Morning of Chemistry

An Epic Adventure in Science

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Presenter Bios

Mike Marvel leads the Chemistry team at Flinn Scientific. Prior to joining Flinn, Mike spent three years as an Assistant Professor of Chemistry at Aurora University, where he taught Inorganic and General Chemistry and led an undergraduate research program funded by American Chemical Society and National Science Foundation. Mike has authored or co-authored thirteen manuscripts in peer-reviewed journals, on topics ranging from unique pedagogies in the science lab to the commercial applications of solid state metal oxides. Mike holds a Bachelor of Arts in Chemistry from Connecticut College and a Ph.D. in Inorganic and Solid State Chemistry from Northwestern University.

Joan Berry has been with Flinn Scientific for five years. Three years have been with the Product Management team, as a Staff Chemist, helping to develop new and interesting products, and two years, as the Chemical Repack Supervisor with the Operations team. Joan earned a Masters in Chemistry from Illinois State University where she also performed laboratory research in the synthesis of new inorganic hexanuclear rhenium complexes. Joan mentored students in the research lab and was a teacher's aide in general lab sections at ISU. In 2012, Joan's research contributions were published in the Inorganic Chemistry Journal.

Jillian Saddler is part of the Product Management team at Flinn Scientific. Prior to joining Flinn Scientific, Jillian was a high school chemistry teacher for eight years. She has experience teaching AP Chemistry, Honors Chemistry, and Chemistry. During her college years, she was also a teaching assistant for the University of Illinois at Urbana-Champaign, teaching both CHEM 101 and CHEM 202 classes. Jillian has presented workshops on Chemistry, AP Chemistry, and Higher Ed Safety at state and national conferences. She enjoys collaborating and helping teachers engage students in science.

Whoosh Bottle

FLINN SCIENTIFIC CHEM FAX!

Introduction

Wow your students with a whoosh! Students will love to see the blue alcohol flame shoot out the mouth of the bottle and watch the dancing flames pulsate in the jug as more air is drawn in.

Concepts

- Exothermic reactions
- Activation energy
- Combustion

Background

Low-boiling alcohols vaporize readily, and when alcohol is placed in a 5-gallon, small-mouthed jug, it forms a volatile mixture with the air. A simple match held by the mouth of the jug provides the activation energy needed for the combustion of the alcohol/air mixture.

Only a small amount of alcohol is used and it quickly vaporizes to a heavier-than-air vapor. The alcohol vapor and air are all that remain in the bottle. Alcohol molecules in the vapor phase are farther apart than in the liquid phase and present far more surface area for reaction; therefore the combustion reaction that occurs is very fast.

Since the burning is so rapid and occurs in the confined space of a 5-gallon jug with a small neck, the sound produced is very interesting, sounding like a "whoosh." The equation for the combustion reaction of isopropyl alcohol is as follows, where 1 mole of isopropyl alcohol combines with 4.5 moles of oxygen to produce 3 moles of carbon dioxide and 4 moles of water:

$$(CH_3)_2CHOH(g) + {}^{9}\!/\!_{2}O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) \qquad \Delta H = -1886.6 \text{ kJ/mol}$$

Materials

Isopropyl alcohol, $(CH_3)_2CHOH$, 20–30 mL

Whoosh bottle, plastic jug, 5-gallon

Fire blanket (highly recommended)

Funnel, small

Graduated cylinder, 25-mL

Match or wood splint taped to meter stick

Safety shield (highly recommended)

Safety Precautions

Please read all safety precautions before proceeding with this demonstration.

- Isopropyl alcohol is a highly flammable liquid and vapor. Keep away from heat, sparks, open flames, and hot surfaces. May cause drowsiness or dizziness. Avoid breathing mist, vapors or spray. Use in a well-ventilated room.
- Isopropyl alcohol cause serious eye irritation. *Always* wear protective eyewear when performing this demonstration. Anyone viewing this demonstration should also wear eye protection. Please review current Safety Data Sheets for additional safety, handling, and disposal information.
- *Always* recap the alcohol bottle and move it far from the demonstration area. *Never* leave an open bottle of alcohol in the vicinity of the demonstration.
- A safety shield is highly recommended for explosions. Even the mildest explosion creates some chance of shattering and flying objects. Protective eyewear must be worn by the demonstrator as well as by anyone viewing the demo.
- *Never* perform alcohol explosions in glass bottles. The large quantities of gases (H_2O and CO_2) produced during the rapid combustion will easily shatter a glass container. Serious accidents have occurred performing this demonstration in a glass container—do not use glass. Only use a plastic jug, such as a 5-gallon water jug.
- Always pour out excess unvolatilized liquid alcohol from the plastic jug before igniting. If any liquid alcohol is left, it will increase the amount of gaseous afterburning. The liquid could also ignite, which may cause the plastic jug to melt. Always keep a lid or some sort of cover handy, which can be placed over the mouth of the jug to extinguish the flame if it begins to melt the plastic. Excess alcohol in the lip of the mouth of the jug and on the outside of the jug

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should be wiped off in order to avoid its igniting and softening the plastic jug.

- *Never, ever* use a pure oxygen environment as the potential for an extremely violent and deadly explosion is possible.
- Never use methyl alcohol for this demonstration. The high volatility of methyl alcohol means that it has the potential for the most violent combustion of any alcohol.
- Replace the plastic "whoosh bottle" should it show grazing, frosting, cracking, or any small flaws. Routinely replace the bottle after approximately 20 uses or so.
- Do not perform this demonstration directly underneath smoke/heat detectors or sprinkler systems.
- Make sure the ceiling is at least 4 feet above the whoosh bottle to prevent possible scorching and fire.

Preparation

Before each demonstration, inspect the plastic whoosh bottle for grazing, frosting, cracking, or any small flaws. Replace the bottle if it shows signs of fatigue.

Procedure

1. Add about 20–30 mL of isopropyl alcohol to the 5-gallon plastic jug. Do not add more than 30 mL of alcohol. Recap the bottle of alcohol tightly and move it far from the demonstration area.
2. Lay the jug sideways on a flat surface allowing the alcohol to flow from base to mouth. Slowly swirl the jug for about 30 seconds, trying to spread alcohol liquid completely over the entire interior surface. This allows the liquid alcohol to volatilize and makes the vapor concentration uniform throughout the bottle. If a lot of liquid alcohol is still visible, swirl the bottle for another 30 seconds.
3. Pour out any excess liquid alcohol and shake out the bottle. Wipe the inside and outside neck of the bottle to remove any remaining liquid.
4. Stand the jug on the floor, placing it in the front of the room and behind a safety shield. *Note:* If desired, the demonstration can be performed on a fireproof demonstration table provided that the ceilings are at least 10 feet high.
5. Dim the lights in the room.
6. Light a match or wood splint that is taped to a meter stick or other long stick.
7. Stand back and, at arm's length, bring the burning match or wood splint over or slightly down into the mouth of the bottle. *Note:* Be sure you are on the safe side of the safety shield as well.
8. Observe the explosive "whoosh" that results.
9. After the reaction has subsided and all the flames are out, wait for a minute or two until the bottle has cooled slightly. Pour out the water droplets from the bottle into a 25-mL graduated cylinder using a small funnel. As much as 12–14 mL of water may result, showing that water is one of the products of the combustion of alcohol.

Repeating the Demonstration

The demonstration *cannot* be repeated immediately for a few reasons—for one, the demonstration *will not work* due to the buildup of CO_2 in the bottle. There is not enough oxygen in the bottle to allow combustion to occur. More importantly, it is extremely dangerous to add alcohol to the jug if the jug is still hot. A flash-back can occur, causing a fire.

In order to successfully repeat the demonstration for another class, follow the steps below:

1. Allow the bottle to cool to room temperature.
2. Pour out the water that forms as a result of the combustion.
3. Fill the bottle with about 10 of cold tap water and swirl the tap water around in the bottle. Pour the tap water into the sink, and repeat the washing with more cold tap water. Pour all the water out into the sink.
4. Dry out the bottle as much as possible by either allowing it to sit upside down or (to speed up the drying) by drying it with

a long string of paper towels pushed into the mouth. A few water droplets on the inside of the bottle do not seem to hinder the combustion.

5. In order to reduce the amount of water in the bottle and speed up the drying, try a double rinse of the bottle with a small amount of isopropyl alcohol.
6. Review the *Safety Precautions* again and follow steps 1–9 in the *Procedure* section.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. Excess alcohol may be disposed of by allowing it to evaporate in a fume hood according to Flinn Suggested Disposal Method #18a. Rinse the jug well before storing it for future use.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts
Disciplinary Core Ideas: Middle School MS-PS1 Matter and Its Interactions PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions **Disciplinary Core Ideas: High School** HS-PS1 Matter and Its Interactions PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions	**Science and Engineering Practices** Developing and using models Constructing explanations and designing solutions	**Crosscutting Concepts** Cause and effect Energy and matter Structure and function

Observations

The first effect that may be observed is the characteristic “whoosh,” which involves a moderately violent thrust of flames and blue gas out of the mouth of the bottle. Some afterburning or dancing flames of burning vapor in the body of the bottle may also result.

The second effect is a slower burn of gas down the inside surface of the bottle, producing a ring, plate, or cone of fire, which may be accompanied by an upward thrust or ball of yellow flames in the center of the jug. The sound accompanying these slower burns is actually more of a “whomp.” This effect can also be observed by using 70% isopropyl alcohol, illustrating reduced vapor pressure due to dilution and a slower rate of reaction.

Tips

- Various sound and flame effects may be produced depending on the alcohol used and its dilution with water. Try using ethyl alcohol or n-propyl alcohol. Compare the results to isopropyl alcohol. Ethyl alcohol proceeds somewhat faster and more violently due to its higher volatility. Propyl alcohol burns slower producing more heat, which may damage the bottle. *Do not try this demonstration with methyl alcohol.* The high volatility of methyl alcohol means that one must be particularly cautious when using methyl alcohol as it has the potential for the most violent combustion and possible rupture of the bottle.
- Depending on how much alcohol vapor is in the bottle, you may have to place the flame slightly inside the mouth of the whoosh bottle before it ignites.
- The demonstration works best if the alcohol vapor is prepared immediately before the demonstration. If the bottle with the vapor sits for a while, the vapor tends to settle and is harder to light.
- Reagent isopropyl alcohol (99%) or 70% isopropyl alcohol can be used for the demonstration. The 70% alcohol produces a slightly slower burn due to the water vapor.

- Use a graduated cylinder to measure the volume of water produced by the reaction. Instruct your students to perform calculations to determine the volume of water expected from the starting amount of isopropyl alcohol.

  For example, if 20 mL of isopropyl alcohol (density = 0.78 g/mL) are used:

  20 mL × 0.78 g/mL = 15.6 g × 1 mole/60 g = 0.26 mol isopropyl alcohol

  From the balanced equation,

  0.26 mol isopropyl alcohol × 4 mol H_2O/1 mol isopropyl alcohol = 1.04 mol H_2O

  So,

  1.04 mol H_2O × 18 g/mol = 18.7 g = 18.7 mL of H_2O expected

  Discuss possible reasons why the actual volume of water may have been slightly less, such as evaporation or the droplets of water remaining on the inside of the bottle.

Acknowledgments

Flinn Scientific would like to thank John Fortman, Dept. of Chemistry, Wright State University, Dayton, OH for all of his research in providing safety notes and variations on this excellent demonstration. John has written an excellent article on this demonstration; see the reference listed below. Lee Marek, Naperville North H. S., Naperville, IL (retired) and Bill Deese have also popularized this demonstration.

Reference

Fortman, J. J.; Rush, A. C.; Stamper, J. E. *J. Chem. Ed.* **1999,** *76*, 1092–1093.

Materials for the *Whoosh Bottle—Chemical Demonstration Kit* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP5943	Whoosh Bottle—Chemical Demonstration Kit
SE225	Safety Shield, 300 × 160
I0019	Isopropyl Alcohol, 500 mL
E0009	Ethyl Alcohol, 500 mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Polyurethane Foam System

Introduction

Try this amazing demonstration! Simply mix two liquids together and watch as the mixture e xpands to about 30 times its original volume. The result is a hardened, lightweight polyurethane foam.

Concepts

- Polymers
- Catalysis

Materials

Polyurethane Foam System (Part A and Part B)*	Disposable glove, clear (optional)
Acetone (optional)	Food coloring (optional)
Disposable cups (clear plastic, if available), 2	Paper towels or newspaper
**Materials included in kit.*	Tongue depressor or stirring rod

Safety Precautions

This activity should only be performed in a fume hood or well ventilated area. Avoid breathing any vapors produced and avoid skin contact, as both Part A and Part B may contain skin and tissue irritants. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. In a fume hood or well ventilated area, pour approximately 20 mL of liquid Part A in a disposable cup. *Note:* The exact volume is not critical. *Do not use glassware!* It is almost impossible to remove the hardened foam. Please use only disposable materials for the handling and mixing of the chemicals.
2. Place approximately 20 mL of liquid Part B in a second disposable cup. *Note:* The volume of Part B should be approximately equal to that of Part A.
3. If desired, add several drops of food coloring to one of the cups and stir thoroughly to mix.
4. Spread a paper towel or newspaper flat on the table and place one of the cups in the center of the paper towel.
5. Pour the contents from the second cup into the cup on the paper towel and stir thoroughly until you see the foam beginning to expand. Remove the stirring rod. *Note:* Use a disposable stirring rod, such as a tongue depressor, to stir the contents.
6. Observe the foam as it expands to about 30 times its original volume. The cup will get warm, indicating an exothermic reaction. Do not touch the foam until it is completely hardened.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The disposable cups may be thrown in the trash. Any leftover liquids should be mixed together, allowed to react, and then the solidified polymer may be disposed of in the trash according to Flinn Suggested Disposal Method #26a.

Tips

- For a fun alternative, place about 35 mL of Part A and Part B in a paper cup, mix, and then pour the mixture into a latex glove. Make sure some of the mixture is in each finger of the glove. Now watch the foam expand and fill the glove. When completely hardened, the glove can be removed (probably not in one piece), if desired. You will have made a "hand" out of the polyurethane foam. The liquid may also be placed in plastic molds.
- Any 50/50 mixture of Part A and Part B may be used, but take into consideration the amount of expansion when measuring out the liquids.

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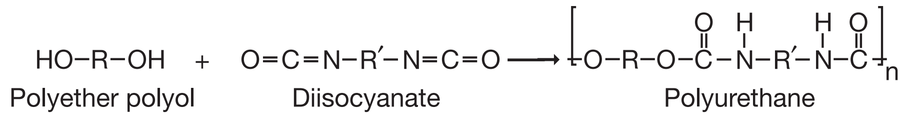
- Acetone may be used to remove any hardened polymer on the table.
- Do not touch the foam. It will take about 15 minutes for the surface to firmly set and may contain unreacted material for up to 24 hours. Some people will have allergic reactions to unreacted monomers.

Discussion

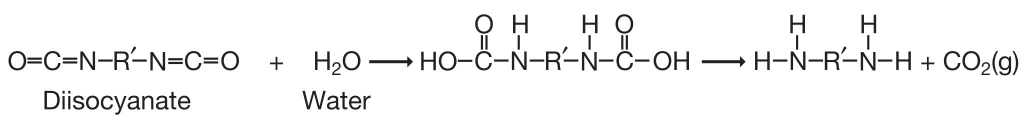
There are many forms of polyurethane such as fibers, coatings, elastomers, flexible foams, and rigid foams. The foam in this system is a rigid foam that is used in furniture, packaging, insulation, flotation devices, and many other items. Here, a rigid polyurethane foam is produced by mixing equal parts of two liquids, called Part A and Part B. This lightweight foam expands to about thirty times its original liquid volume and will become rigid in about five minutes.

Part A is a viscous cream-colored liquid containing a polyether polyol, a silicone surfactant, and a catalyst. The polyether polyol may be a substance such as polypropylene glycol [$HO(C_3H_6O)_nH$]. The hydroxyl (–OH) end of the polymer is the reactive site. The silicone surfactant reduces the surface tension between the liquids. The catalyst is a tertiary amine which aids in speeding up the reaction without being chemically changed itself. Part B is a dark brown viscous liquid containing diphenylmethane diisocyanate [$(C_6H_5)_2C(NCO)_2$] and higher oligomers (dimers, trimers or tetramers) of diisocyanate. When the polyether polyol (Part A) is mixed with the diisocyanate (Part B), an exothermic polymerization reaction occurs, producing polyurethane (see Equation 1).



Equation 1

During the course of the polymerization reaction, a small amount of water reacts with some of the diisocyanate. A decomposition reaction occurs and produces carbon dioxide gas, thus causing the solution to foam and expand in volume. Pores in the mixture are created from the gas; these pores are visible when looking at the rigid substance. The multifunctionality of both reactants leads to a high degree of crosslinking in the polymer, causing it to become rigid within minutes. (See Equation 2.)



