Stop-’N-Go Light

Oxidation–Reduction Demonstration Kit

Introduction

The color of this chemical “traffic light” reaction changes from yellow to red to green and then back to yellow again.

Concepts

- Oxidation–reduction
- Redox indicator

Materials

Dextrose solution, $C_6H_{12}O_6$, 0.13 M, 700 mL*
Indigo carmine solution, 1%, 70 mL*
Sodium hydroxide solution, NaOH, 1.0 M, 700 mL*
Erlenmeyer flask, 500-mL
Graduated cylinder, 10-mL
Graduated cylinder, 100-mL
Stopper, to fit flask

**Materials included in kit.*

Safety Precautions

Indigo carmine is moderately toxic by ingestion and is a body tissue irritant. Sodium hydroxide solution is a corrosive liquid and skin burns are possible. It is very dangerous to eyes. 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.

Procedure

1. For best results, prepare the indigo carmine indicator solution fresh within one week of use.
2. Place 100 mL of dextrose solution and 100 mL of sodium hydroxide solution into a 500-mL Erlenmeyer flask.
3. Add 10 mL of the indigo carmine solution to the flask. Firmly insert the stopper.
4. Allow the solution to sit undisturbed until it is fully reduced (yellow). It can then be shaken to obtain all of the colors (see *Tips*).

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 Stop-’N-Go Light solution may be neutralized according to Flinn Suggested Disposal Method #10.

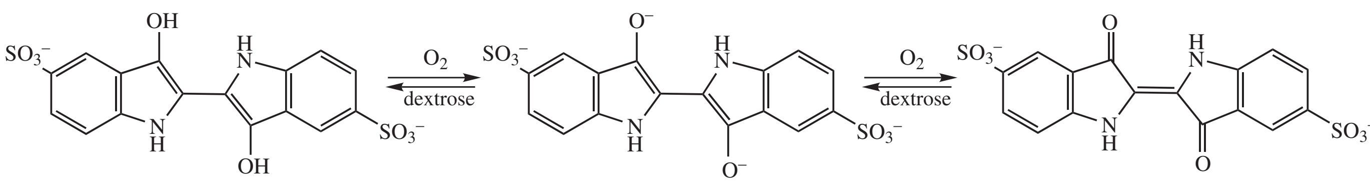
Tips

- The solution will be green initially. Allow the solution to sit undisturbed until it becomes a bright amber (yellow). This may take 20–30 minutes. To decrease this initial waiting period, gently warm the solution to about 35 °C.

- Show the amber solution to the class and then place the flask behind your back and shake it gently. Show the students that the solution is now red. When it changes back to amber, again place the flask behind your back, shake it vigorously, and show the students the green color. A little practice will quickly determine how many shakes are needed for the red color and how many additional shakes for the green color.
- The "traffic light" solution will repeat this yellow to red to green cycle for 20 minutes or so depending on how often it is shaken and how much oxygen is reintroduced by opening the bottle.

Discussion

Indigo carmine is an organic redox and acid–base indicator. It exists in different oxidations states having different colors. The reduced form of indigo carmine is yellow, while the fully oxidized form is blue (green in the pH range 11–13 in the "traffic light" solution). There is also an intermediate red form whose structure has not been fully determined. In this demonstration, the blue (oxidized) form of indigo carmine is first added to a solution of dextrose and sodium hydroxide. It immediately turns green due to the pH change. Dextrose is a reducing sugar—it reduces the indigo carmine indicator to the yellow (reduced) form in the presence of base. When the yellow solution containing the reduced form of indigo carmine is then shaken, oxygen from the air above the liquid dissolves in the solution and re-oxidizes the indigo carmine. The overall oxidation occurs in two steps, first to the intermediate red form, and then to the fully oxidized (green) form. This two-step oxidation sequence can be controlled by the rate of shaking, which influences the amount of oxygen that dissolves in the solution. When the solution is no longer being shaken, dextrose molecules again reduce the indigo carmine back to the yellow color. This sequence of oxidation–reduction color changes can be repeated many times. After about 10 or 15 color cycles, when all of the oxygen in the flask has been used up, the redox reaction will cease. (Removing the stopper will introduce more air so the process can be repeated.) See below for the structures of the oxidized and reduced forms of indigo carmine, and the proposed structure of the red intermediate (Shakhashiri).



