, but if left sitting on a surface, it quickly settles into puddle.

During use, an Ooz Ball® will dry out and should be re-moistened using a few drops of water or oil-free moisturizer. Since it absorbs water very slowly, it should be held for a few seconds under the faucet and then stored in its pod for several hours or overnight.

SUPER LIQUID (MOON BLOB)

Super Liquid, also known as Moon Blob, is composed of a material called poly(ethylene oxide) or Polyox. This material is a water-soluble polymer that is nonionic and depending on the specific polymer, has a molecular weight between one-hundred-thousand and five million. The structure of the resin is



A water solution of poly(ethylene oxide) is a non-Newtonian fluid (see discussion under Silly Putty) in which the viscosity decreases under stress. These types of fluids are called thixotropic liquids. Some examples are margarine, catsup, mayonnaise, and ball-point pen ink.

Poly(ethylene oxide) solutions are also elastic. Thus, depending on the type of stress applied, the polymer molecules can be compressed or expanded. This is often referred to as a viscoelastic fluid.

Some of the properties of Polyox solutions are:

- a) A 0.75% solution will self-siphon if the upper container is tipped upward while pouring.
- b) A 0.75% solution is elastic and will stretch up to about 1 meter (about 3 feet) if quickly pulled upward. Upon release the liquid will snap back into its container without splashing.
- c) A 1% solution poured into a funnel will exhibit die-swell as it emerges from the from the bottom of the funnel.
- d) A 2% - 2.5% solution will exhibit elastic recoil if stirring in a circular motion is suddenly stopped. The liquid will recoil into its upper container if a pouring solution is cut with a scissors about 5 cm below the lip of the container.
- e) A 2% - 2.5% solution will climb up a straight stirring rod turning at a speed of about 5 revolutions per second. This is known as the Weissenberg effect:
- f) A 0.01% solution will reduce friction of liquid flow through a tube or pipe using a head of water about 1 meter with a piece of capillary tube 8 cm long by 1 mm bore attached to the liquid supply.

MAD SCIENTIST® MONSTER LAB®

The Mad Scientist® Monster Lab® from Mattel, Inc., allowed the user to “make disgusting, gross monsters...then sizzle the flesh off their bones!” The set included a plastic Monster Vat, plastic monster “Bones”, Green Monster Flesh®, Secret Froth Formula, and Powdered Flesh Remover for dissolving monsters.

The green Monster Flesh® Compound is modeling material, similar in texture to Play Doh® (manufactured by Kenner Products), but not as water soluble since it is composed of silica gel rather than flour. The Monster Flesh® is mixed with Secret Froth Formula (sodium bicarbonate or baking soda) and molded onto a monster skeleton. The monster is then placed in a plastic tank containing a water solution of Monster Flesh® Remover (citric acid, - commonly sold as sour salt in the supermarket). The reaction between the sodium bicarbonate and citric acid - produces sodium citrate and carbon dioxide resulting in bubbles of gas (“sizzle”) and breaking apart of the Monster Flesh® into small pieces. Lemon juice or vinegar can be substituted for the citric acid.

TERMINATOR™ 2 BIO-FLESH REGENERATOR

The Terminator™ 2 Bio-Flesh Regenerator, from Kenner , based on the movie Terminator 2: Judgment Day™, allows the user to mold and destroy their own Terminator™.

The user is supplied with two Terminator™ Endoskeleton Action Figures which are placed in a mold, slipped into a plastic base unit, and then injected with Bio-Flesh to produce Terminators™. The Bio-Flesh “skin” can be torn off the Terminators™ in “battles”.

Terminator™ 2 Bio-Flesh is the material that a dentist may use in making a mold of a patient’s teeth. It is - composed of potassium alginate (a seaweed derivative), silica in the form of diatomaceous earth and cristobalite (a silicon dioxide mineral), tetrasodium pyrophosphate (to provide cross linking to form a gel-type material), and some coloring material.

SUPER BALL®/STUPID BALL

A Super Ball® is a highly resilient ball which was originally manufactured by the Wham-O Mfg. Co. Similar products are marketed under names such as High-Bounce Ball or similar names by other manufacturers.

A Super Ball® is a ball or sphere having extremely high resilience factor in excess of 90% and a high coefficient of friction. These two qualities cause the ball to react in an extraordinary and unpredictable manner when bounced or struck. Thus, any spin applied to the ball will be accentuated when it rebounds from a hard surface.

The Super Ball® has a specific gravity of 1-1.3 (The specific gravity of water is 1.0). It is composed of about 100 parts polybutadiene, 0.5 to 15 parts sulfur vulcanizing agent, and 5 to 15 parts of filler such as hydrated silica, carbon black or lithium oxide. The sulfur vulcanizing agent is added in excess of that in products such as automobile tires (which contain about 3 parts sulfur) to produce cross-linking between polybutadiene chains resulting in the high resiliency. The ball is molded at a pressure of between 500 and 3,000 p.s.i. for 10 to 30 minutes at a temperature of 285-340°F (140-171°C). This produces the Super Ball® with the properties described above. In addition, it has been found that these balls also exhibit an ability to conserve energy. That is, when bounced, the ball will dissipate very little of the energy imparted to it in the form of heat.