Equation 2

References

Rosato, D. V. *Rosato's Plastics Encyclopedia and Dictionary*; Hanser: New York, 1993; pp 318–320, 572.

Shakashiri, B. Z. *Chemical Demonstrations: A Handbook for Teachers of Chemistry;* University of Wisconsin: Madison, 1983; Vol. 1, pp 216–218.

Materials for the *Polyurethane Foam System* are available from Flinn Scientific, Inc.

Catalog No.	Description
C0335	Polyurethane Foam System
A0009	Acetone
V0003	Vegetable Dyes (food coloring), set/4

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

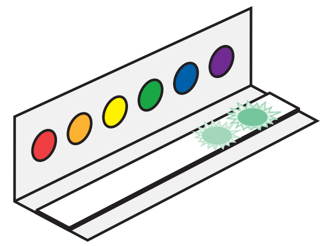
Energy in Photons Kit

Introduction

Students often confuse the concepts of intensity of light and energy of light. This demonstration provides a clear way to demonstrate that the intensity, or brightness, of light is NOT the same as the amount of energy a particular color of light possesses.

Chemical Concepts

- Phosphorescence
- Transmittance
- Absorbance
- Emission



Materials

Energy in Photons Demonstrator Card—assembled and ready to use*

Light source—classroom lights work well

**Materials included in kit.*

Safety Precautions

Always follow standard laboratory safety rules when performing demonstrations.

Procedure

1. Open the Demonstrator Card and show the class the phosphorescent strip. Explain to them that the common term for phosphorescence is "glow-in-the-dark" and that this strip will glow in the dark.
2. Directly expose the entire phosphorescent strip to the classroom lights for about 15 seconds. Now turn off all the classroom lights and completely darken the room. The entire strip will glow brightly for several minutes and then begin to fade. Once students are satisfied with the glow, turn the classroom lights back on.
3. Show the six colored filters on the Demonstrator Card to the class. Hold the Demonstrator Card up to the light so that the color of light transmitted through each filter is clearly visible. Observe that the color of light transmitted through each filter is the same color as the filter.
4. Have the class predict what will happen if the Demonstrator Card is closed so that only "filtered" light is allowed to shine upon the phosphorescent strip.
5. Close the Demonstrator Card tightly making sure that no light can reach the phosphorescent strip from the sides. Paper clip the sides closed. Expose the closed Demonstrator Card to the classroom lights for at least 30 seconds.
6. Now turn off all the classroom lights and completely darken the room again. Open the Demonstrator Card and show the phosphorescent strip to the class. The strip will only glow under the blue and violet filters!
7. Compare the class' predictions with the actual results. Many students will be surprised that the "lighter" colors, like yellow and orange, did not let "enough light" through to cause the strip to glow. Explain that even though these colors may look brighter, or more intense, only the blue and violet filters let through light with enough energy to make the phosphorescent strip glow (see Discussion for a detailed explanation).
8. Have the class estimate the maximum wavelength needed to excite the phosphorescent strip (and cause it to glow) by using an approximate wavelength for each filter color or by reading the transmission curves for the filters. They should find the wavelength to be about 480 nanometers (nm) (see *Discussion* for a detailed explanation).

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9. From the following equation, students can then calculate the minimum energy a photon must have to cause the strip to phosphoresce, or glow.

   $E = hc/\lambda$

   where E = energy in J
   h = Planck's constant = 6.626×10^{-34} J·sec
   c = speed of light = 2.998×10^{8} m/sec
   λ = wavelength in m

   According to the following calculation, they should find that the minimum photon energy is 4.1×10^{-19} J.

$$E = \frac{(6.626 \times 10^{-34}\,\text{J·sec})(2.998 \times 10^{8}\text{m/sec})}{(480\text{ nm})(1 \times 10^{-9}\text{m/nm})} = 4.1 \times 10^{-19}\text{ J}$$

Tips

- The spots under the blue and violet filters should always glow brightly, but sometimes a small glow can be seen under some of the other filters. This is partly due to stray light creeping in around the filters. Try to keep the Demonstrator Card as tightly closed as possible to prevent any extra light from getting to the phosphorescent strip and causing a slight glow. The slight glow can also be explained by looking at the transmission curves of the filters. For example, the yellow filter clearly lets through light of wavelengths down to about 450 nm. The phosphorescent strip needs an exciting wavelength of about 480 nm or lower. Therefore, a tiny bit of light with enough energy is actually being transmitted through the yellow filter onto the phosphorescent strip.
- To store the Demonstrator Card, insert the solid black strip into the Card so that it is covering the phosphorescent strip. Close the Demonstrator Card and store it in the envelope. This will protect the phosphorescent strip from light and thus lengthen its useful life.

Extensions

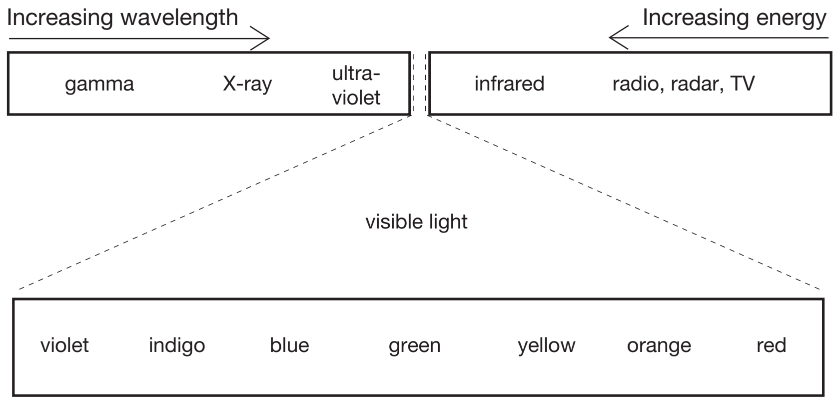
1. To reinforce the concept that it is the energy of the light that matters rather than the intensity, obtain two light sources of different intensity, such as a 40 W bulb and a 100 W bulb. Shine each lightbulb onto the closed Demonstration Card and show your students that in both cases only the violet and blue filters cause the strip to phosphoresce.
2. The maximum wavelength needed to cause the strip to glow can be verified in a spectrophotometer. Cut a narrow strip (so it will just fit in a cuvet) of the phosphorescent strip. First set 0% T with the sample compartment empty. Use an empty cuvet as the blank to set 100% T. Then place the piece of phosphorescent strip in the cuvet, not directly in the spectrophotometer, and measure the absorbance of the strip. Make sure the coated side of the strip is facing the direction from which light comes in the spectrophotometer. For wavelengths of 480 nm and lower, a small glowing spot can be seen on the phosphorescent strip. At higher wavelengths, no glowing is observed. This experiment is best performed in the dark so that the glowing spot is easily seen.
3. The wavelengths of light contained in classroom lights can be compared to those in a UV (black) light using the Demonstrator Card. Perform the demonstration as outlined above using the classroom lights. Then, turn off the lights and shine a black light onto the closed Demonstrator Card for about 30 seconds. When the black light is turned off and the Demonstrator Card is opened, more glowing circles can be observed. Looking at the transmission curves for the filters, explain to the class that many of the filters do not absorb wavelengths between 300 and 400 nm. Therefore, the filters are transmitting these high-energy wavelengths which are sufficient to excite the phosphorescent strip and make it glow.

Discussion

The Electromagnetic Spectrum

In 1865, J. C. Maxwell showed that visible light is a form of *electromagnetic radiation*. All forms of electromagnetic radiation consist of oscillating electric and magnetic fields traveling at a constant speed, the speed of light, 2.998×10^{8} m/s. Other familiar forms of electromagnetic radiation include microwave radiation from a microwave oven, X-rays, the infrared radiation in heat from a fire, and radio waves. Together, all forms of electromagnetic radiation make up the electromagnetic spectrum.

Electromagnetic Spectrum



The visible portion of the electromagnetic spectrum is only a small part of the entire spectrum. It spans the wavelength region from about 400 to 700 nm. The human eye sees light of 400 nm as violet and 700 nm as red. Because wavelength is inversely proportional to energy according to the equation $E = hc/\lambda$, violet light is higher energy light than red light. The color of light seen with the human eye varies from red to violet (low to high energy) according to the familiar phrase ROY G BIV: red, orange, yellow, green, blue, indigo, violet. As the color of the light changes, so does the amount of energy it possesses. White light, like that from a fluorescent light, contains all of the colors in the visible spectrum.

Intensity versus Energy of Light: The Photoelectric Effect

Another characteristic of light, in addition to its energy, is its intensity. *Intensity* can be thought of as the brightness of the light. According to the theories of classical physics, energy is proportional to intensity, so that the more intense a light source, the more energy it gives off. Under this assumption, very bright (intense) yellow light should cause the phosphorescent strip in the Demonstrator Card to glow. However, this is not observed. Instead, the phosphorescent strip glows only when blue or violet light is shined on it. This phenomenon is analogous to the photoelectric effect, one of the classical paradoxes that led to the discovery of quantum mechanics.

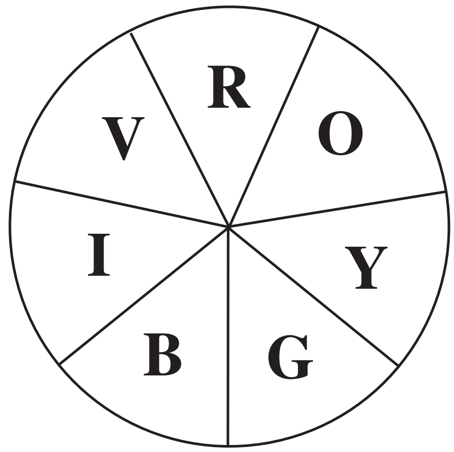
The *photoelectric effect* involves the ejection of electrons from a metal surface when light is shined on it; the energy of the electrons ejected depends upon the wavelength of the light, not the intensity. Einstein explained the photoelectric effect by suggesting that light consists of photons, each with energy $E = h\nu$. If a photon of light strikes a metal surface with more energy than the energy binding an electron to the surface, the photon will cause an electron to be ejected. The more intense a light source (greater number of photons), the greater the number of electrons ejected. If a photon striking the surface of a metal does not have more energy than the energy binding an electron to the surface, an electron cannot be ejected, no matter how many photons (with this amount of energy) strike the surface.

The glowing of the phosphorescent strip in the Demonstrator Card is due to the emission of photons, analogous to the ejection of electrons from the surface of a metal. The phosphorescent material has a critical wavelength (or energy) of light. If a light source is shined on the phosphorescent strip and it contains photons whose energy is greater than the energy needed to cause the strip to glow, it will glow. If the intensity of this source is increased, the glowing of the strip will increase. If, however, a light source is shined on the phosphorescent strip that contains photons whose energy is less than the critical energy for the phosphorescent strip, no glowing will occur, no matter how bright the light source.

Absorption and Transmission of Light

Why do the filters appear violet, blue, green, yellow, orange, and red? They are each composed of different molecules—molecules that absorb different wavelengths of light. For example, the red filter appears red to the human eye because it is transmitting red light. When white light is shined upon the red filter, the molecules in the filter absorb some of the wavelengths of the light and transmit others. All non-red wavelengths of light will be absorbed by the red filter to some extent, although green light will be absorbed the most. The green photons hit the filter and are absorbed by the molecules in the filter. They do not make it through the filter, and hence, a green color is not seen from this filter. In contrast, red photons are not absorbed by the molecules in the red filter, so they pass right through the filter, and a red color is observed.

How is it known that the red filter absorbs the green wavelengths of light? Red and green are *complementary colors*—they are across from each other on the color wheel.

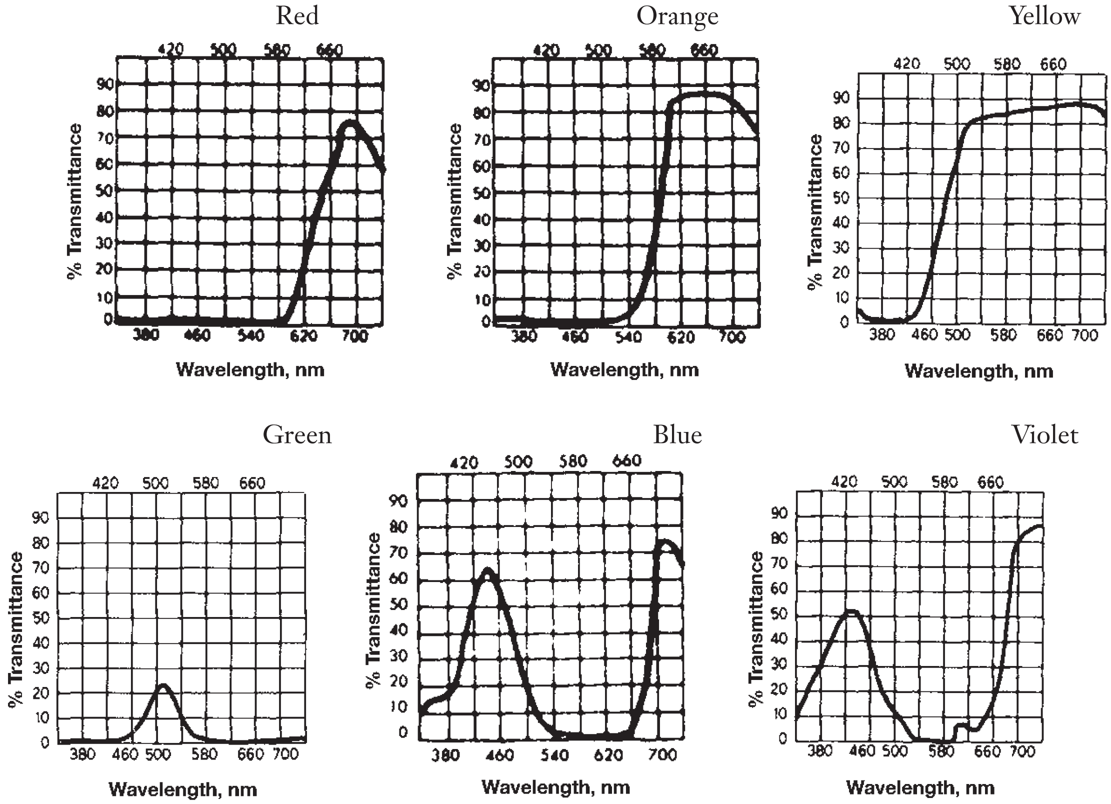


In general, colors opposite each other on the color wheel are complementary colors. For example, by looking at the wheel, the fact that violet and yellow are complementary colors can be seen. Therefore, in analogy to the red filter, it can be assumed that the violet filter absorbs yellow light and transmits violet light. The color wheel and the idea of complementary colors can be used as a first estimation of the wavelengths that are absorbed by a substance based on its color.

The following table lists the wavelengths associated with each of the colors in the visible spectrum and their complements. The representative wavelength can be used as a benchmark for each color. For example, instead of referring to green as light in the wavelength range 500–600 nm, one could simply say that green light is 520 nm.

Representative Wavelength, nm	Wavelength Region, nm	Color	Complementary Color
410	400–425	Violet	Yellow-green
470	425–480	Blue	Orange
490	480–500	Blue-green	Red
520	500–560	Green	Red-Violet
565	560–580	Yellow-green	Violet
580	580–585	Yellow	Violet
600	585–650	Orange	Blue
650	650–700	Red	Blue-green

Transmission curves are available for each of the filters in the Demonstrator Card. These curves show which wavelengths of light are actually transmitted by each filter—the highest peak on each curve points to the wavelength that is transmitted the most.



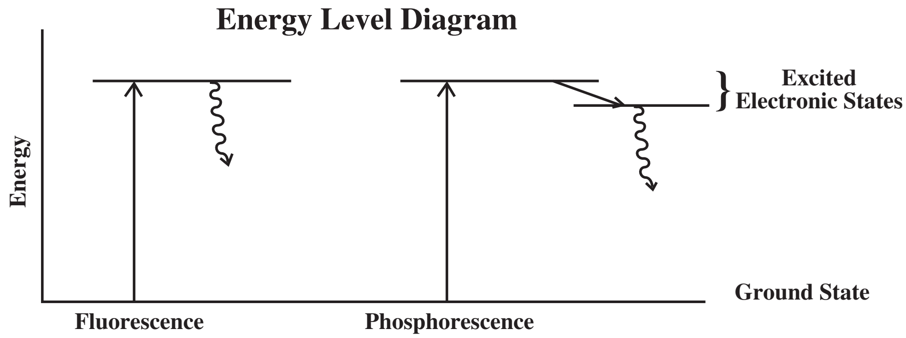
From these curves, the absorbed wavelengths of light can be inferred since absorbance is inversely proportional to transmittance according to the equation A = – log T. Compare the estimation of the absorbed wavelengths for each filter from above with the actual absorption as shown in these transmittance curves. It is evident that these filters are not "pure" filters—they do not transmit a single wavelength, or even a single color in most cases. But, they do filter enough of the other wavelengths so that only a single color appears to be shining through the filter.