Reduced Form (Yellow) *Intermediate Form (Red)* *Oxidized Form (Green)*

Connecting to the National Standards

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

Unifying Concepts and Processes: Grades K–12
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, chemical reactions

Answers to Worksheet Questions

1. What is an oxidation–reduction reaction?

   An oxidation/reduction (or "redox") reaction occurs when one or more electrons are transferred between molecules. Oxidation refers to a loss of electrons (and rise in oxidation state), and reduction refers to a gain of electrons (and subsequent decrease in oxidation state).

2. Once the indigo carmine is added to the flask containing dextrose solution and sodium hydroxide solution, what physical change is observed to indicate the indigo carmine as been fully reduced?

   The color is changed from green to bright amber (yellow).

3. Once the solution has been reduced what do you observe as
   a. The solution is shaken gently?
   Upon gentle shaking the solution turns red.
   b. The solution is shaken more vigorously?
   Upon vigorous shaking the solution turns green.
4. What compound reduces and what compound oxidizes the indigo carmine and what color will the solution turn in each scenario?

   Indigo carmine is reduced by alkaline sugar and turns amber. Indigo carmine is oxidized by the oxygen in the bottle and turns green.

Acknowledgment

Special thanks to Jim and Julie Ealy (retired), The Peddie School, Hightstown, NJ, for providing the instructions for this activity.

References

Ferguson, H. W.; Schmuckler, J., et al. *Laboratory Investigations in Chemistry,* Silver Burdett: Parsippany, NJ, 1970.

Shakhashiri, B. Z. *Chemical Demonstrations: A Handbook for Teachers in Chemistry;* Univ. of WI, Madison; Vol. 2, pp 145–146.

Soifer, M. and Garber, M., (Students of Joseph Schmuckler, Haverford High School, Haverford, MA), 1969.

The *Stop-'N-Go Light—Chemical Demonstration Kit* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP2083	Stop-'N-Go Light—Chemical Demonstration Kit

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

Name: ____________________

Stop-’N-Go Light Demonstration Worksheet

Discussion Questions

1. What is an oxidation–reduction reaction?

2. Once the indigo carmine is added to the flask containing dextrose solution and sodium hydroxide solution, what physical change is observed to indicate the indigo carmine as been fully reduced?

3. Once the solution has been reduced what do you observe as:

   a. The solution is shaken gently?

   b. The solution is shaken more vigorously?

4. What compound reduces and what compound oxidizes the indigo carmine and what color will the solution turn in each scenario?

AP2083PUB

Water to Grape Juice to Milk

Chemical Demonstration Kit

Introduction

Magically turn water to grape juice to lemonade to 7-Up® to milk to finally—after consuming all that, you'll surely need—Pepto-Bismol®!

Concepts

- Acids and bases
- Solubility and precipitates

Materials (for each demonstration)

Barium nitrate solution, $Ba(NO_3)_2$, saturated, 8–10 mL*

Phenolphthalein solution, 1%, 3–4 drops*

Sodium bicarbonate, $NaHCO_3$, 1 g*

Sodium hydroxide solution, NaOH, 0.1 M, 10 drops*

Sodium hydroxide solution, NaOH, 6 M, 5–6 mL*

Sulfuric acid solution, H_2SO_4, 9 M, 1.5 mL*

Water, distilled or deionized, 200 mL

Beral-type pipets, 5*

Glasses or beakers, 400-mL, 6

**Materials included in kit*

Safety Precautions

Sulfuric acid solution is severely corrosive to eyes, skin and other tissue. Sodium hydroxide solution is corrosive and a body tissue irritant. Barium nitrate solution is a strong oxidizer and moderately toxic by ingestion. Phenolphthalein solution is an alcohol-based solution; it is flammable and moderately toxic by ingestion. Avoid body tissue contact with all solutions. 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.