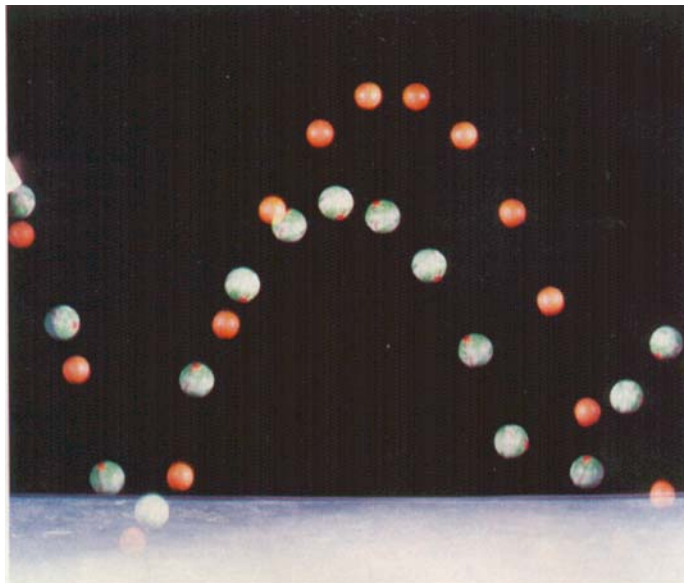


Figure 17. A Super Ball® bounces higher than an ordinary rubber ball.

The Stupid Ball was first made by Phillips Petroleum Co. from their Solprene® Elastomer. Non-bounce balls may be composed of several different materials. Common materials used are a block co-polymer of poly(styrene-butadiene) or a block co-polymer of poly(vinyl-butadiene). This material has a specific gravity that is higher than that of a smart ball (one sample had a specific gravity of 1.17 compared to a Super Ball® at 1.03) and a structure that has a low resiliency and absorbs energy. Thus, when the ball is dropped, it does not bounce.

These properties make the Stupid Ball material useful for a number of applications. The poly(styrene-butadiene) co-polymer is used in automobile tires where it helps to absorb some of the bumps encountered on the highway. This type of material has also found use in lining the ballistic containers used by bomb squads (these look like big trash cans). Should a bomb explode, this material will absorb a significant amount of energy.

A BAD CASE OF WORMS®, MAGIC OCTOPUS AND WALL WALKERS

A Bad Case of Worms®, marketed by Mattel Toy Corp., consisted of a small plastic case, resembling a suitcase, containing two yellow colored plastic “worms”. Worms are a soft, limp plastic that is tackified (made sticky). The plastic is also washable so that the surface can be restored without losing the tackifier. The plastic is an isoprene polymer, similar to the Stupid Ball material described earlier, manufactured by Shell Petroleum Co.

Similar to A Bad Case of Worms®, are the Magic Octopus and various Wall Walkers in the shape of spiders, other insects, bats, and skeletons. These are stickier than the Worms, and have better adhesion to surfaces. Some may contain excess plasticizer and leave an “oily” residue on the surface that may be difficult to remove.

To use a Worm or a Wall Walker, one throws it against a smooth, clean surface, such as a wall, to which it will stick. After a while, the Worm or Wall Walker will slowly release from the wall and “crawl” down the wall. The

rate of motion will depend on the cleanliness of both the wall and the Wall Walker's surface. Once the Wall Walker no longer adheres to a surface, it is washed with soap and water to restore its tackiness.

There are also small automobile-type vehicles called Tacky Wacky® Vertical Racers. These have a Wall Walker-type of material for a roller that allows the Tacky Wacky® to race down a vertical race track made of coated paper. Other variations are the Wacky Tacky™ Acrobat or the Magic Wall Stunter™ which have hands and feet composed of the Wall-Walker-type of material that allows them to tumble down a wall.

Variations of the Magic Octopus and Wall Walkers are the Frog and the Snapper Hand. These are highly tackified and stretchy soft rubber bands shaped as a Frog's tongue attached to a frog shaped handle or a band with a hand shaped end. These are cast out like a fishing line toward a small object which will stick to the tacky end and be retrieved when the band snaps back. There is also another variation called Boogers™ from the planet Nose from Toy Headquarters, Inc. Packed in plastic nose-shaped Nose Cones, these green colored creatures will stick to walls and other surfaces.

Different plastics are used to make Wall Walkers. They may be composed of an isoprene polymer (a synthetic rubber), styrene-butadiene copolymer, or a poly(styrene-butylene-ethylene) copolymer along with tackifiers, and coloring materials. In some cases, wall walkers glow in the dark. This is due to the addition of a phosphorescent zinc sulfide.

GLUE BALL®

A Glue Ball®, manufactured in Taiwan for Hyman Products Inc., consists of two very sticky half spheres that can be used independently or stuck together as a single ball. The Glue Ball® can be stretched, squeezed, or squashed and it will return to its original shape. It will stick to many surfaces such as windows, doors, or walls and will "walk" down a vertical surface. Similar toys are sold under the name of Smartball™, Tacky Wacky Wall Roller™, Jelly Ball, and others.

The Glue Ball® is made of a gel composed of an intimate melt blend admixture of poly(styrene-ethylene-butylene-styrene) triblock copolymer with high levels of plasticizing oil. The resulting transparent gel will not tear or crack under stretching or compression and has the property of elastic memory recovering and retaining its original molded shape after extreme deformations such as high velocity impact and stress conditions.

During use, the Glue Ball® will pick up dirt and other materials on its surface. Its original texture can be restored by washing it with soap and water.

A variation of the Glue Ball®, called Living Ice®, was available in Mattel's Monster Lab® or separately in toy stores. This was a mixture of approximately one-third poly(styrene-ethylene-butylene-styrene) triblock copolymer with two-thirds plasticizing oil. This gel is not as elastic as a Glue Ball®, tearing apart easily at room temperature, but it does reversibly cross-link, joining together without evidence of tearing. Living Ice® is not tackified.

Living Ice® can be used like Slime® if warmed in the hands or under warm water. It becomes goopy and can be stretched. If thrown against a smooth surface such as a window, it will stick to the surface. If cooled in a refrigerator or freezer, Living Ice® will bounce like a rubber ball.

over 800 times its weight of distilled water. It can be found in nursery supply stores under the names of Water Lock or Water Grabber.

Another type of superabsorbent material is a sodium polyacrylamide material sold under the name of Soil Moist in nursery supply stores or Ghost Crystals by Flinn Scientific. Ghost crystals form larger “chunks” of the superabsorbent gel.