The cutoff wavelength for exciting the phosphorescent strip is about 480 nm. Photons with a higher wavelength (less energy) will not cause the strip to glow, while photons with lower wavelengths (more energy) will cause the phosphorescent glow. Looking at the table on page 4, 480 nm is right on the border between blue and green light. Therefore, blue or violet photons (which are not absorbed by the blue and violet filters, but are instead transmitted through these filters) will contain enough energy to excite the strip and cause it to glow. The green, yellow, orange, and red filters absorb the blue and violet photons instead of allowing them to be transmitted. Therefore, the light coming through these filters does not contain enough energy to excite the phosphorescent strip and, as a result, no glow is observed.

Phosphorescence

Luminescence is the emission of radiation (light) by a substance as a result of absorption of energy from photons, charged particles, or chemical change. It is a general term that includes fluorescence, phosphorescence, and chemiluminescence, to name just a few special types. *Phosphorescence* is different from the other types of luminescence in that light continues to be emitted even after the exciting source has been removed. This is sometimes referred to as the "afterglow." In this demonstration, the exciting source is the classroom lights. The strip in the Demonstrator Card glows even after the lights have been turned off (removal of the exciting source), so it can be classified as a phosphorescent material.

Why does a phosphorescent material continue to glow even after the exciting source has been removed? This can be explained by looking at an energy level diagram for the phosphorescent material. In both phosphorescence and fluorescence, a light source is shined on the material, and a photon is absorbed. The energy from the photon is transferred to an electron which makes a transition to an excited electronic state. From this excited electronic state, the electron naturally wants to relax back down to its ground state. When the electron relaxes back down, it does not necessarily jump down to the ground state in a single step. The relaxation pathway varies, and is different depending on whether the material is fluorescing or phosphorescing.



In fluorescence, the electron relaxes down to a lower energy state and emits a photon in the process. If this photon has a wavelength in the visible portion of the electromagnetic spectrum, we observe a colorful, glowing effect. This process is practically instantaneous so the fluorescence is observed as soon as the exciting source is present and disappears as soon as the exciting source is removed. An example of fluorescence is the way white shirts washed in Tide® glow under a black light.

In phosphorescence, the excited electron first makes a slow transition to another excited state very close in energy to the initial excited state. From this second excited state, the electron then relaxes down to a state lower in energy, emitting a photon in the process. The characteristic afterglow of phosphorescence is due to the delayed emission that occurs because the transition between the first two excited states is slow.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy.
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure of atoms, structure and properties of matter, interactions of energy and matter

Answers to Worksheet Questions

1. Describe what happened in this demonstration.

   A phosphorescent strip was placed inside a card with six colored filters, violet, blue, green, yellow, orange, and red. The strip was exposed to the classroom light via these filters for about thirty seconds. The lights were then turned off and the strip was removed. Only the areas underneath the violet and blue filters glowed.

2. Explain why the phosphorescent strip only glowed in the blue and violet regions upon being covered with the entire demonstrator card?

   The reason that the blue and violet regions allowed the strip to glow and the other colors did not is because photons with a higher wavelength (less energy) will not cause the strip to glow. Photons with lower wavelengths (more energy) will cause the strip to glow. Blue and violet have a smaller wavelength of 430–480 nm which means they have more energy and enable the strip to glow.

3. What is the difference between intensity and energy of light, and how does it relate to this demonstration?

   The intensity of a light is its "brightness." The more intense a light is, the more photons are transmitted. A light's energy, on the other hand, is inversely proportional to a light's wavelength. Therefore, violet light has a shorter wavelength but more energy than red light. The brighter colors here were yellow and orange, but the colors with the most energy were violet and blue. Thus violet and blue were the only colors with enough energy to cause the phosphorescent strip to glow.

4. In phosphorescence, a photon is absorbed by a substance when a light shines on it. The photon is transferred to an electron, which becomes "excited" and jumps to a higher energy level. It then slowly works its way down to its ground state, first moving to a slightly lower excited state. Another photon is released when the electron moves from the second excited state to its ground state. Explain how this process produces phosphorescence's characteristic "afterglow."

   Because the electron's move back to its ground state is delayed, the release of the photon is delayed. That photon is responsible for glow of the substance, so therefore the glow is delayed as well.

5. Phosphorescence requires an exciting source to occur. What was the exciting source in this demonstration?

   The light in the classroom was the exciting source.

Acknowledgments

Thanks to Rhonda Reist of Olathe High School, Olathe, KS for providing us with the idea for this "brilliant" demonstration.

Additional materials for the *Energy in Photons Kit* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP4576	Energy in Photons Kit
P0272	Phosphorescent Flash Paint
AP4794	Phosphorescent Vinyl Sheet, 120 × 120
AP8685	Flinn Scientific Spectrophotometer

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Energy in Photons Demonstration Worksheet

Discussion Questions

1. Describe what happened in this demonstration.

2. Explain why the phosphorescent strip only glowed in the blue and violet regions upon being covered with the entire demonstrator card?

3. What is the difference between intensity and energy of light, and how does it relate to this demonstration?

4. In phosphorescence, a photon is absorbed by a substance when a light shines on it. The photon is transferred to an electron, which becomes “excited” and jumps to a higher energy level. It then slowly works its way down to its ground state, first moving to a slightly lower excited state. Another photon is released when the electron moves from the second excited state to its ground state. Explain how this process produces phosphorescence’s characteristic “afterglow.”

5. Phosphorescence requires an exciting source to occur. What was the exciting source in this demonstration?

Giant Bubble Wand

Introduction

Generate students' excitement by enveloping them inside a giant bubble. The Giant Bubble Wand will make the biggest bubbles you've ever seen—big enough for up to two students.

Concepts

- Properties of matter
- Qualitative and quantitative observation skills

Materials

Joy® brand liquid detergent, 2.31 L (2.4 qt.)	Glycerin, 120 mL (4 oz.)
Water, distilled, 22.57 L (6 gal.)	Hula Hoop®
Wading pool	Hacksaw or hand saw
Power drill with a flat head (slotted) screwdriver bit	Milk crate
PVC pipe, 3/4″ i.d., 1.5 m	Giant Bubble Wand Apparatus kit

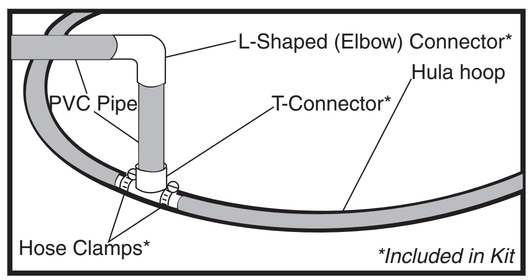
Safety Precautions

Be certain that students wear goggles when they are in or near the bubble. The soap solution can be irritating to the eyes. Also be sure that the students have help getting on and off the crate. The soap solution will make the area very slippery. When preparing solutions, always wear chemical splash goggles.

Preparation

To build the bubble wand

First, measure and cut the PVC pipe into two pieces, one 15 cm long and the other 135 cm long. Connect the two pieces with the L-shaped connector. Secure the Hula Hoop to the T-shaped connector with the hose clamps. You will have to unscrew the hose clamps completely in order to get them around the Hula Hoop. Tighten the screws firmly with the flat head screwdriver.



Finally, attach the T-connector to the 15 cm long PVC piping and your bubble wand is complete.

To prepare the bubble solution

Set up the wading pool in the center of the classroom. Cover the floor under and around the wading pool with newspaper (the more paper the better). The soap solution can make tile floors very slippery.

Now pour 22.57 liters of distilled water, 2.31 liters of Joy® and 120 mL of glycerin into the wading pool. Stir gently with the bubble wand. Avoid forming suds as you stir, they will interfere with the soap film's longevity. Allow the soap solution to settle for at least one hour.

Publication No. 9304
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Procedure

1. Place the milk crate in the center of the wading pool.
2. Place the bubble wand into the solution, surrounding the milk crate.
3. Ask for a student volunteer and have the student put on a pair of goggles.
4. With the help of another student, the volunteer should step onto the milk crate that is in the wading pool.
5. Now, carefully lift the bubble wand up and out of the solution until it is 30 to 40 cm above the student's head. Be careful not to allow the bubble to touch the student (the bubble will pop).
6. To produce a two-person bubble, ask a second student to stand 30 cm from the wading pool, on the newspaper. Then pull the bubble up and over the second student in the shape of an inverted U. Be sure to clear the first student's head by 60 to 80 cm.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Pour soap solution down the drain according to Flinn Suggested Disposal Method #26b.

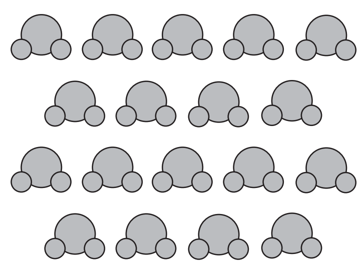
Tips

- Give each student a turn to be inside a bubble. The other students should be making observations, both quantitative and qualitative. Use the sample data table on the following page.
- Designate the student who will be in the bubble next as the measurer. This student should measure the height and diameter of each bubble for the class to record.
- Designate the student that was just inside the bubble as the timekeeper. This student will record the length of time elapsed before the bubble collapses.
- You may want your students to prepare the bubble solution on the day prior to the demonstration. To do this, divide the class into lab groups and instruct each group to prepare a portion of the bubble solution. As an example, if you divide your class into 10 lab groups, each lab group would prepare 2.5 liters of bubble solution.
- As the students collect data, they will learn that the larger the bubble, the shorter the time it will last. Ask your students to graph the product of height times diameter ($h \times d$) versus time (t). See the sample graph on the following page.
- Discuss the difference between ***qualitative*** observations such as "The bubble is blue and red" and ***quantitative*** observations such as "The bubble is 160 cm tall." Students should learn that both types of observations are very important.

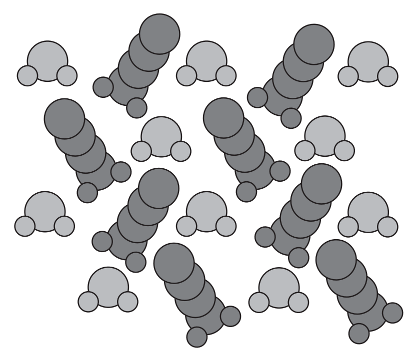
Discussion

Your students have seen bubbles hundreds of times but they may want to know what a bubble is and how and why a bubble is formed. A soap bubble is gas enclosed by a thin film of soap solution. It is usually formed when air is forced through a thick film of soap solution.

The soap solution is made from detergent and water. The detergent separates the water molecules which have strong attractive forces for each other, thereby reducing the surface tension of the liquid. The lower surface tension allows the liquid to form a thin film. The detergent also lowers the evaporation rate of the liquid; evaporation being one of the arch enemies of the bubble.



Water molecules have strong attractive forces for each other.



Detergent molecules seperate the water molecules and reduce the attractive forces between them.

The relationship between the surface tension and bubble formation can be understood with the help of an analogy. A plastic sandwich bag and a balloon behave differently when air is forced into each one. The sandwich bag consists of material that is very inelastic. When air is forced into the bag, it inflates until the bag is full, then it pops. The balloon consists of material that is very elastic. When air is forced into the balloon, it fills with air then stretches into a much larger size. In a similar way, water's high surface tension does not allow it to stretch into a film until the detergent is added to reduce the surface tension and make it more elastic. Without the detergent the water would behave more like the plastic bag.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Process: Grades K–12
Evidence, models, and exploration
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter.
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter.

Acknowledgement

Special thanks to Mike I. Shaw and Greg F. Smith of Chestnut Grove Middle School in King, North Carolina for this idea.

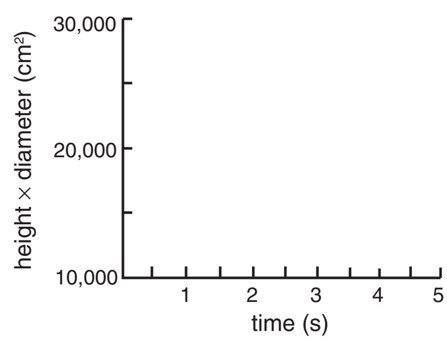
Reference

Shaw, M. I. and Smith, G. F. ***Science and Children***. 1995, ***33*** (1), 24–27.
Cassidy, J. ***The Unbelievable Bubble Book;*** Kultz: Palo Alto, CA, 1987; pp 43–53.

Sample Data Table

Student	Height (cm)	Diameter (cm)	Time (s)	Color	Shape
Genna					
Andrew					
Stephanie					
Jacob					
Tawanna					

Sample Graph



Materials for the *Giant Bubble Wand* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP9304	Giant Bubble Wand Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Giant Soap Bubbles

FLINN SCIENTIFIC CHEM FAX!

Introduction

Glycerin soap bubble solution is far superior to those commonly found in most toy departments. You can make giant bubbles! Here's how to do it!

Concept

- Surface tension

Materials

Dawn® or Joy® dishwashing liquid, 100 mL
Glycerin, 50 mL
Distilled or deionized water, 850 mL
Beaker, 250-mL
Beaker or graduated cylinder, to measure volume amounts
Large container, 1-L or 2-L
Stirring rod or large spoon

Safety Precautions

The bubbles break with a fair amount of force; keep away from your face. The solution will be slippery; be careful to avoid falling if some solution drips on the floor. Glycerin may irritate skin and eyes, and is an allergen to some people. Contact with strong oxidants (chromium trioxide, potassium chlorate, potassium permanganate) may cause an explosion. LD_{50} *12600 mg/kg. Wear chemical splash goggles, a chemical-resistant apron, and chemical-resistant gloves. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.*

Procedure

1. To make 1 L of soap bubble solution, mix approximately 100 mL of Dawn® or Joy® dishwashing liquid with approximately 50 mL of glycerin in a 250-mL beaker.
2. Fill a large container with 850 mL of distilled or deionized water.
3. Add the dishwashing liquid/glycerin solution to the water in the large container.
4. Stir the mixture with a stirring rod or large spoon. Avoid shaking the mixture to prevent the production of excessive amounts of suds.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Flush the bubble solution down the drain according to Flinn Suggested Disposal Method #26b.

Tips

- It is important to use distilled or deionized water in order to prevent interference from dissolved metal ions. If the solution does not seem to work well, let it sit for a few days to a week. Aging seems to improve the characteristics of soap solutions.
- Giant bubbles can be made by pouring the bubble solution into a large, flat pan. A loop, such as a giant coat hanger loop, can be dipped into the solution. Run or use a fan to create the giant bubble.
- It is best to make these giant bubbles out-of-doors.
- To produce even larger, long-lasting soap bubbles, increase the concentration of the detergent to 200 mL and the glycerin to 100 mL. Add this mixture to only 700 mL of distilled or deionized water. Again, stir the solution. You may have to experiment with your soap mixture to get very large bubbles.

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061616

• Try other interesting bubble products such as the Bubble Thing, the Giant Bubble Wand Kit, or Professor Bubbles' Official Bubble Handbook sold by Flinn Scientific.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter

Acknowledgment

Thanks to David Katz, Associate Professor, Community College of Philadelphia, Philadelphia, PA who provided Flinn Scientific with this bubble recipe.

Materials for making your own soap bubble solution as well as other bubble products are available from Flinn Scientific, Inc.

Catalog No.	Description
G0007	Glycerin, 500 mL
G0008	Glycerin, 4 L
C0241	Cleaner, Dishwashing
AP1963	Bubble Thing
AP2258	Professor Bubbles' Official Bubble Handbook
AP9304	Giant Bubble Wand Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Exploding Hydrogen Bubbles in Your Hands

Properties of Hydrogen

FLINN SCIENTIFIC CHEM FAX!

Introduction

Make and ignite hydrogen-filled soap bubbles! It's a very visual, fun, inexpensive and easy demonstration that is sure to excite your students.