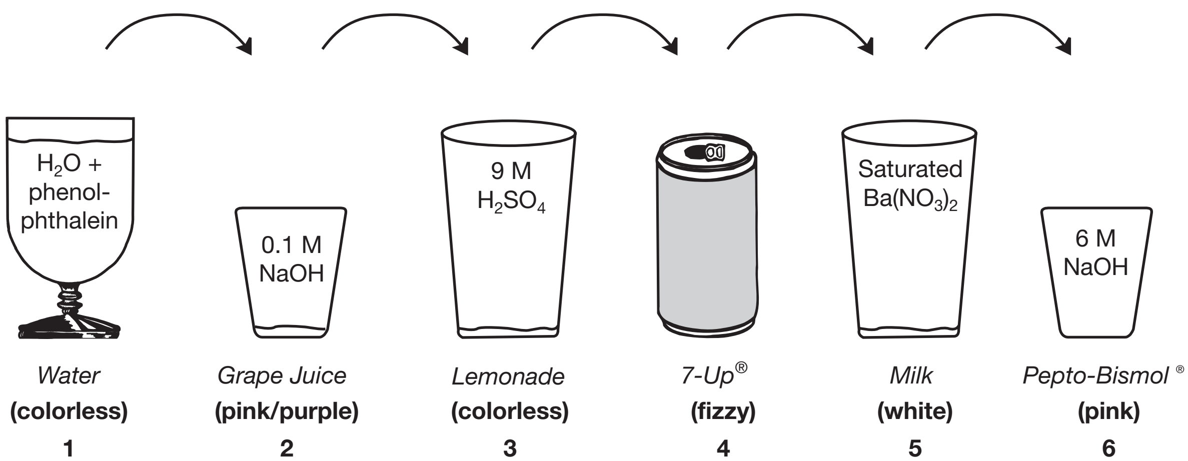
Preparation

Prior to audience arrival, treat and label six glasses or beakers as follows

Glass 1—Water	200 mL of distilled or deionized water
	3–4 drops of 1% phenolphthalein solution
Glass 2—Grape Juice	10 drops of 0.1 M NaOH solution
Glass 3—Lemonade	1.5 mL of 9 M H_2SO_4 solution
Glass 4—7-Up®	1 g (½ scoop) of $NaHCO_3$ and 1 pipet (2–3 mL) of water; swirl gently
Glass 5—Milk	3 pipets (7–9 mL) of saturated $Ba(NO_3)_2$ solution
Glass 6—Pepto-Bismol®	2 pipets (5–6 mL) of 6 M NaOH solution (must be sufficient to overcome the acid)

Procedure

1. Begin with a story (if you like) as glass 1 ("*water*") is held up. Phenolphthalein is colorless in a neutral environment.
2. Pour the contents of glass 1 into glass 2. A color forms. Phenolphthalein is pink in a basic environment.
3. Pour the contents of glass 2 into glass 3. The pink color disappears and the solution is once again colorless. Phenolphthalein is colorless in an acidic environment.
4. Pour the contents of glass 3 into glass 4. The acidic solution reacts with the sodium bicarbonate to create bubbles of carbon dioxide gas.
5. Wait for the fizzing to stop and then pour the contents of glass 4 into glass 5. The clear solution turns a cloudy white ("*milk*"). The white precipitate is a result of the barium ions interacting with the sulfate ions to form barium sulfate.
6. Pour the contents of glass 5 into glass 6. The cloudy white mixture turns to a cloudy light pink mixture ("*Pepto-Bismol*"). The pink color forms because phenolphthalein is pink in a basic environment.



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 can be flushed down the drain with plenty of water according to Flinn Suggested Disposal Method #26b. Remaining amounts of the reagents included in the kit can be saved for later use or disposed of according to the appropriate Flinn Suggested Disposal Methods.