LIGHTSTICKS

CYALUME® lightsticks, manufactured by American Cyanamid Co., with similar items available from other manufacturers, are devices that produce a “cool-light” by means of a chemical reaction. The reaction is similar to the one that produces light in a firefly, but the chemicals involved are different.

A lightstick consists of dilute hydrogen peroxide solution in a phthalic ester solvent contained in a thin glass ampoule which is surrounded by a solution containing a phenyl oxalate ester and the fluorescent dye 9,10-bis(phenylethynyl)anthracene, (blue lightsticks use 9,10-diphenylanthracene) all contained in a plastic tubular container. When the glass ampoule is broken, by bending the lightstick, the hydrogen peroxide and the phenyl oxalate ester react to form phenol and some intermediate (short lived) compounds. During the reaction, the energy given off is transferred to the dye molecules. The excited dye molecules (designated as Dye*) give off the excess energy in the form of light without any noticeable heat. Thus the name, “cool-light”.

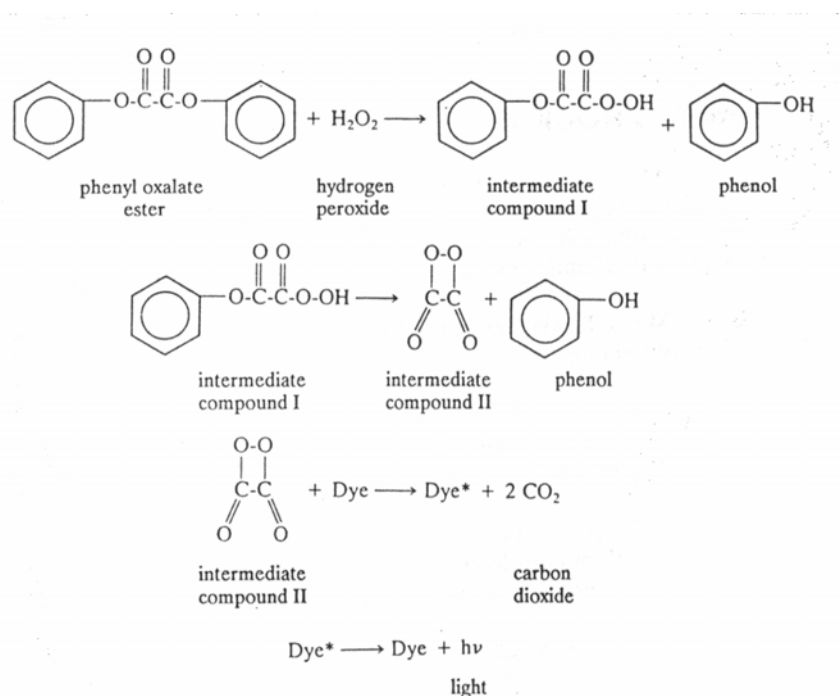


Figure 20. Summary of the lightstick reaction (from Shakhshiri, *Chemical Demonstrations*, Vol. 1, Univ. Wisconsin Press, 1983)

Lightsticks can be used to demonstrate how the rate of a chemical reaction varies with temperature. To do this, initiate three lightsticks. Place one lightstick in ice water, one in hot tap water (not boiling), and leave one at room temperature as a control. The effect of temperature on the reaction can be observed within a few minutes.

Lightsticks are used as emergency lights and safety lights in industry and for camping. As toys, they are made in the form of earrings, necklaces, bracelets, rings, eyeglasses, and bowties. They are also used to light up balls, golf balls, and flying disks for nighttime playing.

A recent variation of lightsticks are Magic in the Night® light shapes. These are adhesive backed packets in various shapes, such as circles, diamonds, and stars, and filled with lightstick chemicals which are stored in separate glass ampoules. Both ampoules must be broken in order to mix the chemicals.

Lightsticks are dated to indicate their life time. If stored in a cool place, they remain active for at least one year past that date. Light shapes have no expiration date.

MAGIC SAND®

Magic Sand®, also called Super Sand™ and Mystic Sand, is sand (silicon dioxide) that has been treated with a colored dye and coated with a finely divided hydrophobic silicon coating. Due to its hydrophobic coating, Magic Sand® can be placed in water to form underwater towers or columns and designs, and then be removed and found to be completely dry. Because of its water repellency, the particles of Magic Sand® will stay together as a separate phase in the water similar to the phase separation of a polar and a non-polar liquid such as vinegar and oil

The Magic Sand® is an application of an invention from Cabot Corporation, Boston, Mass, originally used for the removal of oily contaminants from water systems. A similar material is a fumed silicon dioxide, called Cab-O-Sil, marketed by Cabot Corp. which is used for many applications such as thickening, thixotropy, suspension of solids, and optical clarity in products such as coatings, adhesives, cosmetics, inks, plastics, and rubbers. It is also used as an anti-caking agent to promote the free flow of dry powders.

Magic Sand® is prepared by treating an inland sand (which has grains with rounded edges for better flow characteristics) with an organohalosilane such as dimethyldichlorosilane, $(\text{CH}_3)_2\text{SiCl}_2$. In the reaction, the surface of the sand becomes coated with a thin monolayer silicone film, $(\text{CH}_3)_2(\text{OH})\text{Si-O-}$ which repels water because it is similar to a hydrocarbon film. Materials such as paper, wood, glass, silk, and porcelain can also be coated with a water-repellent film by simply exposing them to the vapor of organohalosilanes.

A Magic Sand® type of material can be made by spraying oven dried sand (one hour at 250°F) with a water-repellent material such as Scotch-gard®.

MAGIC ROCKS®

Magic Rocks®, manufactured by Magic Rocks and Craft House Corporation, are also known as a “Chemical Garden”. They consist of small “rocks” colored white, blue, green, red, purple, and orange or yellow. When placed in the “growing solution”, the rocks grow forming colored columns. After growth is complete, the growing solution can be poured off and replaced by water so that the Magic Rock garden can be maintained for decoration.