Concepts

- Density of gases
- Combustion
- Water displacement

Materials

Hydrochloric acid, HCl, 3 M, 75 mL
Zinc mossy, Zn, 20 g
Joy® or Dawn® dishwashing liquid, 40 mL
Glycerin, 6 mL
Water, 400 mL
Matches
Igniting stick (see *Preparation*)
  Candle
  Latex or plastic tubing, 1 m
  Meter stick
  Tape, cinch ties, or rubber bands, 2

Gas generator bottle (see *Preparation*)
  Gas generator bottle or flask
  Two-holed stopper
  Thistle tube or long-stem funnel
  Bent glass tubing
  Funnel, small

Safety Precautions

Hydrochloric acid is toxic by ingestion or inhalation and severely corrosive to skin and eyes. Hydrogen gas is very flammable and yields explosive mixtures with air. Perform this demonstration outdoors or in a room with high ceilings. The hydrogen bubbles rise rapidly and produce a sizable flame when ignited. Perform away from all flammable materials and ignite the bubbles away from the gas generator, yourself, and the audience. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Students and other spectators should also wear chemical splash goggles during this demonstration. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

• Prepare a soap bubble solution by mixing 40 mL of Joy or Dawn dishwashing liquid, 400 mL of water (distilled or deionized water works better than tap water) and 6 mL of glycerin.

• • Set up the gas generator as shown in Figure 1. Carefully insert one end of the bent glass tubing through a two-holed rubber stopper. Attach latex or plastic tubing to the free end of the glass bend. Insert a small funnel into the other end of the latex or plastic tubing. Insert the stem of a thistle tube or long stem funnel through the other hole in the stopper. Make sure the stem will be close to the bottom of the flask when the stopper is inserted into the neck of the flask. Place 20 grams of mossy zinc in the

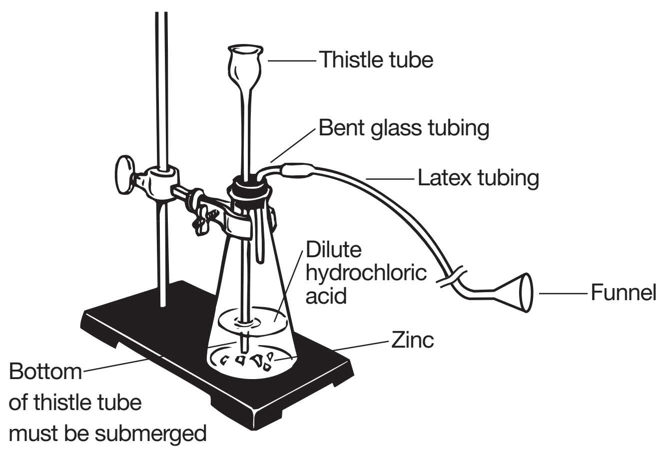

Figure 1. Gas generator

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bottom of the flask. Stopper the flask. A gas generating bottle is available from Flinn Scientific, Cat. No. AP1558.

- Prepare an igniting stick as shown in Figure 2. Attach a candle to the end of a long stick such as a meter stick, wood pointer, or dowel rod. Attach the candle to the stick using tape, plastic cinch ties, or rubber bands.

Figure 2. Igniting stick

Procedure

1. Pour 75 mL of 3 M hydrochloric acid through the thistle tube into the gas generating flask. The stem of the thistle tube should be submerged into the acid solution to prevent loss of hydrogen gas.
2. The mixture will begin to fizz as the hydrogen gas is produced. Allow the hydrogen gas to flow through the tubing for about 3 minutes to flush all the air out of the system.
3. While the hydrogen gas is being produced at a generous and consistent rate, dip the small funnel into the soap bubble solution and then raise it slightly above the solution. As a hydrogen-filled bubble begins to form, lift the funnel up and give the funnel a little shake to release the bubble. When released, the bubble will rise quickly.
4. Ignite the hydrogen bubble using the igniting stick. *Caution:* Keep the igniting stick away from the gas generator and ignite the bubbles in an area away from any flammable materials. Do not ignite the hydrogen-filled bubbles near a smoke detector or heat sensor.
5. Repeat steps 3 and 4 to collect more hydrogen bubbles. Add more acid to the gas generator as needed to keep a constant flow of hydrogen gas.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The soap solution may be rinsed down the drain with excess water according to Flinn Suggested Disposal Method #26b. The acid solution may be neutralized using Flinn Suggested Disposal Method #24b. The zinc may be rinsed with water and saved for future use.

Tips

- The hydrogen bubbles will rise very quickly—it is difficult for one person to generate the bubbles and also ignite them. This demonstration works best with two demonstrators, one generating the bubbles and the other "chasing" them with the igniting stick. Practice this demonstration before performing it in front of students.
- If there are difficulties forming bubbles, then the hydrogen gas production may be too fast or slow. To slow down the gas production, either wait a few minutes or dilute the acid with water. To increase the rate, add more acid.
- The characteristics of this soap solution seem to improve upon aging. Try to make the solution a few days in advance.

Discussion

Zinc reacts with hydrochloric acid to produce hydrogen gas according to Equation 1.

$$Zn(s) + 2HCl(aq) \rightarrow H_2(g) + ZnCl_2(aq) \qquad \textit{Equation 1}$$

Hydrogen gas is less dense than air and the hydrogen bubbles will rise quite rapidly once released. When the hydrogen bubbles are ignited, the hydrogen reacts with oxygen in the air to produce water according to Equation 2.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) \qquad \textit{Equation 2}$$

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Form and function

Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy

Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, motions and forces, interactions of energy and matter

Acknowledgment

Many science teachers perform this demonstration but we give special thanks to Penney Sconzo, The Westminster Schools, Atlanta, GA for providing us with these instructions.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Exploding Hydrogen Bubbles in Your Hands* activity, presented by Kathleen Dombrink, is available in *Properties of Hydrogen* and in *Energy in Combustion Reactions*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Exploding Hydrogen Bubbles in Your Hands* are available from Flinn Scientific, Inc.

Catalog No.	Description
H0034	Hydrochloric Acid Solution, 3 M, 500 mL
Z0003	Zinc, Mossy, 500 g
G0007	Glycerin, 500 mL
C0192	Candles, 5 × 1¼ , pkg./4
AP1558	Gas Generating Bottle
GP8004	Thistle Tube, Glass
AP8160	Thistle Tube, Polyethylene
GP5040	Funnel, Short-stem, Fluted

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Cool Light

Chemiluminescence

Introduction

Chemiluminescence demonstrations are popular with students and teachers alike. When light is produced without heat, that's cool!

Concepts

- Chemiluminescence
- Oxidation–reduction
- Catalyst

Materials

Hydrogen peroxide, H_2O_2, 3%, 15 mL

Luminol, 0.1 g

Potassium ferricyanide, $K_3Fe(CN)_6$, 0.7 g

Sodium hydroxide solution, NaOH, 5%, 50 mL

Water, distilled or deionized, 2000 mL

Erlenmeyer flasks, 1-L, 2

Erlenmeyer flask, 2-L

Funnel, large

Graduated cylinder, 50-mL

Ring stand and ring

Safety Precautions

Hydrogen peroxide is an oxidizer and skin and eye irritant. Sodium hydroxide solution is corrosive, and especially dangerous to eyes; skin burns are possible. Much heat is released when sodium hydroxide is added to water. If heated to decomposition or in contact with concentrated acids, potassium ferricyanide may generate poisonous hydrogen cyanide. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

1. Prepare Solution A by adding 0.1 g of luminol and 50 mL of 5% sodium hydroxide solution to approximately 800 mL of distilled or deionized (DI) water. Stir to dissolve the luminol. Once dissolved, dilute this solution to a final volume of 1000 mL with DI water.
2. Prepare Solution B by adding 0.7 g of potassium ferricyanide and 15 mL of 3% hydrogen peroxide to approximately 800 mL of DI water. Stir to dissolve the potassium ferricyanide. Once dissolved, dilute this solution to a final volume of 1000 mL with DI water.
3. Set up the demonstration equipment as shown in Figure 1.

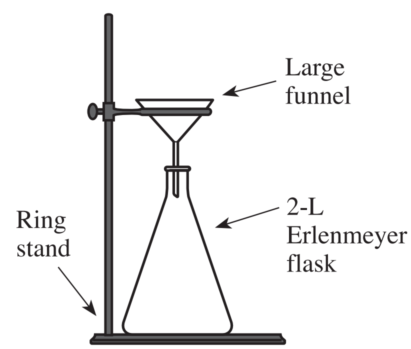

Figure 1.

Procedure

1. Turn down the lights. The room should be as dark as possible.
2. Recruit a volunteer or second presenter. Together, pour Solution A and Solution B into the large funnel simultaneously. As the two solutions mix, chemiluminescence begins.
3. As the reaction progresses, it can be enhanced by adding small amounts of potassium ferricyanide and 5–10 mL of 5% sodium hydroxide solution into the flask.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The final solution may be disposed of according to Flinn Suggested Disposal Method #26b.

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Tips

- This demonstration is especially appealing if it is set up so the students can see the mixture through spiraling clear plastic tubing. Simply follow the directions for setup at the end of these instructions. This type of apparatus gives a large surface area for light to be emitted and also provides a flowing effect along with the luminescence, thus increasing the overall visual impact.
- Another means of displaying luminol's luminescence is to take the two solutions (A and B above), place them in spray bottles, and spray them, creating a luminescent cloud. The key to this procedure is to get the solutions into as fine a mist as possible. *Caution:* Do not spray the solutions toward anyone or in a manner in which they can be easily inhaled.
- Use only distilled or deionized water when preparing the solutions. Hard water and softened water contain high con centrations of ions (such as chloride ions) that may interfere with the excited state of the luminol and prevent chemilu minescence.

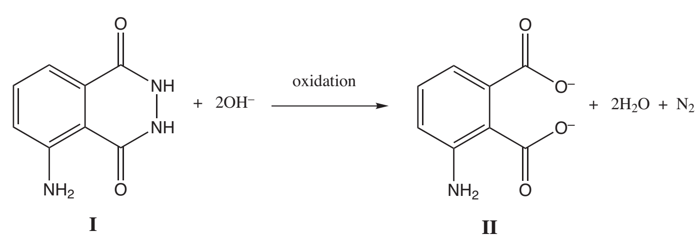
Discussion

Chemiluminescence is defined as the production or emission of light that accompanies a chemical reaction. Light emission results from the conversion of chemical energy into light energy due to changes in the composition of a chemiluminescent material. The "flame test" colors observed when different metal salts are burned in a Bunsen burner flame are examples of a type of chemiluminescence known as pyroluminescence. The glow of solid phosphorus in air is another classic example of chemiluminescence—light, along with some heat, is produced when the phosphorus undergoes an oxidation reaction. The oxidation of luminol (3-aminophthalhydrazide) in this demonstration illustrates a type of "cool light" chemiluminescence in which little or no heat is produced.

The light-producing chemical reactions of luminol were discovered by H.O. Albrecht in 1928. Since that time numerous procedures have been developed to produce light using luminol. Experiments have shown that the following "ingredients" are necessary for luminol to exhibit chemiluminescence—a basic (alkaline) pH, an oxidizing agent, and a catalyst. In this demonstration, the oxidizing agent is hydrogen peroxide, the catalyst is the iron(III) cation in potassium ferricyanide, and sodium hydroxide is used to maintain the basic pH needed for the reaction to occur.

Oxidation of luminol and the resulting chemiluminscence occurs in the following sequence of reactions:

- Sodium hydroxide acts as a base and converts luminol (structure I) into a dianion.
- Hydrogen peroxide oxidizes the dianion form of luminol to the aminophthalate ion (structure II), which is produced in an excited electronic state. Nitrogen gas is also released in this reaction.
- The excited aminophthalate ion decays to a lower energy ground state and gives off light in the process. The emitted light has a wavelength of 425 nm, which is in the blue region of the visible spectrum.



The "Cool Light" demonstration has value not only for the obvious reason of demonstrating chemiluminescence, but also to show the effects of a catalyst, pH, and temperature on a reaction, as well as how reaction rates are affected by concentration.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, interactions of energy and matter

Answers to Worksheet Questions

1. Describe what happened in this demonstration.

   Two solutions were poured through a large funnel simultaneously. The mixture of the two solutions began to glow.

2. Oxidation is necessary for luminol to luminesce. The chemicals used in this experiment were 5% sodium hydroxide, 3% hydrogen peroxide, and potassium ferricyanide. Which of these do you think served as the oxidizing agent?

   Hydrogen peroxide was the oxidizing agent in this demonstration.

3. In chemiluminescence, a molecule in an "excited" state (i.e., electrons are at a high energy level) is produced. The electrons in the molecule then must return to their stable state (i.e., lower energy level. Explain how this is linked to the production of light.

   When an electron drops to a lower energy level, energy must be released. This energy is released in the form of light.

4. Define chemiluminescence. Give an example of chemiluminescence found in nature.

   Chemiluminescence is a process in which light is produced through a chemical reactions. An example of this that is found in nature is the firefly.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Cool Light* activity, presented by Irene Cesa, is available in *Chemiluminescence*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Cool Light* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Cool Light—Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP8627	Cool Light—Demonstration Kit
L0078	Luminol, 5 g
S0074	Sodium Hydroxide, 100 g
P0050	Potassium Ferricyanide, 100 g
H0009	Hydrogen Peroxide, 3%, 500 mL
GP9155	Erlenmeyer Flask, Borosilicate Glass, 2-L

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Cool Light Worksheet

Discussion Questions

1. Describe what happened in this demonstration.

2. Oxidation is necessary for luminol to luminesce. The chemicals used in this experiment were 5% sodium hydroxide, 3% hydrogen peroxide, and potassium ferricyanide. Which of these do you think served as the oxidizing agent?

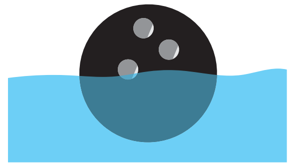
3. In chemiluminescence, a molecule in an "excited" state (i.e. electrons are at a high energy level) is produced. The electrons in the molecule then must return to their stable state (i.e. lower energy level. Explain how this is linked to the production of light.

4. Define chemiluminescence. Give an example of chemiluminescence found in nature.

The Floating Bowling Ball

Introduction

Why do some things float while others sink? Capture your students' attention with this eye-catching demonstration of a bowling ball floating in water!



Concepts

- Density
- Volume

Materials

Aquarium or clear large plastic tub

Bowling ball, 8-lb

Additional bowling balls of various weights

Water

Safety Precautions

Gently place the bowling balls in the water. For heavier bowling balls, you will have to place them in the water gently and slowly lower them to the bottom of the aquarium. Not doing so could result in the aquarium glass breaking. Follow all laboratory safety guidelines.

Preparation

1. Fill the aquarium or tub 2/3 full with water.
2. Gently place the 8-pound bowling ball in the aquarium.

Disposal

The aquarium and bowling balls should be saved for future demonstrations.

Tips

- This demonstration is a great discrepant event for students to see as they walk into the classroom.
- Another option is to start with only water in the tank. Have students predict which bowling balls will float or sink from a variety of bowling balls with different weights (bowling balls 12 pounds and lighter will float).
- An extension of this activity could be to test more household items to see if the objects will sink or float. Extend the activity and have students calculate the densities of the objects before placing them in the tank.
- The following kits can be used to further explore density:

– Salting Out—Density Bottle Demonstration Kit (Flinn Catalog No. AP7931)
– Measurement Challenge—A Density Laboratory (Flinn Catalog No. AP5939)
– Density Cube Set (Flinn Catalog No. AP6058)

Publication No. 11350
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Discussion

Density is a characteristic property of matter, and materials can be identified by their density. Density is defined as the mass of a substance per volume (Equation 1).

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \qquad \textit{Equation 1}$$

Density is commonly expressed as g/cm^3 or g/mL. The density of pure water is 1.00 g/cm^3 at 20 °C. Objects with a density greater than 1.00 g/cm^3 will sink in pure water. Objects with a density less than 1.00 g/cm^3 will float in pure water.

Bowling balls are the same volume but can vary in weight. The circumference of a bowling ball is 27 inches. While the bowling balls are the same size, they have different masses and are made of different materials. The lower the mass, the smaller the density. When the density is less than 1.00 g/mL, the bowling ball will float.

To determine if a bowling ball will float or sink, the density can be calculated. First, the radius must be calculated from the circumference (Equation 2) and inches are changed to centimeters (1 inch = 2.54 cm):

$$27 \text{ inches} = 68.58 \text{ cm}$$
$$\text{Circumference} = 2\pi r \qquad \textit{Equation 2}$$
$$68.58 = 2\pi r$$
$$r = 10.9 \text{ cm}$$

Then the volume of the bowling ball can be calculated using Equation 3.

$$V = 4/3\pi r^3 \qquad \textit{Equation 3}$$
$$V = 4/3\pi(10.9)^3$$
$$V = 5446.8 \text{ cm}^3$$

Lastly, the weight in pounds needs to be converted to grams before calculating the density (1 pound = 453.6 grams).

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

A sample calculation for an 8-lb bowling ball is given below.

$$\text{Density} = (8 \text{ lb} \times 453.6 \text{ g/lb})/(5446.8 \text{ cm}^3) = 0.67 \text{ g/cm}^3$$

Since the density of the 8-lb bowling ball is less than the density of water, the ball floats.