Magic Rocks® consist of a sodium silicate solution in water, Na_2SiO_3 , (the growing solution) and small chunks of various chemical salts. Some commonly used salts and their colors are:

calcium chloride (white), copper(II) sulfate (blue), cobalt(II) chloride (red), iron(III) chloride (yellow or orange), nickel(II) nitrate (green), and manganese(II) chloride (pink or purple). In the past, lead(II) nitrate was used as for white crystals.

To keep the salts stable (some of these are deliquescent or slightly efflorescent), they seem to be dispersed in an alum or aluminum hydroxide and thus do not crumble easily. Attempting to dissolve the colored “rocks” in water or dilute acid results in a gelatinous precipitate.

The reaction between the salt that composes the Rock and the sodium silicate results in the formation of a gelatinous precipitate that forms a barrier between the reactants. This film then develops cracks and, since it is not firmly adhered to the salt, allows further contact between the reactants. The mobile reactant (the salt) penetrates between the precipitate and the support and a new layer of precipitate displaces the first. New precipitate may be formed

wherever a crack appears and the shape of the precipitate may be anything from a roughly symmetrical, cauliflower-like growth to long, slender shoots or thin, serrated sheets.

The fact that the “rocks” are composed of highly soluble salts with a high rate of solution result in rapid growth of precipitate. The cracks in the gelatinous layer is caused by a large difference in osmotic pressure between the silicate growing medium and the saturated salt solution. The sodium silicate does not have a high osmotic pressure even when concentrated because much of the silica present is in the form of aggregates (colloidal micelles or giant ions) so that the ionic strength is quite low.

If one observes the slender shoots formed in the first stages of growth, they will see an air bubble leading the growth upward in a jerky, side to side type of motion. This is often cited as evidence that a gelatinous membrane bursts periodically and a new precipitate forms.

To make a chemical garden, mix 100 mL of sodium silicate solution (available from chemical supply companies and some hobby shops) with 400 mL of water in a 600-mL beaker or glass. Add sufficient sand (silicon dioxide) to form a thin layer on the bottom of the container and allow it to settle. Add crystals or chunks of any of the above salts to the solution, but do not add too many at one time to prevent cloudy solutions and heavy precipitates. After the garden is grown, it can be saved by siphoning off the sodium silicate solution and replacing it with water.

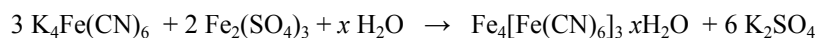
MAGIC TREE®

Magic Tree® is a miniature artificial tree that grows forming ornamental “buds” in as little as 15 minutes, and “magically” growing into a delicate tree in about 2 hours. Magic Tree® is manufactured by New Tomorrow, Inc.

A Magic Tree® consists of two pieces of green or white colored blotter paper cut so as to be assembled into a small evergreen tree with spots of dye on the ends of the branch tips. The tree is placed in a solution made by mixing a small packet of blue powder with 1 teaspoon of water and, over a period of time, small crystals will grow on the ends of the branches. After about 2 hours, the ends of the branches contain clusters of crystals. The tree can be dried and, if protected, can last for months.

The dyes on the Magic Tree® are mainly water soluble food colors. The growing solution is made from an alkaline salt, ammonia, and water. A representative solution can be made from 6 tbsp sodium chloride (this is not an alkaline salt), 1 tbsp ammonia, 6 tbsp water, and 6 tbsp liquid laundry bluing. In operation, the solution moves up the tree by capillary action. The tree is permeated by the solution, however, the branch tips, being tapered to a point, experience the most rapid rate of evaporation resulting in crystal formation.

Laundry bluing, used to whiten fabrics which have turned yellow or gray, is composed of a colloidal solution of Prussian blue which is used as a blue pigment that makes fabrics appear white. Prussian blue is made by reacting potassium ferrocyanide with iron(III) sulfate:



Note: $x = 14-16$

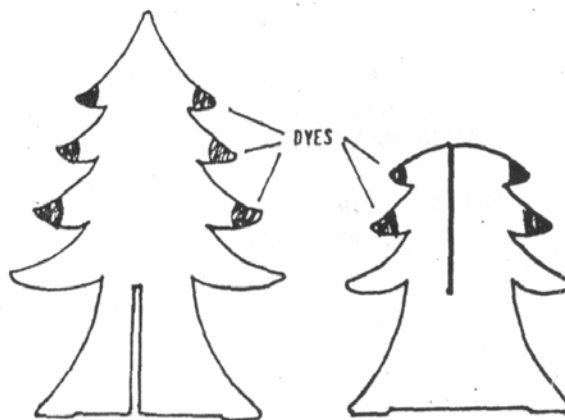


Figure 21. An unassembled Magic Tree®

Prussian blue is formed as a precipitate (it is not soluble in water). This reaction, however, is the ideal case when the reaction occurs very slowly. If formed quickly, as is usually the case, the Prussian blue is more likely to have the formula $K[Fe^{II}Fe^{III}(CN)_6] \cdot xH_2O$. It contains iron in both the +2 and +3 oxidation states, as denoted by the Roman numerals. The intense color is due to charge-transfer from Fe^{II} to Fe^{III} . (There is no color if both iron atoms are in the same oxidation state.)



Figure 22. Assembled Magic Tree® in growing solution.



Figure 23. Magic Tree® showing crystal growth.