Materials for *The Floating Bowling Ball* are available from Flinn Scientific, Inc.

Catalog No.	Description
FB2012	Aquarium, All-Glass®, 20 gallon (24″ × 12″ × 16″)
AP6058	Density Cube Set
AP5939	Measurement Challenge—A Density Laboratory Kit
AP7931	Salting Out—Density Bottle Demonstration Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Alcohol Cannon Apparatus Kit

Introduction

Use this apparatus kit to construct a safe "alcohol cannon" to launch soft foam balls. The alcohol cannon is an exciting way to demonstrate the controlled combustion of isopropyl alcohol—and to "launch" your students into a discussion of chemical reactions!

Concepts

- Combustion
- Thermochemistry
- Gas laws
- Exothermic reactions

Materials

Isopropyl alcohol, $(CH_3)_2CHOH$, 99%, 4 mL

Alcohol cannon apparatus*

Butane safety lighter (e.g., Aim 'n Flame, etc.)

Foam ball, 7″

Pipet, Beral-type

**Materials included in kit.*

Safety Precautions

Isopropyl alcohol is a flammable liquid and a dangerous fire risk. Combustion of isopropyl alcohol may produce a potentially violent explosion. Follow the directions exactly with respect to the amount of alcohol and the type of ball used. Warn observers to anticipate the noise and demonstrate the proper way to "cup" or cover ears. ***Do not add more alcohol than called for in the instructions.*** *Scaling up this demonstration will present dangerous conditions to both the demonstrator and the observers. Always recap the alcohol bottle after adding alcohol to the cannon and move the bottle far from the demonstration area. Never leave an open bottle of alcohol in the vicinity of the demonstration. Perform this demonstration outdoors or in a well-ventilated area such as a large gymnasium. Make sure there are no flames in the area.* ***Do not attempt to launch any object heavier or harder than the foam ball.*** *Additionally, instruct students to stand clear of the cannon to avoid the ball as it launched. Wear safety goggles and hearing protection while performing the demonstration. Wash hands thoroughly with soap and water after performing the demonstration. Follow all laboratory safety guidelines. Please review current Material Safety Data Sheets for additional safety, handling and disposal information.*

Preparation

1. Inspect the assembled PVC "cannon" apparatus. Remove any possible debris from the ignition hole and barrel.
2. Remove the end cap and check for debris. Tighten the end cap so it is hand-tight and then loosen the end ¼ to ½ of a turn. *Caution:* After the reaction the threads will swell—if the end is not loosened slightly it will be very difficult to remove. Note that the end cap will not tighten all the way in; some threads will be showing.
3. Inspect the foam ball and practice pushing it into the cannon.
4. Familiarize yourself with the components of the alcohol cannon (see Figure 1).
5. Before firing the cannon for the first time, determine an appropriate location to perform the demonstration to ensure overall safety. Clear the area of all potential obstacles as necessary. Take note of all obstacles including ceiling height if applicable.

Procedure

1. Review all of the safety precautions and go through a mental checklist to make sure all precautions are followed.
2. Fill a pipet with 2 mL of isopropyl alcohol.
3. Holding the pipet, reach your arm into the open end of the cannon as far as possible and squirt the 2 mL of isopropyl alcohol into the cannon (see Figure 2).
4. Quickly compress and stuff the 7″ foam ball into the open

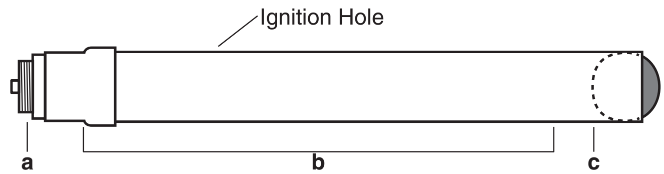

Figure 1. a) End cap b) Assembled cannon c) 7″ Foam ball

Publication No. 7410
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end of the alcohol cannon. Most of the ball should be completely inside the pipe.

5. Refill the pipet with 2 mL of isopropyl alcohol.
6. Squirt the 2 mL of isopropyl alcohol into the ignition hole of the alcohol cannon.

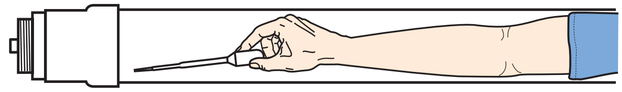

Figure 2.

7. Recap the alcohol bottle and move it far from the demonstration area. ***Never*** leave an open bottle of alcohol in the vicinity of the demonstration.
8. Spin and rotate the cannon for 3–4 minutes to promote evaporation of the isopropyl alcohol.
9. Aim the cannon in the predetermined safe area and hold securely. Make sure no one is in the path of the projectile.
10. Remind observers to "cup" their ears.
11. Place the safety lighter near the ignition hole and ignite.
12. A thump should send the ball flying 20–30 feet.
13. To repeat procedure, remove the end cap to allow air to flow freely through the alcohol cannon, replenishing the oxygen supply for a second launch. Repeat steps 1–11.
14. Use paper towels to clean and dry the alcohol cannon for future use.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The residue remaining in the apparatus after the reaction has ceased may be disposed of using Flinn Suggested Disposal Method #26b. The alcohol cannon and foam ball may be stored for future use.

Tips

- Always practice the demonstration before performing it in front of an audience. It is helpful to become familiar with the demonstration as not to be startled by the noise when conducting it in front of the students.
- The apparatus may be reused many times. Isopropyl alcohol and 7″ foam balls may be purchased separately from Flinn Scientific, Inc.
- The 7″ foam ball must be removable with only a small amount of pressure—otherwise, the gas pressure from the reaction could build up and be dangerous.
- Double check to make sure that the 7″ foam ball to be launched is placed tightly into the end of the alcohol cannon.
- Take into account temperature changes if this demonstration will be performed outdoors. If the temperature is too cold, the isopropyl alcohol will not vaporize well and the demonstration does not work well.
- Never completely seal the alcohol cannon apparatus.
- Never use methyl alcohol for this demonstration. The high volatility of methyl alcohol means that it has the potential for the most violent combustion of any alcohol.
- The alcohol must be completely vaporized inside the tube.
- To perform the demonstration again on the same day or class period, replenishing the air in the empty apparatus (no alcohol) is required—as the demo will not work immediately after the first launch. Unscrew the cap to promote air entry. Ensure that the area, in the room or outside, is clear and vigorously twirl and turn to circulate air back into the long and relatively narrow PVC tube.
- Do not burn alcohol in a pure oxygen environment since the heat of combustion of the isopropyl alcohol/pure oxygen mixture is significantly higher than the isopropyl alcohol/air mixture. Do not fill the apparatus with any gas other than air.
- A Flinn Scientific piezo sparker (Catalog No. AP6286) may also be used to ignite the cannon.
- A video of this demonstration, *Giant Alcohol Cannon*, presented by Jeff Bracken, is available for viewing as part of the Flinn Scientific "Teaching Chemistry" eLearning Video Series. Please visit the eLearning Web site at http://elearning.flinnsci.com for viewing information. This video is part of the *Combustion of Alcohols* and *Energy in Combustion Reactions* video packages. We decided to use 99% isopropyl alcohol instead of ethyl alcohol, which is used in the video. Isopropyl alcohol is much safer.

- Have students perform calculations to determine the amount of gases produced based on the starting amount of isopropyl alcohol.

  For example, if 4.00 mL of isopropyl alcohol (density = 0.78 g/mL) is used:

$$4.00 \text{ mL } (0.78 \text{ g/mL}) = 3.1 \text{ g} \times \frac{1 \text{ mole}}{60.10 \text{ g}} = 0.052 \text{ mole isopropyl alcohol}$$

  From the balanced equation,

$$0.052 \text{ mole isopropyl alcohol} \times \frac{14 \text{ moles of gaseous products}}{2 \text{ mole isopropyl alcohol}} = 0.36 \text{ mole gaseous products}$$

  Seven times more gaseous product is formed than isopropyl alcohol originally added. The pressure inside the cannon increases dramatically and the volume of gas expands. No wonder the ball launches!

Discussion

Low-boiling alcohols vaporize readily, and when alcohol is placed in air, a combustible mixture of alcohol and air is produced. A butane safety lighter held by the ignition hole of the cannon provides the activation energy needed for the combustion of the alcohol/air mixture.

Only a small amount of alcohol is added to the cannon and it quickly vaporizes to a heavier-than-air vapor. The alcohol vapor and air are all that remain in the cannon. Alcohol molecules in the vapor phase are farther apart than in the liquid phase and present far more surface area for reaction; therefore the combustion reaction that occurs is very fast.

Since the burning is so rapid and occurs in the confined space of the cannon with a small ignition hole, as the products form the pressure builds and the ball is launched.

The equation for the complete combustion reaction of isopropyl alcohol shows that 2 moles of isopropyl alcohol combine with 9 moles of oxygen to produce 6 moles of carbon dioxide and 8 moles of water:

$$2(CH_3)_2CHOH(g) + 9O_2(g) \rightarrow 6CO_2(g) + 8H_2O(g)$$

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12

Evidence, models, and explanation

Constancy, change, and measurement

Content Standards: Grades 9–12

Content Standard A: Science as Inquiry

Content Standard B: Physical Science, chemical reactions, motions and forces, interactions of energy and matter

Acknowledgement

Jeff Bracken credits chemistry teacher Kathleen Holley who presented this demonstration at the ACT-2 Conference, Belton, Texas, June, 2001. This demonstration also appears in *"Chemistry Demonstration Aids That You Can Build!" written by Jeff Hapburn, Bruce Mattson, Mary Alice Kubovy, and Joe Lannan* published by Flinn Scientific (Catalog No. AP9320).

Materials for *Alcohol Cannon Apparatus Kit* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP7410	Alcohol Cannon Apparatus Kit
I0019	Isopropyl Alcohol, 99% 500 mL
AP1718	Pipet, Thin-Stem, Pkg/20
EL8000	eLearning Viewing Pass
AP8960	Butane Safety Lighter
AP7415	Foam Ball, 7″
AP6286	Piezoelectric Igniter

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Marshmallow Man Meets the Vacuum Pump

A Boyle's Law Activity

Introduction

Boyle's Law made easy! Amaze your students by expanding a marshmallow figure in a vacuum chamber!

Concepts

- Boyle's Law
- Inverse pressure/volume relationship

Materials

Beaker

Marshmallow bunny or chick, or marshmallow stick-man

Vacuum chamber with plate

Vacuum pump, two-stage

Vacuum tubing

Safety Precautions

Any food-grade items that have been brought into the lab are for lab use only. Do not taste or ingest any food in the lab and do not remove any remaining food items. Check hoses, vacuum chamber, and beaker for cracks before use. Do not use any damaged materials under a vacuum. Always wear chemical splash goggles when performing chemical demonstrations.

Procedure

1. Place the marshmallow figure into the vacuum chamber system. *Note:* Do not place the marshmallow figure near the opening to the pump—it may get sucked into the pump. To guard against this, place a beaker upside down over the opening.
2. Connect the vacuum chamber to the vacuum pump with heavy-walled vacuum tubing.
3. Turn on the vacuum pump to evacuate the chamber.
4. Watch as the marshmallow figure becomes larger and larger.
5. When the chamber is fully evacuated and the figure is as large as it will get, allow air back into the chamber *before* turning off the pump. *Note:* If the pump is shut off before venting to the atmosphere, grease and oil will be pulled out of the pump and into the tubing and vacuum chamber.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. Dispose of materials in the trash according to Flinn Disposal Method #26a.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter

Tips

- When beginning your discussion of gas laws, slightly inflate a balloon, tie it closed, and then place it into the vacuum chamber. Slightly inflating a latex glove and securely tying off the opening also works well. Evacuate the chamber and have your students explain what happens in terms of the gas laws.
- For best results, use fresh marshmallows.
- During the procedure, some of the air bubbles in the marshmallow figure will "break" and the marshmallow may begin to shrink slightly before air is allowed back into the chamber. This is why the figure ends up smaller than the original when atmospheric pressure is restored.
- Another simple activity is to place a cup with a small amount of shaving cream in the vacuum chamber. Again the air bubbles inside the shaving cream will expand.
- Some teachers have made stick people out of marshmallows and toothpicks and expanded them.

Discussion

When the vacuum pump is turned on and the vacuum chamber is evacuated, the pressure inside the chamber decreases. The lower pressure on the marshmallow bunny causes its volume to increase according to Boyle's Law (*Equation 1*). The expansion is due to the many trapped air bubbles (like small "internal balloons") within the marshmallows that initially are at atmospheric pressure. As the pressure outside these air bubbles (within the chamber) is reduced, the bubbles will expand to many times their original volume in order to equilibrate the pressure on either side of the bubble wall. Thus as the pressure decreases, volume increases in an inverse relationship. This increase in volume makes for a memorable visual event and a great stimulus for the discussion of the elements of Boyle's Law. Students can visualize the loss in pressure and easily see the increase in volume.

$$P_1 \times V_1 = P_2 \times V_2 \qquad \textit{Equation 1}$$

Boyle's Law

Acknowledgments

Special thanks to the Weird Science Team of Bob Lewis, Lee Marek, Bill West, and DeWayne Lieneman for bringing this demonstration to our attention. The Weird Science Team was a group of Chemistry teachers from the Chicago suburbs that shared their special brand of demonstrations with thousands of teachers from across the United States.

Materials for *Easter Bunny Meets the Vacuum Pump* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1597	Pump, Vacuum, Two stage
AP4506	Vacuum Chamber with Plate
AP8789	Tubing, Vacuum, 10 feet

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Boiling Water in a Bell Jar

Introduction

Demonstrate the conditions necessary for liquids to boil.

Concepts

- Vacuum properties
- Vapor pressure
- Boiling point

Materials (for each demonstration)

Bell jar, large, transparent
Boiling stone
Clear plastic cup
Three-way valve (optional, depends on operation of vacuum plate)
Thermometer, digital or spirit-filled (appropriate to fit inside the bell jar)
Vacuum plate
Vacuum pump, two-stage
Vacuum tubing
Water, 50–100 mL

Safety Precautions

Wear safety glasses when working with an evacuated bell jar or vacuum pump. All students and teachers near an evacuated bell jar must wear safety glasses. Do not use a mercury thermometer. Mercury vapors could be quickly released into the classroom if the thermometer breaks.

Preparation

1. Fill a clear plastic cup with approximately 50–100 mL of water (students should be able to see the water in the cup). Add a boiling stone to prevent "bumping."
2. Place the water-filled cup off-center on the vacuum plate so that the evacuation portal is not covered (see Figure 2).
3. Place a digital or spirit-filled thermometer in the water. ***Caution:*** Do NOT use a mercury thermometer for this demonstration.
4. Place the bell jar on the vacuum plate, and properly connect the vacuum plate to the vacuum pump (see Figure 1).

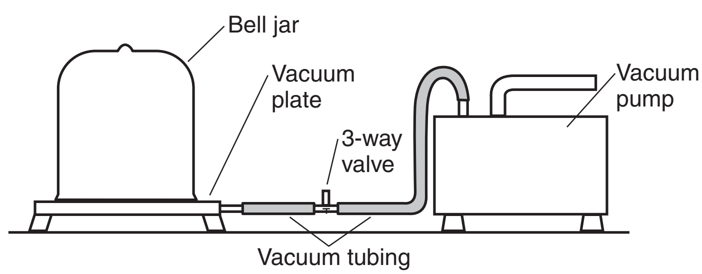

Figure 1.

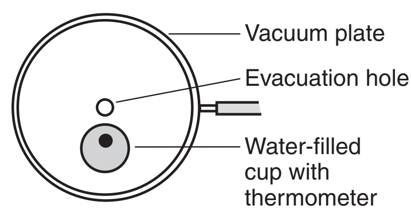

Figure 2.

Procedure

1. Show students the water in the cup inside the bell jar.
2. Use the thermometer to measure the temperature of the water in the cup. Report this temperature to the students to record in their worksheets.
3. Discuss the concepts of vapor pressure and boiling with students.
4. Ask students to predict what will happen when the air is removed from inside the bell jar, reducing the air pressure.
5. Once students have made their predictions, turn on the vacuum pump and evacuate the bell jar. *Note:* If using a digital thermometer, make sure that it is ON before evacuating the bell jar. Some digital thermometers have automatic shut-off features.
6. Students should observe the water in the cup as the air is pulled out of the bell jar. Have them record their observations on the worksheet.

7. Once enough air has been removed from inside the bell jar (the water should be boiling), properly close the valve on the vacuum plate (or the three-way valve) and turn off the vacuum pump. The vacuum should be maintained inside the bell jar and the water should continue to boil.
8. Students should continue to observe the water as the temperature is measured and recorded.
9. Once observations are complete, carefully open the valve on the vacuum plate (or the three-way valve) just enough to allow the bell jar to slowly fill with air. Students should continue to observe the water in the cup. *Caution:* Do not open the valve too quickly, as this may cause a lot of turbulence inside the bell jar, which may knock over the cup of water and possibly break the thermometer.

Teaching Tips

- A two-stage vacuum pump is *required* for this demonstration. A single-stage vacuum pump will not reduce the pressure inside the bell jar enough to cause water to boil at room temperature.
- Use a 400-mL beaker if clear plastic cups are not available.
- Students may need to get close to the bell jar in order to see the water begin to boil at reduced pressure. Make sure all students who approach the evacuated bell jar wear safety glasses. Or, use a ChemCam™ camera to show the demonstration on a TV or monitor.
- Use water at different starting temperatures to show students that vapor pressure is related to temperature. Water at 10 °C will not boil under the reduced pressure of a two-stage vacuum pump.
- If the bell jar is not sealed after is has been evacuated, the water may begin to evaporate causing the water temperature to drop below 10 °C and the water will stop boiling.
- See the demonstration "Freezing by Boiling" in *Solids and Liquids*, Volume 11 in the *Flinn ChemTopic™ Labs* series (Flinn Catalog No. AP6660) for a related activity.

Discussion

Vapor pressure is a measure of the amount of vapor that is present above a liquid at a given temperature. The vapor pressure above a liquid is proportional to the temperature of the liquid, meaning the higher the temperature of the liquid, the higher its vapor pressure will be. A liquid begins to boil when the vapor pressure of the liquid is the same as the atmospheric pressure surrounding the liquid. The reason water boils at a lower temperature in Denver (approximately one mile above sea level) compared to Boston (approximately at sea level) is due to the lower atmospheric pressure at higher altitude. The lower atmospheric pressure in Denver means the vapor pressure of the water reaches local atmospheric pressure at a lower temperature, which causes water to boil at around 97 °C.

There are two ways to make a liquid boil. Either heat the liquid to a temperature in which the vapor pressure matches the atmospheric pressure, or reduce the pressure surrounding the liquid to match the vapor pressure of the liquid at the given temperature. In this demonstration, the pressure surrounding the water is reduced enough to cause the water to boil at room temperature. The vapor pressure of water at room temperature (20 °C) is approximately 18 mm Hg. At 10 °C, water vapor pressure is approximately 9 mm Hg. Therefore, in order for water to boil at room temperature, the atmospheric pressure surrounding the water must be lowered to at least 18 mm Hg.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, understanding of motions and forces
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, motions and forces

Answers to Worksheet *(Student answers will vary.)*

Initial Water Temperature: _______________

Final Water Temperature: ________________

Observations during evacuation process

Vacuum pump was loud and became quieter as the air was sucked out. The water began to bubble after about 30 seconds. The temperature dropped a few degrees, too. When the bell jar was sealed and the vacuum pump shut off, the water continued to boil in the cup. As the air was let into the bell jar, the boiling stopped.

Answers to Questions

1. Why does water boil at room temperature when the pressure is reduced?

   The vapor pressure of the water is greater than the atmospheric pressure surrounding the water, so the water begins to boil.

2. What would happen to the boiling point of water if the pressure were increased above normal atmospheric pressure? Explain.

   The vapor pressure would need to increase to the higher atmospheric pressure, so the temperature of the water would need to rise above 100 °C before it would begin to boil.

3. Why does the temperature of the water decrease as it boils?

   The temperature of the water decreases because the water evaporates and removes heat from the water, causing the temperature to drop.

Reference

http://www.s-ohe.com/Water_cal.html (accessed December 2005)

Materials for *Bell Jar Demonstrations* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1870	Bell Jar with Molded Glass Knob, Glass
AP6543	Cups, Clear Plastic, 16 oz
AP4560	Flinn ChemCam™ Camera
AP6049	Thermometer, Flinn Digital Pocket, Economy Choice
AP1452	Thermometer, Spirit-filled, Partial Immersion
AP1869	Vacuum Plate, Nalgene
AP1597	Vacuum Pump, Two-Stage
AP8789	Vacuum Tubing, 10 feet
AP5353	Valve, Three-Way

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Student Worksheet

Boiling Water at Room Temperature

Initial Water Temperature: _______________

Final Water Temperature: ________________

Observations during evacuation process

Questions

1. Why does water boil at room temperature when the pressure is reduced?

2. What would happen to the boiling point of water if the pressure were increased above normal atmospheric pressure? Explain.

3. Why does the temperature of the water decrease as it boils?

Collapsing Can Demonstration

Introduction

Here's a pressure-packed demonstration that will convince students that air exerts significant pressure!

Concepts

- Pressure differential
- Atmospheric pressure

Materials

Metal can with screw top lid*

Hot plate

**Materials included in kit.*

Tap water, 50 mL

Water bath

Zetex™ gloves, for high and low temperatures

Safety Precautions

Be careful of the hot can and the steam created by heating the water in the can. Wear goggles and protective gloves during the demonstration.

Procedure

1. Locate a metal can with an airtight screw top lid.
2. Remove the lid from the metal can. Be sure the can is clean and free of chemicals—a new, unused can is preferred.
3. Add approximately 50 mL of tap water to the metal can. This should be enough to cover the bottom of the can to a depth of approximately 1 cm.
4. Place the can on a hot plate and heat it until the water boils and steam flows out of the uncapped hole.
5. Using protective gloves, remove the steaming can from the hot plate. Place the can where it can be easily viewed.
6. Immediately place the cap on the can and close tightly.
7. The can will be dramatically crushed and it will likely do so in a loud fashion. For a quick crush, place the sealed can into an ice–water bath to cool the can rapidly.

Tips

- It is important that the cover on the can has an airtight seal. Be sure to get the lid placed tightly on the can before the cooling process begins.
- The collapsed can and an identical un-crushed can make a nice exhibit in a classroom display case.
- If a cap to the can is not available, try a rubber stopper. Be sure the rubber stopper fits snugly in the can opening.
- For a more impressive implosion, immerse the can into a sink of cold water.

Publication No. 4695
021517

Discussion

The tremendous pressure required to "crush" the can comes from the differential in pressure that exists between the outside of the can (normal air pressure) and the partial vacuum created inside the can by the condensing steam. The pressure differential is caused by the condensation of the steam inside the closed system as the can cools. The pressure on the outside of the can remains at atmospheric pressure (14.7 lb/in^2) while the pressure inside the can is significantly reduced as the steam condenses. Remember that the can is not "sucked in"—it is the greater pressure on the outside of the can that pushes in on the can and "crushes" it. The total pressure exerted on the outside of the can may be calculated by determining the surface area of the outside of the can and multiplying this area by atmospheric pressure per unit area.

The *Collapsing Can Demonstration* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP4695	Collapsing Can Demonstration
AP8183	Flinn Hot Plate, 7x7

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Atmosphere Bar

Introduction

What does atmospheric pressure—14.7 pounds per square inch— really feel like?

Concepts

- Force
- Pressure

Background

Firemen use high-pressure hoses. Scuba divers must not dive too deeply because of water pressure. Mountain climbers must not climb too high because of low air pressure. What is pressure?

Pressure is not the same as force. Force is a push or pull one body exerts on another. It is what causes the interaction between two objects. Use the eraser end of a pencil and apply a specific force (push) onto the palm of your hand. You can feel the pressure. Now, turn the pencil around and place the sharpened end into the palm of your hand and apply the same force (push). *Caution:* Do not push too hard as to pierce the skin. Same force—different pressure! The same force on a smaller area produces greater pressure.

Pressure (P) is the amount of force (F) exerted per unit area (A). It is often expressed as:

$$P = F/A \qquad \textit{Equation 1}$$

The *Pascal* (Pa) is the SI unit for pressure. One Pascal of pressure is defined as the force of one Newton per square meter (1 Pa = 1 N/m^2).

The Earth's atmosphere exerts a pressure on everything within it. At sea level, atmospheric pressure is equal to one atmosphere (1 atm) or 101,325 Pa. Equivalent units for 1 atm pressure are 760 mm Hg or 14.7 lbs/in^2. This means that at the Earth's surface, the atmosphere exerts a force of about 100,000 Newtons on every square meter it "touches." This amount of force (100,000 Newtons) can be compared to the weight of a large truck!

Materials

One-inch square steel bar weighing approximately 14.7 lbs

Safety Precautions

Obviously, a 15-lb steel bar can be a dangerous item if used inappropriately. Do not leave the bar unattended and supervise all demonstrations with the bar. Be careful when using the bar in a vertical position and practice holding the bar to avoid any accidental slippage.

Procedure

1. Use a student volunteer. Have the student place his hand palm up on a table top. Carefully place the "atmosphere bar" flat (horizontally) into the palm of the student's hand. Since the force is spread over a fairly large surface, the pressure shouldn't be too great.
2. Carefully lift the bar into a vertical position and slowly let the full mass of the bar be focused on 1 in^2 of the palm of the student's hand. Support the bar carefully and only allow as much pressure as the student can withstand.
3. Have students discuss the pressure exerted by a 14.7-lb bar per square inch of a student's hand. Students will likely remember what one atmosphere of pressure really means for a long time.

Tips

- The concept of pressure being related to the area of the applied force is often difficult for students to understand. Have students try the "pencil" activity described in the background to start a discussion of pressure and area. Other pointed and blunted objects can be used to avoid potential punctures with pencil lead. High heel and flat heel shoes might provide an interesting discussion topic and/or demonstration.

Publication No. 5882
021517

- Introduce the idea of atmospheric pressure being equal to 14.7 lbs/in^2. Contrast that pressure with tire pressures of 30 lbs/in^2 or 90 lbs/in^2.
- Use the Atmosphere Bar to dramatically illustrate what 14.7 lbs/in^2 is really like. Pass the bar around the class and let each student lift it. Most will be quite surprised at its great mass.
- Use this demonstration bar to introduce other examples of air pressure as appropriate to your teaching unit. What role does air pressure play in our lungs and respiratory system? Why don't living organisms collapse under the pressure? What makes for good tire traction—large surface area or small surface area? How do we use air pressure to our advantage? When is air pressure a problem?
- The atmosphere bar may develop rust if you live in a humid area. Simply use steel wool to clean the bar.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, understanding of motions and forces
Content Standard D: Earth Science, structure of the Earth system
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, motions and forces

Acknowledgment

Special thanks to Walter Rohr (retired) of Eastchester High School, Eastchester, NY, for bringing this idea to the attention of Flinn Scientific.

Reference

Meloan, C. E. *J. Chem. Ed.* **1988**, 65, 69.

The *Atmosphere Bar* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP5882	Atmosphere Bar

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Marshmallow in a Vacuum

Boyle's Law

FLINN SCIENTIFIC CHEM FAX!

Introduction

Help students explore and understand Boyle's Law with this simple demonstration. See how a change in pressure affects the volume of a marshmallow. Students will easily remember the relationship between pressure and volume after participating in this activity.

Concepts

- Pressure
- Boyle's law
- Volume
- Gas laws

Materials

Syringe, without needle, plastic, 30-mL

Miniature marshmallow, fresh

Felt-tip pen (optional)

Syringe tip cap (optional)

Safety Precautions

Although the materials used in this activity are considered nonhzardous, please observe all normal laboratory safety guidelines. Food-grade items that have been brought into the laboratory are considered laboratory chemicals and are for lab use only. Do not taste or ingest any materials in the chemistry laboratory. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. If desired, use a felt-tip pen to draw a happy face on the end of a miniature marshmallow.
2. Remove the end cap from the tip of a 30-mL plastic syringe.
3. Remove plunger from the syringe and insert the marshmallow into the syringe.
4. Place plunger back in syringe so the volume reading is approximately at the 15-mL mark.
5. Place a syringe tip cap over the tip of the syringe. Pull the plunger out—decreasing the pressure inside the syringe. The marshmallow should expand as its volume increases.
6. Now push the syringe in—increasing the pressure inside the syringe. The marshmallow should shrink as its volume decreases.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The marshmallow should be removed from syringe and put into the trash according to Flinn Suggested Disposal Method #26a. Clean work area and wash hands thoroughly with soap and water before leaving the laboratory.

Tips

- A finger may be used to "seal" the syringe instead of a syringe tip cap, if needed.
- Compare the marshmallow from the syringe to a fresh marshmallow.

Publication No. 91705
061616

Discussion

When the syringe plunger is pulled out, the volume of the chamber increases but the amount of gas remains constant because it is in a closed system. This causes the pressure inside the syringe chamber to decrease. The lower pressure on the marshmallow causes its volume to increase according to Boyle's Law. The expansion is due to the many trapped air bubbles (like small "internal balloons") within the marshmallow that are initially at atmospheric pressure. As the pressure outside these air bubbles (within the chamber) is reduced, the bubbles will expand to many times their original volume in order to equilibrate the pressure on either side of the bubble wall. Thus, as the pressure decreases ($P\downarrow$), volume increases ($V\uparrow$) in an inverse relationship according to the following equations.

$$PV = nRT$$ *Equation 1 – Ideal Gas Law*

$$P_1 \times V_1 = P_2 \times V_2$$ *Equation 2 – Boyle's Law*

This increase in volume makes for a memorable visual event and a great stimulus for the discussion of the elements of Boyle's Law. Students can visualize the loss in pressure and easily see the increase in volume.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
- Evidence, models, and explanation
- Constancy, change, and measurement

Content Standards: Grades 9–12
- Content Standard B: Physical Science, structure and properties of matter

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Marshmallow in a Vacuum* activity, presented by Jesse Bernstein, is available in *Boyle's Law*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Marshmallow in a Vacuum* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1732	Syringe, 30-mL
AP1297	Felt-tip Pen, Black
AP8958	Syringe Tip Cap

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Cartesian Diver Design Challenge

Introduction

Cartesian divers are great toys that can be used to teach important science concepts. Several variations of Cartesian divers are on the market. Imagine that you and your classmates are members of a research and development team at a toy company and are challenged to design a new Cartesian diver toy. Can you design a toy that includes at least three divers that will descend and ascend in a particular order?

Concepts

- Density
- Buoyancy

Materials

Beaker, 600-mL or plastic cup
Hex nut, ¼-inch
Hot-melt glue gun and glue stick (optional)
Pipets, disposable plastic, graduated
Plastic soda bottle, clear, 1- or 2-L with cap
Scissors

Safety Precautions

The materials used in the standard activity are considered nonhazardous. Exercise caution when handling the hot glue gun. Wipe up any water spills immediately. Please follow all normal laboratory safety guidelines.

Standard Diver Preparation

1. Cut off all but 15 mm of the pipet stem (see Figure 1).

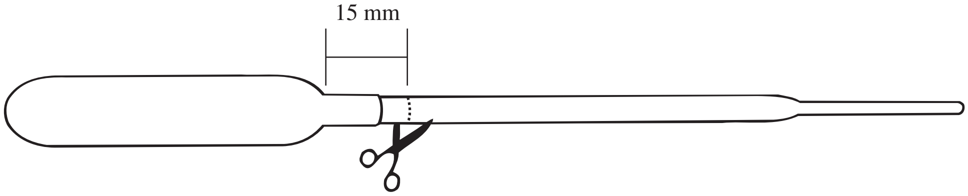

Figure 1. Cutting the Pipet

2. Screw the nut securely onto the pipet stem. The hex nut will make its own threads as it goes.
3. Fill the 600-mL beaker approximately ⅘ full with tap water.
4. Place the pipet–nut diver assembly into the beaker of water and observe that it floats rather buoyantly in an upright position with the hex nut acting as ballast.
5. Squeeze out some of the air and draw water up into the pipet. Now check the buoyancy. If too much water is drawn up into the diver, it will sink. If this happens, simply lift it out of the water, squeeze out a few drops of water and let air back in to replace the water. Using this technique, adjust the amount of water in the assembly so that it just barely floats. (In other words, fine-tune the assembly's density to make it slightly less than that of water.)

Variation: Closed-System Diver

1. Follow steps 1–5 in the *Standard Diver Preparation* section.
2. Remove the diver from the beaker and squeeze out one or two drops of water. Using a cotton swab or paper towel, pat dry the inside rim of the open stem.
3. Holding the bulb with the stem end upward, squeeze the bulb very slightly to expel a very small amount of air. Hold the squeeze while carefully placing a drop of hot-melt glue in the stem opening of the diver, and then relax the squeeze. The drop of hot glue will be pulled into the stem (see Figure 2).