Addition of ammonia, a base, and salt does not change the color of the bluing solution, but the crystals that grow are white. It is suspected that during the evaporation of solvent and resulting crystallization there is probably a reduction of the Prussian blue forming white $K_2Fe^{II}Fe^{II}(CN)_6$ where additional K^+ ions would fill in the crystal lattice due to the openings left by reduction of Fe^{III} to Fe^{II} . Since there are few additional potassium ions in solution, the lattice is probably filled by the Na^+ ions from the salt forming $KNaFe^{II}Fe^{II}(CN)_6$ which should also be white in color. The potassium compound, $K_2Fe^{II}Fe^{II}(CN)_6$, is known as Everitt's salt (first reported by Thomas Everitt in 1835 by boiling potassium ferrocyanide with dilute sulfuric acid).

LIQUID CRYSTALS

Liquid crystals are organic compounds that are in a state between liquid and solid forms. They are viscous, jelly-like materials that resemble liquids in certain respects (viscosity) and crystals in other properties (light scattering and reflection). Liquid crystals must be geometrically highly anisotropic (having different optical properties in different directions)-usually long and narrow - and revert to an isotropic liquid (same optical properties in all directions) through thermal action (heat) or by the influence of a solvent. Liquid crystals are classified as:

smectic: molecules arranged in horizontal layers or strata and are standing on end either vertically or at a tilt.



nematic: molecules possess a high degree of long-range order with their long axes approximately parallel, but without the distinct layers of the smectic crystals.



lyotropic: molecules consist of a nonpolar hydrocarbon chain with a polar head group. In a solvent, such as water, the water molecules are sandwiched between the polar heads of adjacent layers while the hydrocarbon tails lie in a nonpolar environment.



If smectic and nematic liquid crystals are subjected to changes in temperature, they change their form and their light transmission properties splitting a beam of ordinary light into two polarized components to produce the phenomenon of double refraction. This results in the appearance of the characteristic iridescent colors of these types of liquid crystals. This type of liquid crystal finds use in thermometers, egg timers, and other heat sensing devices. Changes in structure can also be accomplished using a magnetic field which make them useful in calculator or other LCD displays. Temperature sensitive liquid crystals were used in Mood Rings.

When lyotropic liquid crystals are subjected to disturbances, such as stirring or squeezing, the layers of crystals are disturbed altering their light transmission characteristics to produce color changes similar to the smectic and nematic liquid crystals described above. These are the type of liquid crystals used in the Press Me stickers.

Some liquid crystal products are: Mood Rings; Liquid crystal stickers, called Press Me stickers, which come in various shapes and swirl into many different colors when gentle pressure is applied; A plastic disc called a Space Fidget®, made by A.R.C., contains mixture of temperature and pressure sensitive liquid crystal material which exhibits color patterns when rubbing its back or changing its temperature; and Fickle Foam, made by Davis Liquid Crystals, which is temperature sensitive liquid crystal sheet mounted on a thin foam pad.

Another application of liquid crystals is in Hot Wheels Color Racers® and Color FX™ cars manufactured by Mattel Toy Corp. These are model cars that are painted with a temperature sensitive liquid crystal paint and which change colors when placed in icy cold or warm tap water.

Other novel applications of liquid crystal materials are in Mattel's Nickelodeon™ Color Writer™ Drawing Screen, in dolls such as Lil Miss Magic Hair™, Hollywood Hair™ Ken , and Secret Hearts™ Barbie , and in Playskool's Magic Lemonade Party™ or Magic Breakfast Party™. In the Nickeloden™ Color Writer™, a heat pen, powered by two batteries, is used to write or draw on a black liquid crystal screen. When warmed, the liquid crystals become

transparent and the colors of the board behind the liquid crystals in visible. To erase the drawing, an ice cube is used, in a metal eraser container. In the dolls, hair or clothing is impregnated with liquid crystal material. Depending on the doll, warming or cooling using a wand or plastic bag filled with water will cause hair color to change, or stars or hearts to appear in hair or clothing. The Magic Lemonade or Breakfast Party, and similar toys, use liquid crystal material to make pitchers, knives, cookies, and muffins change color to simulate pink lemonade, orange juice, and jelly on toast or muffins. In summary, whenever a substance or object changes color with a change in temperature, it is a high probability that liquid crystals are involved.

MELTING MONEY AND MAGIC NURSERY™ TOYS

Melting Money and Melting Memos, which were marketed by So Much Fun!, are paper items that dissolve when placed in water. The paper is composed of carboxymethylcellulose (starch) with 20% or less cellulose (wood fibers). This material has been used by organizations such as the CIA for secret or sensitive documents which can easily be destroyed by wetting with water.

A number of toys using dissolving paper have appeared. Trash Bag Bunch™, from Lewis Galoob Toys, consist of plastic figures contained in a dissolving paper garbage bag. When placed in warm water, the garbage bag dissolves and the figure is obtained. A variation of this is Mattel's Hot Wheels Revealers, Hot Wheels cars wrapped in a dissolving paper cover.

A novel use of dissolving paper is the Magic Nursery™ toys. Magic Nursery™ dolls are packaged in dissolving paper clothes and had to be placed in water to discover if the doll was a boy or a girl. There are also a number of Magic Nursery™ accessories, one of which are Bye-Bye Diapers™. These paper diapers fit Magic Nursery and other 10-inch to 14-inch dolls. Instead of disposing of the diapers after play, they are placed in water and dissolve to leave a plastic package containing a pair of cloth training pants with the words "I'm in training" printed on them.

Currently, dissolving paper is available from Flinn Scientific as melting mole dollars.

SMELLY PATCHES AND SCRATCH AND SNIFF STICKERS

Smelly Patches are cloth patches backed with a heat activated adhesive that can be applied to clothing or other objects. Smelly Patches contain a picture of a fruit such as apples, grapes, strawberries, etc..., and also smell like the fruit that is pictured. The smell is a result of natural fragrances or esters that are microencapsulated onto the surface of the Smelly Patch.