Publication No. 11194
061616

4. Wait 1–2 minutes for the drop of glue to harden and seal the mouth of the diver.

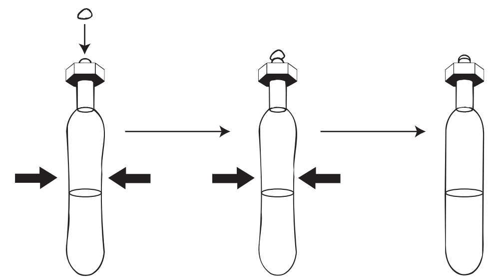

Figure 2.

Procedure

1. Place the standard diver assembly in a plastic 1-or 2-L bottle that has been *completely* filled with water and securely screw on the cap (see Figure 3).
2. Test the standard diver by squeezing the bottle and observe any changes in the position or behavior of the Cartesian diver.
3. Release the "squeeze" and observe any "return" behavior of the diver.
4. Repeat the process and propose an explanation for the results.
5. Test the closed-system diver in the 1-or 2-L bottle. Observe and record its behavior as you squeeze and release the bottle.
6. Does the behavior or action of the closed-system diver reinforce or change your proposed explanation for the results observed in the standard diver test?

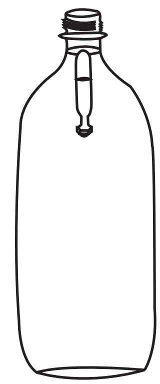

Figure 3.

Design Challenge

The challenge is to design a Cartesian diver toy with three or more divers that will descend in a pre-determined order. The toy should have a "theme" that enhances the design.

1. Form a working group with 2-3 other students and consider the following questions relating to the effects of density and buoyancy on the properties of a Cartesian diver.
   a. Can the density of the diver be quantified?
   b. Is the relationship between the amount of water in a diver and its density linear?
   c. Should the divers be open (standard) or closed? What are the advantages and disadvantages of each type?
   d. Will the temperature of the water or the temperature of the room affect the results?
   e. Does the size of the bottle matter?
2. Students should then plan, discuss, test, and evaluate their designs.
   a. Decide upon the number of divers to include and determine the theme of the toy—other than density, why are the divers descending in a particular order?
   b. Discuss and design a procedure to test the divers.
   c. List any safety concerns and the precautions that will be implemented to keep yourself, your classmates, and your instructor safe during testing.
   d. Consider the strengths and limitations of your design.
   e. How will the testing data be recorded?
   f. How will you analyze the data to determine a successful design?
   g. Review your design, safety precautions, procedure, data tables, and proposed analysis with your instructor prior to testing the design.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
MS-PS1 Matter and Its Interactions
PS1.A: Structure and Properties of Matter
MS-PS2 Motion and Stability: Forces and Interactions
PS2.A: Forces and Motion
MS-ETS1 Engineering Design
ETS1.B: Developing Possible Solutions
ETS1.C: Optimizing the Design Solution

Disciplinary Core Ideas: High School
HS-PS2 Motion and Stability: Forces and Interactions
PS2.A: Forces and Motion

Science and Engineering Practices
Asking questions and defining problems
Developing and using models
Planning and carrying out investigations
Constructing explanations and designing solutions
Engaging in argument from evidence
Obtaining, evaluation, and communicating information

Crosscutting Concepts
Patterns
Cause and effect
Systems and models
Structure and function
Stability and change

Tips

- It is considerably more convenient to adjust the density of the diver and to test for flotation in a 600-mL beaker or in a cup of water, rather than in the bottle itself.
- It is advisable to fill the plastic bottle completely with water. If the bottle contains too much air, then when the bottle is squeezed, the work will go into compressing the large air space at the top of the bottle rather than the smaller air pocket in the diver.
- This assembly is formally known as a Cartesian diver after René Descartes, a 17th century French mathematician.
- The manufacturers of plastic pipets change their designs and specifications occasionally. Therefore, the hex-nut size of ¼ -inch may not exactly fit the pipet. In this case, wrap the stem of the pipet near the bulb with clear tape to increase its diameter.
- One advantage to the closed-system diver is that a drop or two of food coloring may be added before sealing the pipet stem with hot-melt glue. The main disadvantage is that the bulb must be reopened if any adjustments need to be made to the density. One method it to heat a stiff wire in a flame and use the hot end to melt a hole in the plug of glue.
- Instructors may want to limit the number of divers included in the challenge. Up to ten divers in a 2-L bottle is possible, but squeezing the bottle enough to get all the divers to descend may be difficult.
- Students may need one or two examples of a theme for multiple descending divers—numbered divers that descend in order, lettered divers that spell a word or secret message, etc.
- Show students a few manufactured or homemade variations of the standard Cartesian diver before presenting the Design Challenge. Two manufactured variations, *Squidy* and *Hook Cartesian Divers* are available from Flinn Scientific (Catalog Nos. AP8721 and AP4548, respectively).
- A *Cartesian Diver Construction—Super Value Kit* is available from Flinn Scientific (Catalog No. AP9082). Enough pipets and hex nuts are provided to build 100 Cartesian divers. A *Cartesian Diver Design Challenge—Guided-Inquiry Kit* (Catalog No. AP7926) is also available and includes instructions and materials for three different design challenges.
- A video of this activity, *Cartesian Diver-sions*, presented by Bob Becker, is available for viewing as part of the Flinn Scientific "Best Practices for Teaching Chemistry" Teacher Resource Videos. Please visit the Flinn Website at http://www.flinnsci.com for viewing information. The activity is found with the *Gas Laws* videos.

Discussion

The sinking and rising of a standard Cartesian diver can be explained in two ways.

1. Consider the diver assembly to consist of the pipet bulb, the hex nut, and the air and water inside. As the bottle is squeezed, water is forced up into the assembly (because the air pocket inside the bulb is compressible, but the water in the bottle is not). This adds to the mass of the diver assembly without changing the volume, thus increasing the density of the diver assembly (density = mass/volume).
2. On the other hand, consider the diver assembly to consist of the bulb, the hex nut, and the air inside, but not the water—it is part of the surrounding fluid. As the bottle is squeezed, it compresses the air pocket and thus decreases the total volume of the diver. Since the mass remains constant, the diver assembly's density increases.

Either way, when the Cartesian diver's density increases, it becomes greater than that of the surrounding water, and the diver sinks. When the pressure is released, the compressed air pocket inside the bulb pushes the extra water back out, and the diver assembly assumes its original density, which is slightly less than the density of the water, and it rises to the surface.

The closed-system diver responds differently to the increased pressure since the glue plug prevents water from entering the diver. When the bottle is squeezed, the sides of the pipet bulb curve inward, decreasing the volume. With no change in mass, the density increases and the diver sinks.

Acknowledgment

Special thanks to Bob Becker, Kirkwood High School, Kirkwood, MO for providing the idea and the instructions for this activity to Flinn Scientific.

Cartesian diver drawings provided by Susan Gertz.

References

Sarquis, M. & Sarquis, J. L. *Fun with Chemistry: A Guidebook of K–12 Activities;* Institute for Chemical Education, University of Wisconsin: Madison, 1993; Vol. 2; pp. 123–140.

Materials for *Cartesian Diver Design Challenge* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP7926	Cartesian Diver Design Challenge—Guided-Inquiry Kit
AP9082	Cartesian Diver Construction—Super Value Kit
AP8721	Squidy—Cartesian Diver
AP4548	Hook—Cartesian Diver

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Nitinol "Live" Wire

Introduction

See a "live" wire snap back into its remembered shape when it is put into hot or cold water.

Concepts

- Metal alloys
- Crystal structures

Materials

"Live" Wire (nitinol wire, pronounced "night 'n all")	Bunsen burner (or candle)
Beaker of ice water	Matches
Beaker of near-boiling water	Pliers or tongs

Procedure

Part A. See the wire remember its straight shape

1. Start with the Live Wire in a "straight" form.
2. Hold one end of the wire and place it into the beaker of ice water until it is thoroughly chilled.
3. Remove the wire and quickly use your hands to bend it into crazy shapes (or better yet, if you can, bend it while it is still in the ice water).
4. While holding one end of the bent Live Wire, carefully dip it into the near-boiling water. The wire should instantaneously pop back straight again. Amazing that a piece of wire can "remember" and return to its original straight shape (see Figure 1).

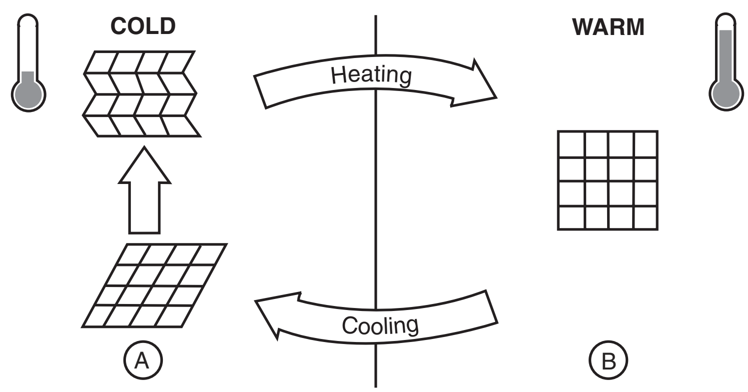

Figure 1.

Part B. "Train" the wire to remember a new shape

1. Starting with the straight wire, use your hands or pliers to bend the wire at room temperature into a desired shape.
2. While firmly holding the wire in this shape with pliers or tongs (you may need 2 pairs), heat it in a Bunsen burner flame (or candle flame) until it is just slightly red. The wire will at first "fight" and want to straighten out. (You must "train" it.) *Note:* Overheating will not help in this procedure and may actually damage the wire.
3. Allow the wire to cool to room temperature, still holding it in its "trained" shape.
4. Chill the wire by dipping it into ice water. Remove the wire from the ice water and immediately straighten it out.
5. Using tongs, dip the wire into a near-boiling water bath.
6. The wire should "remember" the bent shape in which you "trained" it and form back into that shape.
7. Both Parts A and B may be repeated millions of times if the wire's unique crystal structure is not damaged by overextending or overheating.

Disposal

If not overheated or overextended (which may damage the wire's unique crystal structure), the nitinol wire can perform for over 20 million cycles.

Discussion

The Live Wire is actually part of a class of metals known as Shape Memory Alloys (SMAs). These alloys have crystal structures that can form different shapes at distinct temperatures. The crystal structure is easily deformed at cool temperatures (see A), and then when heated, the crystal structure returns to its original shape with great speed and force (see B).

The Live Wire is a nickel–titanium alloy and thus is given the acronym Nitinol. Nitinol consists of nearly equal percentages of the two metals and is specially alloyed and annealed to produce a small grained, extremely uniform crystal structure. A difference of less than 1% in composition will change its transition temperature by 150 °C. Therefore, the materials require very careful formulation and processing.

The Shape Memory Effect (SME) of the nickel–titanium alloy was accidentally noticed by William Beuhler and his research team at the U.S. Naval Ordnance Laboratory in 1961. However, the first SME was discovered in 1932 by Arne Ölander, a Swedish researcher, who observed the Shape Memory Effect of a gold–cadmium alloy. During the 1960s and 1970s, other Shape Memory Alloys were found. Researchers around the world studied alloys of titanium, copper, iron and gold which had this newly found property.

The most successful applications have come more recently. Raychem Corporation came out with Shape Memory Alloy pipe connectors that will shrink, thus producing a better seal in jet engines and hydraulic systems. Toki Corporation of Tokyo, Japan, improved nitinol for specific use by electrical activation. At the 1986 International Symposium on SMAs, papers were presented on possible applications including basic alloy research and development, crystal structures, medical applications (such as using SMA wires like electric muscles in robotic or prosthetic devices), product designs, and manufacturing studies.

Since not all areas of Shape Memory Alloys have been explored, the research and interest is still growing today.

Reference

Properties of 6 mil BioMetal™ Wire, Mondo-tronics, Inc., Sunnyvale, California, 1987.

The *Nitinol "Live" Wire* is available from Flinn Scientific, Inc.

Catalog No.	Description
1937	Nitinol "Live" Wire

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Ferrofluid Nanotechnology Demonstration

Introduction

A magnetic liquid, also known as a ferrofluid, may seem like a space-age concept. That's because it is—the idea was conceived by NASA in the 1960s to control the flow of liquid fuels in space! This activity provides a simple procedure for preparing a ferrofluid and demonstrating its properties. Magnetite (Fe_3O_4) is prepared by combining Fe^{2+} and Fe^{3+} ions with a weak base (ammonia) in dilute aqueous solution. The magnetite produced in this manner consists of extremely small, solid-phase particles that are only about 10 nm in diameter. Shrinking the size of particles to the nanometer scale (one-billionth of a meter) changes their physical and chemical properties. Rather than settle out of solution as a solid, the so-called nanoparticles form a stable colloid, giving rise to a magnetic liquid!

Science Concepts

- Nanotechnology
- Magnetic properties
- Colloids vs. solutions
- Ferrimagnetism

Materials (for each demonstration)

Ammonia water solution, NH_3, 1 *M*, 50 mL*
Hydrochloric acid solution, HCl, 2 *M*, 40 mL*
Iron(II) chloride, $FeCl_2 \cdot 4H_2O$, 8 g*
Iron(III) chloride, $FeCl_3 \cdot 6H_2O$, 5.4 g*
Tetramethylammonium hydroxide solution, $(CH_3)_4NOH$, 25%, 2 mL*
Neodymium magnet*
Pipet, disposable, glass (Pasteur)*
Weighing dish, small*
**Materials included in kit.*

Beaker, 100-mL
Buret, syringe or pipet, 50-mL
Erlenmeyer flasks or beakers, 50-mL, 2
Glass stirring rod
Graduated cylinder, 10-mL
Magnetic stirrer and stir bar (or stirring rod)
Ring stand and buret clamp
Stir bar retriever
Wash bottle and distilled water

Safety Precautions

Tetramethylammonium hydroxide solution is a corrosive liquid—it may cause skin burns and is especially dangerous to the eyes. The solution is toxic by ingestion and skin absorption and may cause respiratory tract irritation. Hydrochloric acid solution is a corrosive liquid and is toxic by ingestion and inhalation. Ammonia vapors are irritating to the lungs and eyes. Perform this demonstration in a fume hood or in a well-ventilated lab only. Iron(II) and iron(III) chlorides are slightly toxic by ingestion and are body tissue irritants. The potential health effects of nanoparticles have not been fully identified. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

1. Prepare a 2 *M* solution of iron(II) chloride in hydrochloric acid by adding 4.0 g of $FeCl_2 \cdot 4H_2O$ to 10 mL of 2 *M* hydrochloric acid (provided with the kit) in a 50-mL Erlenmeyer flask or beaker. Stir to dissolve and mix well. *Note:* This solution does not store well and should be prepared fresh the day of use. Only 1 mL of the solution is needed per demonstration—prepare the solution in smaller-volume batches as needed if the demonstration will be repeated on different days. (Eight grams of iron(II) chloride are provided with the kit.)
2. Prepare a 1 *M* solution of iron(III) chloride in hydrochloric acid by adding 5.4 g of $FeCl_3 \cdot 6H_2O$ to 20 mL of 2 *M* hydrochloric acid (provided with the kit) in a 50-mL Erlenmeyer flask or beaker. Stir to dissolve and mix well. This solution may be stored for up to one week.