Microencapsulation is a process where substances such as inks or dyes, adhesives, cosmetics, pharmaceuticals, or fragrances are contained in microscopic capsules, 20 to 150 microns in diameter, which can be broken mechanically, electrically, or chemically to release the contents. The microcapsules are composed of different materials depending on the substance packaged and the method by which it is to be released. Gelatin is widely used as an encapsulating agent. The advantage of microencapsulation is that the capsules remain stable and inert until broken down. A major producer of microencapsulated materials is the 3M Corporation.

A similar product to the Smelly Patches are scratch and sniff spots which are often used in magazine or direct mail advertisements or children's books. There are also scratch and sniff stickers. In both cases, an individual usually uses a fingernail to mechanically break the microcapsules releasing the contents.

Flavors and fragrances may utilize a single ester or a mixture of esters and other substances. Some esters that smell like common materials that can be prepared in the laboratory are listed in Table 1.

Table 1. Common esters used for flavors and fragrances

Ester	Smells like	Prepared from
isoamyl acetate	banana	isoamyl alcohol and acetic acid
ethyl butyrate	pineapple	ethanol and butanoic acid
benzyl acetate	peaches	benzyl alcohol and acetic acid
n-propyl acetate	pears	n-propyl alcohol and acetic acid
benzyl butyrate	flowers	benzyl alcohol and butanoic acid
methyl butyrate	apples	methanol and butanoic acid
isobutyl propionate	rum	isobutyl alcohol and propionic acid
octyl acetate	oranges	octanol and acetic acid
methyl anthranilate	grapes	methanol and 2-aminobenzoic acid

Esters can be made, in the laboratory, by mixing a few mL each of an alcohol and an organic acid and adding a few drops of concentrated sulfuric acid or phosphoric acid. The acid should generate sufficient heat to initiate the reaction, but the mixture can be heated in a water bath if necessary. If the esters are intended to be passed around a group of people, add a small amount of glass wool to the container to prevent spilling or splashing.

NITINOL: THERMOBILES AND BUTTERFLIES

Nitinol is a nickel-titanium alloy that was first made at the U.S. Naval Ordnance Laboratory. This alloy exhibits a shape memory effect, that is, it radically changes shape when subjected to a temperature change. Nitinol wire is soft at a low temperature and can easily be bent into simple shapes. At high temperature, the Nitinol wire becomes stiff reverting to its original shape.

One application of Nitinol is the Thermobile (see Figure 24), a device consisting of a wire loop around two pulleys, one brass and one plastic, that generates power without a motor or batteries. The Thermobile is manufactured by Innovative Technology International, Inc.

The Thermobile works by immersing the bottom edge of the brass pulley into hot water between 50°C and 75°C. Within a few seconds, the Thermobile will begin to spin continuing as long as the bottom is at a temperature above 50°C. What takes place is that the Nitinol wire, bent around the metal pulley, will try to straighten itself out and, in the process, will cause the wheel to spin. The effect can also be produced by using solar energy, with the aid of a magnifying glass, to heat the brass pulley.

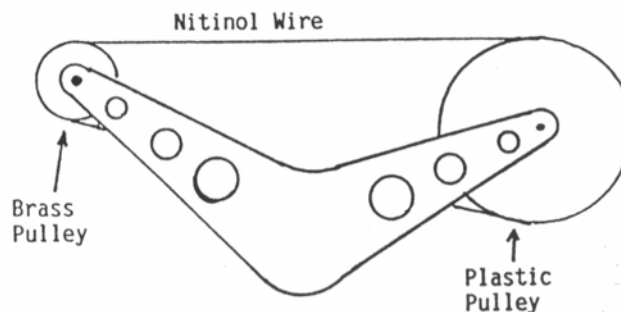


Figure 24. A Thermobile

An improved version of Nitinol wire, consisting of approximately 50% each of nickel and titanium is manufactured by Toki Corporation under the name BioMetal®. This alloy has been stretched and, when heated, will shorten to its original shape. BioMetal® wire is used in a device called Space Wings and a Kinetic Butterfly, butterfly types of devices which flaps their wings due to the contraction of the BioMetal® wire.

DISAPPEARING INK

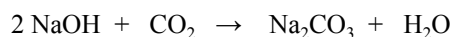
Disappearing ink is a bright blue water-based solution which, when squirted on clothing, table cloths, or other materials, will disappear within minutes leaving only a colorless “water spot” that will evaporate slowly. When dry, there is a small amount of white residue that remains.

The pH of the disappearing ink solution is about 10-11 (moderate to strong base). Addition of acid, such as hydrochloric acid, HCl, causes the solution to turn colorless forming a white precipitate. Addition of base, such as sodium hydroxide, NaOH, dissolves the precipitate and restores the blue color. If the “ink” is squirted on cloth, the colorless water spot that remains after the color fades is slightly acidic with a pH of about 5-6. Addition of base to the water spot causes the blue color to return. The blue color is also obtained if base is placed on the dried “ink” spot.

Due to its color change with pH, the material used to make the disappearing ink was identified as an acid-base indicator called thymolphthalein, C₂₈H₃₀O₄ (colorless to blue at pH 9.3-10.5). This was confirmed by infrared spectrophotographic analysis by the author.

The disappearing ink is made by dissolving a small amount of thymolphthalein in ethyl alcohol followed by dilution with water. The blue color is obtained by the addition of a small quantity of sodium hydroxide solution. A red disappearing ink can be made using phenolphthalein in place of the thymolphthalein.

The pH change which causes the color to fade is a result of the reaction of the sodium hydroxide, NaOH, with carbon dioxide, CO₂, in the air to form sodium carbonate, Na₂CO₃, according to the following reaction:



Once the sodium hydroxide is neutralized, the acidity of the alcohol changes the “ink” to colorless.

Disappearing ink, both blue and red, are used as the fuel in Zap-it® guns. These are battery powered water pistols used to shoot the colored liquid which acts as an indicator to show a victim is “shot”.

A novel application of the disappearing ink reaction is Mattel’s Hollywood Hair™ Barbie dolls. The extra long hair of the doll is coated with phenolphthalein indicator. When sprayed with Magic Hair Mist, consisting of ethyl alcohol, water, and a base, such as sodium hydroxide, the hair of the doll turns pink. As the hair dries the pink color fades to colorless.

MYSTIC SMOKE

Mystic Smoke is a grease-like paste that produces puffs of “smoke” from the fingertips when they are squeezed together and then snapped apart. It is used by magicians or jokesters to pinch some smoke from a cigarette (either lighted or unlit) and throw it away, or to pull out “cobwebs” from an old book or their wallet.

Mystic Smoke is a grease-like paste made from a mixture of machine oil, linseed oil, scale wax, carnauba wax, soap, latex, resins, and rosin. In use, a small amount is rubbed onto the thumb and first finger of a warm hand until it is undetectable. The fingers are squeezed together, allowing the Mystic Smoke material to adhere to itself, and then snapped apart producing spider web-type strings that give the appearance of smoke

Several types of heavy greases and petroleum jelly (Vaseline) were tried by the author in an attempt to duplicate the Mystic Smoke effect without success.

SPARKLERS

Sparklers in gold, red, green, and blue colors are often used to decorate birthday cakes or similar items for parties, or for celebrating holidays. Sparklers consist of a metal wire with about 3/4 of it covered with a silver or colored hard material. The combustible material is most commonly a gunpowder type material consisting of sodium and/or potassium nitrates (chlorates may be used) with sulfur and carbon. The sparks are provided by powdered metals such as iron, aluminum, or magnesium. The metal powder is coated with paraffin wax to prevent oxidation during storage and to allow the metal to fall off the sparkler as it burns producing the characteristic sparks. Colors are produced by adding nitrate or chloride salts of strontium (red), barium (green) and copper (blue). The combination of added metal salts and paraffin wax are responsible for making the sparkler difficult to ignite. When using sparklers, take care to keep them away from the face and body, as well as away from any flammable material. After combustion is complete, the wire will be hot.

FLASH PAPER

Flash Paper is available in magicians' supply store and novelty shops. It can be purchased in pads of 20 2½ in. x 3 in. sheets (6.3 cm x 7.6 cm) and in 8 in. x 10 in. sheets (20 cm x 25 cm). It is also available in the form of Flash Bills, which approximate the size and color of a U.S. one dollar bill, and Flash Cotton.

Flash paper is commonly used by magicians to throw fire into the air or with magic wands that shoot bursts of flame. Flash paper burns leaving almost no ash.

Flash paper is nitrocellulose, sometimes called guncotton (approx. formula $C_6H_7O_2(ONO_2)_3$). It is prepared by treating cellulose, in the form of paper or cotton, with a mixture of nitric and sulfuric acids. There are many different forms of nitrocellulose obtained by varying the strength of acids used, temperature and time of reaction, and the acid/cellulose ratio. Other uses of nitrocellulose are in fast drying automobile lacquers, collodion, rocket propellant, medicine, printing ink base, coating bookbinding cloth, and leather finishing. Nitrocellulose, as used in flash paper, is extremely flammable and some forms can explode on sharp impact.

FLASH POWDER

Flash powder can be obtained at magicians' supply stores in two different forms. One type is a pre-mixed powder, and the second type is a photographic flash powder that comes packaged in two separate containers. In practice, flash powder is used in the theater for special effects, usually with a special flash pot, when making persons or things disappear.

The pre-mixed flash powder was analyzed by the author and found to be mainly a gunpowder or black powder consisting of sodium and potassium chlorates and/or nitrates with sulfur and carbon.

The two component photographic flash powder is the type that was often used before the invention of flash bulbs. Its use can sometimes be observed in some silent movies and early talking movies. The two components were analyzed and the one component was found to be a mixture of powdered magnesium and powdered aluminum, with potassium chlorate as the second component.

Flash powders, when mixed, are extremely flammable and shock sensitive and, if covered or placed in a closed container, are explosive. Mix only in plastic containers with plastic utensils and with great caution. Mix only as much as you plan to use and **never store mixed flash powder**. Once mixed the material is unpredictable and should be used immediately.

DRAGON'S BREATH

Dragon's Breath is available from magicians' supply stores. When sprayed into a fire, it burns producing a large billow of flame like a dragon's breath. This is the material a magician uses to produce a puff of flame from his/her hand.

Dragon's breath is composed of lycopodium, a fine yellowish powder which is composed of club-moss spores (available from many laboratory supply houses). The process of spraying it into a fire results in a dust explosion as the fine particles burn when heated in an abundance of fresh air. It can be demonstrated that lycopodium does not burn in bulk by attempting to burn a small pile of it on a ceramic or other flame proof board. Lycopodium can be sprayed from a plastic wash bottle, a small rubber bulb, or simply thrown into a flame.

Care should be exercised in using lycopodium powder as some individuals are allergic to the spores.

SNAKES

Magic Snakes, sometimes called Pharaoh's Serpents, come as small pellets which, when ignited, "grow" into long curving columns of ash resembling a "snake". Originally, snakes were composed of mercury(II) thiocyanate, $\text{Hg}(\text{CNS})_2$, which was bound into a pellet by using dextrin or a gum. Due to the toxic nature of the mercury(II) thiocyanate and of the combustion products, sulfur dioxide and mercury vapors, the mercury compound has been replaced. The black, non-mercury snakes now available are composed of a naphthol pitch that has been mixed with linseed oil, treated with nitric acid, washed and air dried, then broken up and further treated with picric acid. The product is then mixed with gum arabic, pelleted, dried, and aged for several months.