Publication No. 7118
021517

Procedure

1. Using a graduated cylinder, measure and add 4.0 mL of 1 *M* $FeCl_3$ solution to a 100-mL beaker.
2. Rinse the graduated cylinder with distilled water, then measure and add 1.0 mL of 2 *M* $FeCl_2$ solution to the beaker.
3. Place a stir bar in the combined Fe(II)/Fe(III) solution and place the beaker on a magnetic stirrer. (If a magnetic stirrer is not available, use a stirring rod to continuously mix the solution as the ammonia water is added in step 5).
4. Fill a clean, 50-mL buret with 1 *M* ammonia solution. Clamp the buret to a ring stand and position the tip of the buret directly over the 100-mL beaker containing the combined Fe(II)/Fe(III) solution.
5. Partially open the buret stopcock and allow the ammonia solution to drip slowly, with continuous stirring, into the combined Fe(II)/Fe(III) solution. Try to add the ammonia at the rate of 1 mL every 10 seconds. (Magnetite will precipitate out of the solution in the form of a brownish black solid.)
6. When 50 mL of ammonia has been added, turn off the magnetic stirrer.
7. Remove the magnetic stir bar using a stirring bar retriever. Rinse the stir bar over the beaker with a small amount of distilled water.
8. Place the neodymium magnet under the beaker to "pull" the black solid to the bottom of the beaker.
9. Decant the clear liquid from the beaker into a waste flask. (Continue holding the magnet under the beaker to avoid losing the solid when pouring off the liquid.)
10. Transfer the solid to a weighing dish by rinsing with a small amount of distilled water from a wash bottle. Rinse the beaker with 2–3 mL of water to get as much of the solid as possible into the weighing dish.
11. Decant (pour off) as much water as possible from the solid in the weighing dish. (Hold a magnet under the weighing dish to keep the solid in the weighing dish.)
12. Wash the solid *twice* more with distilled water: Add 1–2 mL of water, pour off the water by holding the magnet under the weighing dish, and repeat.
13. Using a glass (Pasteur) pipet, add 2–3 mL of tetramethylammonium hydroxide solution to the solid (magnetite) in the bottom of the weighing dish.
14. Using a *glass stirring rod*, stir the product and the tetramethylammonium hydroxide solution for at least one minute to get thorough mixing and to suspend the magnetite particles in the liquid.
15. Move the magnet around under the weighing dish to attract the "ferrofluid" or magnetic liquid to the center of the dish. Discard any extra liquid that is not attracted to the magnet. The ferrofluid should be neither too "thick" (viscous) nor too "thin" (watery).
16. With the weighing dish in one hand, hold the magnet in the other hand, *about 1 cm below the weighing dish* (do not touch the dish directly with the magnet). Slowly move the magnet around under the dish until small spikes are observed in the ferrofluid. (This step may take some practice, but the spikes get larger and more noticeable when the magnet is positioned just right with respect to the "magnetic liquid.")
17. *(Optional)* The ferrofluid may be stored in a sealed glass vial. For best results, transfer the solid directly from the beaker to a vial in step 10, before washing the solid and suspending the solid in the tetramethylammonium hydroxide solution.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The waste ammonia solution in step 9 may be neutralized with hydrochloric acid, if needed, before being discarded down the drain with plenty of excess water according to Flinn Suggested Disposal Method #10. The colloidal ferrofluid may be stored in an open container (such as the weighing dish in which it is prepared) in the hood until all of the liquid has evaporated and only a solid remains. The solid may then be packaged for landfill disposal according to Flinn Suggested Disposal Method #26a.

Tips

- This kit contains enough materials to perform the demonstration as written seven times: 350 mL of 1 *M* ammonia water, 8 grams of iron(II) chloride, 15 grams of iron(III) chloride, 100 mL of 2 *M* hydrochloric solution, 20 mL of 25% tetramethylammonium hydroxide solution, 7 disposable glass (Pasteur) pipets, 7 weighing dishes, and one neodymium magnet. *Note:* These amounts include "extra" iron(II) chloride and iron(III) chloride, as well as more hydrochloric acid, in case the Fe(II) and Fe(III) solutions will not be used up within the recommended storage time.

- It is difficult to transfer the ferrofluid after it has been prepared. If the ferrofluid will be stored, carry out the washing and rinsing steps directly in a vial, as described in the optional step 17.
- Solutions and colloids differ in the size of the particles that are dispersed in the liquid phase. The following table summarizes the properties of solutions, colloids, and suspensions. Notice that the particle size range for each type of mixture is just that, a range, and not an absolute or fixed value.

Property	Solution	Colloid	Suspension
Particle Size	0.1–1 nm (atoms, ions)	1–200 nm	>200 nm (aggregates of large molecules)
Settling Behavior	Stable, does not separate.	Stable, does not separate.	Particles separate on standing.
Filtration	Particles pass through filter.	Particles pass through filter.	Particles do not pass through filter.

- Visit the *Journal of Chemical Education* Web site at http://jchemed.chem.wise.edu/JCESoft/CCA/CCA2/MAIN/FEFLUID/CD2R1.HTM to view photos of a ferrofluid and its properties.

Discussion

Nanoscience or nanotechnology involves the preparation, characterization, and uses of nano-sized particles having dimensions in the 1–100 nm range (1 nm = 1×10^{-9} m). Nanoparticles have unique physical and chemical properties that are very different from the macroscopic properties of traditional or "bulk" solids. Many of these properties have taken on special importance in recent years as the applications of nanotechnology have been intensively studied. In particular, the electronic, magnetic, and optical properties of nanoparticles have proven to be very useful in the creation of new products using nanotechnology. Magnetic liquids, also known as ferrofluids, are stable colloids containing nanocrystalline magnetite particles.

Magnetite, Fe_3O_4, also known as ferrosoferric oxide, is a naturally occurring, strongly magnetic, mixed iron(II)/iron(III) oxide. (There are two Fe^{3+} ions for every Fe^{2+} ion in the crystal structure.) Magnetite is prepared in this demonstration by reacting $FeCl_3$ and $FeCl_2$ in a 2:1 mole ratio with dilute ammonia, NH_3. The basic ammonia solution provides hydroxide ions, OH^-, which combine with iron cations to produce the Fe_3O_4 oxide after loss of water molecules (Equation 1). The concentration of reactants is the main factor influencing the size of the magnetite particles produced in this reaction. Dilute solutions favor the formation of magnetite nanoparticles that are less than 10 nm in diameter.

$$2Fe^{3+}(aq) + Fe^{2+}(aq) + 8OH^-(aq) \rightarrow Fe_3O_4(s) + 4H_2O(l) \qquad \textit{Equation 1}$$

In order to produce a stable colloid, the Fe_3O_4 nanoparticles in the ferrofluid must be coated with a substance that will prevent them from "clumping together" and settling out of solution. This is accomplished by washing the initial brownish black precipitate with water and then adding a solution of tetramethylammonium hydroxide, which acts as a surfactant. Hydroxide anions bind to the surface of the oxide nanoparticles, coating the particles and giving them a net negative charge. Tetramethylammonium cations form a positively charged outer shell around the anions and stabilize the nanoparticles. The surface-coated, charged magnetite particles in the ferrofluid repel each other and are therefore prevented from forming clusters and precipitating out of solution.

Magnetite is an example of a *ferrimagnetic* or "superparamagnetic" substance—it is polarized by and strongly attracted to an external magnetic field. Fe(II) and Fe(III) ions are both paramagnetic due to the unpaired d electrons in their electron structures, but they have different numbers of unpaired electrons and thus different magnetic moments. In the crystal structure the magnetic domains formed by alignment of the unpaired electrons in Fe^{2+} and Fe^{3+} ions are antiparallel. Because the magnetic moments are not equal, however, Fe_3O_4 has a net magnetic moment or magnetization. In the absence of an external magnetic field, the ferrofluid flows and behaves like a "normal" albeit viscous liquid. When a magnet is brought near a dish or vial containing the ferrofluid, the "solid" nanoparticles are attracted to and will "follow" the magnet around the dish or vial. The ferrofluid forms interesting three-dimensional shapes or structures as the magnetic moments of the nanoparticles align themselves with the external magnetic field. Noticeable peaks or spikes in the ferrofluid correspond to the magnetic field lines.

Ferrofluids are more than just an intellectual curiosity. They have innovative commercial or practical applications, including as dampeners or heat sinks in loudspeakers, as seals in high speed computer disk drives, as magnetic inks for laser printers, and even, apparently, as radar-absorbing paints that allow military aircraft to escape radar detection.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation

Content Standards: Grades 5–8
Content Standard B: Physical Science; properties and changes of properties in matter
Content Standard F: Science in Personal and Social Perspectives; science and technology in society

Content Standards: Grades 9–12
Content Standard B: Physical Science; structure of atoms; structure and properties of matter; interactions of energy and matter
Content Standard F: Science in Personal and Social Perspectives; science and technology in local, national, and global challenges

References

Berger, P. et al. "Preparation and Properties of an Aqueous Ferrofluid," J. Chem. Educ. 1999, 76, 943.

Chun, D. et al. "Synthesis of an Aqueous Ferrofluid," California NanoSystems Institute and Materials Creation Training Program, http://voh.chem.ucla.edu/outreach.php3 (accessed December 2006).

Ferrofluid Nanotechnology Demonstration is available as a Demonstration Kit from Flinn Scientific, Inc.

Catalog No.	Description
AP7118	Ferrofluid Nanotechnology Demonstration Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Disappearing Rainbow

Introduction

A rainbow of solution colors appears and disappears as acids and bases are added to a series of indicators.

Concepts

- Acids and bases
- pH indicators

Materials

Hydrochloric acid solution, HCl, 0.01 M, 1 L
Sodium hydroxide solution, NaOH, 0.01 M, 800 mL
Sodium hydroxide solution, NaOH, 3 M, 50 mL
Indicator solutions, 30 mL each:

Violet—0.45 g of phenolphthalein and 0.2 g thymolphthalein in 30 mL of 95% ethyl alcohol.

Blue—0.2 g of thymolphthalein in 30 mL of 95% ethyl alcohol.

Green—0.2 g of thymolphthalein and 2 g of p-nitrophenol in 30 mL of 95% ethyl alcohol. Add 5 drops of 1 M HCl to acidify.

Yellow—1 g of *p*-nitrophenol in 30 mL of 95% ethyl alcohol. Add 5 drops of 1 M HCl to acidify.

Orange—2 g of *p*-nitrophenol and 0.15 g phenolphthalein in 30 mL of 95% ethyl alcohol. Add 5 drops of 1 M HCl to acidify.

Red—1.5 g of *p*-nitrophenol and 0.75 g phenolphthalein in 30 mL of 95% ethyl alcohol. Add 5 drops of 1 M HCl to acidify.

Beakers, 400-mL, 6
Beakers, 1000-mL, 2
Dropping bottles, 6

Safety Precautions

p-Nitrophenol is toxic by ingestion. Dilute hydrochloric acid solution is corrosive to eyes, skin, and other tissue. Dilute sodium hydroxide solution is corrosive; skin burns are possible. Indicator solutions contain ethyl alcohol, a flammable liquid and a fire risk; keep away from flames and heat. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling and disposal information.

Preparation

1. Set up six 400-mL beakers on an overhead projector or in front of the class.
2. Add 3 drops of "violet" indicator solution to the first beaker. Add 3 drops of "blue" indicator solution to the second beaker. Continue adding three drops of the appropriate indicator solution to each beaker.

Procedure

1. Fill each 400-mL beaker with approximately 50 mL of the 0.01 M hydrochloric acid solution. All six resulting solutions should be clear and colorless.
2. Add approximately 75 mL of 0.01 M sodium hydroxide solution to each beaker. Each solution will change from colorless to a bright, vivid color of the rainbow!
3. Add approximately 100 mL of the 0.01 M hydrochloric acid solution to each beaker. The solutions will once again be colorless.
4. Add 3 M sodium hydroxide solution dropwise to each beaker until the color reappears.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The final solution may be flushed down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, chemical reactions

Tips

- The indicators are dissolved in 95% ethyl alcohol. The alcohol will readily evaporate, leaving the indicator powder in the beaker—unseen to the observers of the demonstration. Save the indicator solutions for future demonstrations.
- At the end of the demonstration (step 4), pour all of the colored solutions together into a large glass pitcher or beaker containing a few drops of concentrated acid. The combined solution will be clear and colorless.
- The specific amounts of acid and base solutions are not important. Each addition of acid or base solution must neutralize the solution in the beaker and drive the pH in the opposite direction. This process may be repeated many times using increasingly more concentrated acid and base solutions.
- For brighter yellows, *m*-nitrophenol can be used in place of *p*-nitrophenol.

Discussion

The three indicators used in this demonstration—phenolphthalein, thymolphthalein and *p*-nitrophenol—are colorless in acidic solution. In basic solution phenolphthalein is red, thymolphthalein is blue, and *p*-nitrophenol is yellow. Any color in the spectrum may be prepared by combining these primary colors in different amounts. The indicator solutions added to each beaker readily evaporate, leaving the exact, minute proportions of the appropriate dry indicators on the bottom of each beaker. Students will not see this step of the procedure. They will only see the pouring of the acid and base solutions and the color changes. This demonstration is a wonderful "magic show" demonstration, especially when performed to music, such as "The Rainbow Connection."

Reference

Shakhashiri, B. Z. *Chemical Demonstrations*, Volume 3; University of Wisconsin: Madison (1989).

Materials for *Disappearing Rainbow* are available from Flinn Scientific, Inc.

This activity is also available as a Flinn Chemical Demonstration Kit that contains all the materials to perform this demonstration seven times.

Catalog No.	Description
AP8979	Disappearing Rainbow Demonstration Kit
P0017	Phenolphthalein, 25 g
T0073	Thymolphthalein, 5 g
N0073	p-Nitrophenol, 25 g
N0088	*m*-Nitrophenol, 25 g

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Old Foamey

A Classic Demonstration of a Catalyst

Introduction

Bubbles and heat, foam and steam, "Old Foamey" has it all! Mix hydrogen peroxide with dishwashing liquid, add sodium iodide catalyst, then stand back and marvel as the decomposition reaction erupts in a cascade of steaming foam.

Concepts

- Catalyst
- Decomposition reaction

Materials

Hydrogen peroxide, H_2O_2, 30%, 20 mL

Sodium iodide solution, NaI, 2 M, 5 mL

Dishwashing liquid, 10 mL

Food coloring (optional)

Beaker, 100-mL

Graduated cylinder, Pyrex®, 100-mL

Graduated cylinder, 10-mL

Plastic demonstration tray

Wood splint (optional)

Safety Precautions

Hydrogen peroxide, 30%, will act as an oxidizing agent with practically any substance. This substance is severely corrosive to the skin, eyes and respiratory tract; a very strong oxidant; and a dangerous fire and explosion risk. Do not heat this substance. Sodium iodide is slightly toxic by ingestion. Although the dishwashing liquid is considered non-hazardous, do not ingest the material. Do not stand over the reaction; steam and oxygen are produced quickly. Wear appropriate chemical splash goggles, chemical-resistant gloves and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

Prepare the 2 M sodium iodide solution by dissolving 30 grams of sodium iodide in 25 mL of distilled or deionized water in a 100-mL beaker. Add water to give a total volume of 100 mL and mix well.

Procedure

1. Place a 100-mL graduated cylinder on a plastic tray that is several inches deep.
2. Measure out 20 mL of the 30% hydrogen peroxide into the 100-mL graduated cylinder. *Caution:* Wear chemical resistant gloves and goggles when handling 30% hydrogen peroxide. Contact with skin may cause burns.
3. Measure out 10 mL of dishwashing liquid into the 10-mL graduated cylinder and add it to the cylinder containing the hydrogen peroxide. Add a few drops of food coloring, if desired. Have your students observe that little or no reaction occurs.
4. Measure out 5 mL of sodium iodide solution using the 10-mL graduated cylinder. Quickly but carefully add the sodium iodide solution to the 100-mL graduated cylinder.
5. Step back and observe the reaction.
6. *(Optional)* Light a wood splint and blow out the flame to produce a glowing splint. Insert the glowing splint into the foam—it will reignite.

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Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The leftover foam and solution in the cylinder may be rinsed down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- The decomposition reaction produces lots of foam—so much that this demonstration is often called "Elephant's Toothpaste." Carry out the demonstration in a large plastic demonstration tray or, if none is available, in the laboratory sink. Cleanup, at least, is easy because of the generous amount of dishwashing liquid used.
- The decomposition reaction is highly exothermic. Carry out the reaction in heat-resistant, borosilicate (e.g., Pyrex®) glassware and check all glassware for chips or cracks before use. Allow the glassware to cool before disposing of the reac tion mixture.
- This demonstration can be scaled up for larger audiences. A 500-mL or 1-L Pyrex graduated cylinder works well with about 100 mL of hydrogen peroxide. The amount of dishwashing liquid and catalyst solution do not have to be increased proportionally.
- A slight brown tinge is observed at the edge of the foam at the beginning of the reaction. The yellow-brown color is due to the presence of free iodine produced by the oxidation of the catalyst, sodium iodide. The yellow color disappears when the catalyst is regenerated.
- Other catalysts that will catalyze this reaction include manganese(IV) oxide, MnO_2, and manganese metal, Mn.

Discussion

The decomposition reaction of hydrogen peroxide is highly exothermic and produces lots of heat and steam. The action of a catalyst is demonstrated through the use of sodium iodide, which speeds up the decomposition reaction. The products of the reaction are water vapor and oxygen gas. The presence of oxygen gas in the foam is demonstrated by the glowing splint test. When a glowing splint is inserted into the foam, it spontaneously reignites due to the increased concentration of oxygen.

$$2H_2O_2(aq) \xrightarrow{I^-(aq)} 2H_2O(g) + O_2(g) + \text{Energy}$$

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, interactions of energy and matter

Acknowledgment

Special thanks to Jim and Julie Ealy of The Peddie School in Hightstown, NJ.

Reference

Stone, C. H. J. Chem. Ed. **1944,** *21*, 300.

Materials for *Old Foamey* are available from Flinn Scientific, Inc.

Catalog No.	Description
S0083	Sodium Iodide, 25 g
H0037	Hydrogen Peroxide, 30%, 100 mL
C0241	Dishwashing Liquid
AP2085	Old Foamey—Chemical Demonstration Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.