CAPS AND BLASTER BALLS

Caps used in cap guns usually contain 0.20 grains or less of a pyrotechnical material composed of potassium chlorate, KClO_3 ; red phosphorus, P_4 ; manganese dioxide, MnO_2 ; magnesium oxide, MgO or calcium carbonate, CaCO_3 ; sand, SiO_2 ; and glue to bind it together. The manganese dioxide catalyzes the decomposition of potassium chlorate to form oxygen and potassium chloride. The magnesium oxide or calcium carbonate acts as an anti-acid to prevent deterioration due to moisture in storage. The sand helps to produce friction. The mixture of potassium chlorate and phosphorus is explosive and extremely unpredictable in any quantity.

A variation of the caps used in cap guns are called Blaster Balls marketed by Placo Products Co., Cosmos®, and others. These consist of a set of two ceramic balls of different colors (usually yellow and black, or red and blue), which are both coated with a thin layer of the same chemical mixture of potassium chlorate, sulfur, glue, and powdered glass (silica). To use Blaster Balls, holding one ball in the hand, toss the other ball into the air and catch it by bringing the hand with the ball upward cracking the balls together. When the coated surfaces of the two balls hit together, there is a cap-like blast produced. The same cap-like blast can be produced if a single ball hits a high silica-containing substance, such as concrete, indicating that the silica produces sufficient friction, and heat, to detonate the chemical mixture. A pair of Blaster Balls can produce over 200 blasts. (NOTE: Although Blaster Balls are non-flammable, a mixture of potassium chlorate and sulfur is explosive and is unpredictable in any quantity.)

SNAP'N POPS

Snap'n Pops, also called Devil Bangs, Rio Snappers, or Bang Snaps are noisemakers made in Brazil or Korea. A Snap'n Pop is a cigarette paper rolled and twisted into the shape of a roughly spherical teardrop with a tail. The teardrop is loaded with about 0.18 gram of small gravel or coarse sand coated with 0.0008 gram of silver fulminate, $\text{Ag}_2(\text{CNO})_2$. When the device is thrown against a hard surface, friction between the granules sets off the silver fulminate with a quick bang.

The explosion generates little flame and almost no gas, as compared with toy caps, so that the granules are not widely scattered. Except for the paper wrap, they are nonflammable. They are safe in storage and shipment. They are not set off by heating to 75°C (167°F) but will detonate if exposed to a flame. Even when detonated in the hand, it causes no burn, tingle, or damage.

BIG-BANG® CANNONS

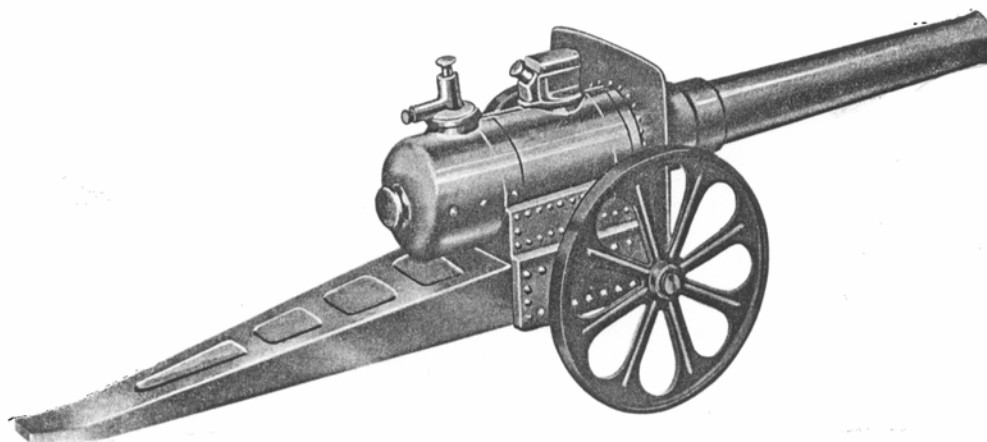
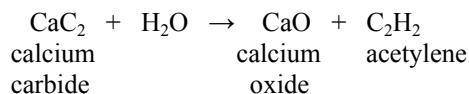
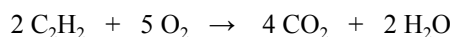


Figure 25. A Big-Bang® Cannon

A Big-Bang® Cannon (see Figure 25), made by The Conestoga Company, Bethlehem, Pa., is fueled by a substance called Bangsite®. Bangsite® is powdered calcium carbide. The Bangsite® is placed in a breech block on the cannon and a small amount is emptied into the firing chamber which contains a small amount of water. On reaction with water, acetylene is produced:



The acetylene produced mixes with the oxygen in the air within the firing chamber. When a spark is produced by the firing mechanism, the acetylene gas burns rapidly to produce carbon dioxide and water vapor according to the reaction:



This rapid burning produces heat resulting in the almost instantaneous expansion of the gases forcing them out of the muzzle of the cannon. The combustion of the remaining gases is completed outside of the cannon leaving a -

partial vacuum outside the muzzle and within the cannon. The resulting “inrush” of the atmosphere to fill the void is perceived as an explosion producing a loud bang or noise. (see Figure 26)

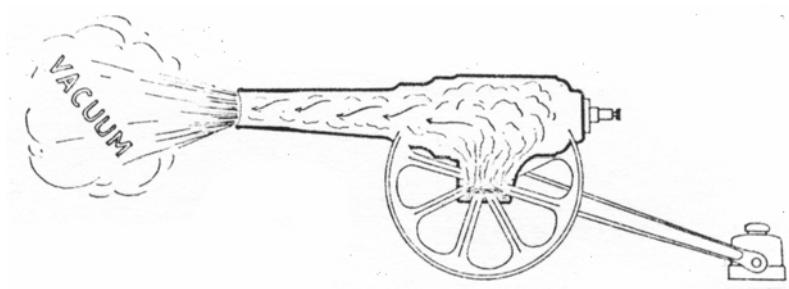


Figure 26. Firing the cannon