Tips

- There are enough chemicals to perform the demonstration 14 times. This allows the demonstration to be shown to each class twice—once for entertainment and a second time to discuss the chemistry and reactions occurring. Plus there is plenty for practice and preparation purposes.
- Be creative and dramatic with this demonstration for more effect. Use a variety of glasses, such as a water goblet for the water and a juice glass for the grape juice. A few drops of yellow food coloring and perhaps a lemon slice in glass 3 will help with the lemonade.
- The volume of a Beral-type pipet is approximately 2.5–3 mL. Volumes given are approximate and the amounts indicated are for a final solution volume of 200 mL. The amounts can be scaled up or down if a different amount of solution is desired, depending on the size of glasses used. Check the volumes of the chosen glasses and practice before performing this demonstration to an audience.
- The small volumes of liquid in the glasses or beakers will almost certainly not be spotted by the audience.
- This makes an impressive introductory demonstration for your chemistry class. One teacher's idea—Present the demo to the class as an entertaining activity, going through the motions while telling a story about a chemistry department dinner party, with no explanations as to what types of reactions are taking place. Repeat the demonstration later in the year during

the acid/base unit. This time, discuss the reactions occurring inside the glasses. To begin, only share information with the students about the contents of the first glass. Have them "guess" the contents of each consecutive glass that would be consistant with observations. Then reveal what was in each glass and have students write the reactions.

- You may have seen this demonstration done as water to wine to a martini to champagne to milk to Pepto-Bismol®.

Discussion

Phenolphthalein indicator solution is an acid–base indicator that remains colorless in an acid solution but turns from colorless to pink at about pH of 9, having a distinct pink color in a basic solution.

Following is a summary of what is occurring in each glass

Glass 1: Phenolphthalein + Water $\rightarrow$ Colorless solution

Glass 2: Phenolphthalein + Base $\rightarrow$ Pink solution

Glass 3: Phenolphthalein + Acid $\rightarrow$ Colorless solution

Glass 4: $HCO_3^-(aq) \rightarrow CO_3^{2-}(aq) + H^+(aq) \rightarrow CO_2(g) + H_2O(l)$ *Fizzing*

Glass 5: $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ *White precipitate*

Glass 6: Phenolphthalein + Base $\rightarrow$ Pink and cloudy

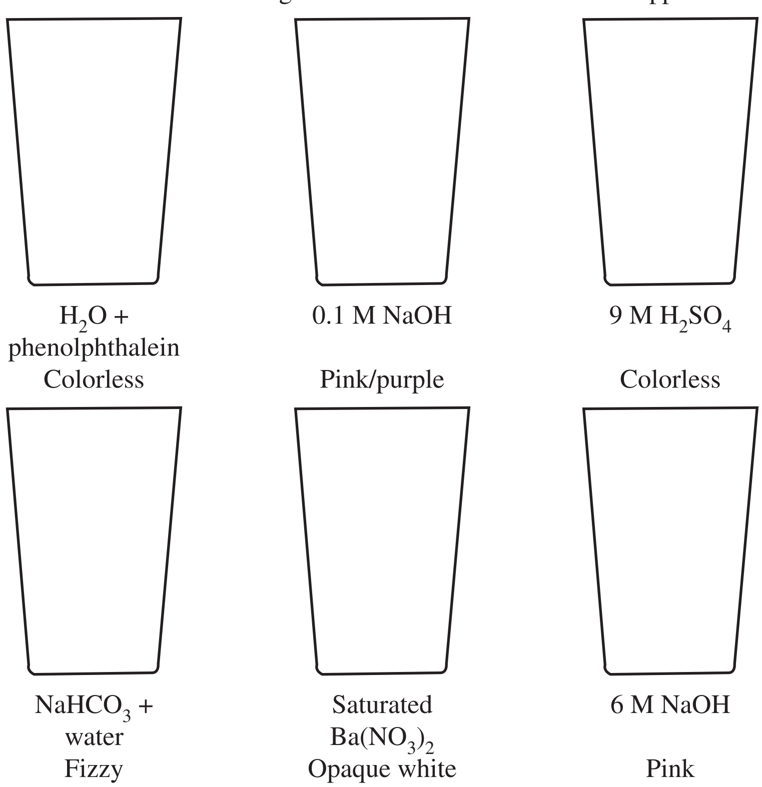
Connecting to the National Standards

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

Unifying Concepts and Processes: Grades K–12
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, chemical reactions

Answers to Worksheet Discussion Questions

1. Draw the setup for this demonstration. Label each glass with its contents and note the appearance the solution had in each glass.



2. Explain the color change, and any other observations, for each glass.

   Glass #1 – *Water is neutral. Phenolphthalein, an acid–base indicator, is colorless in a neutral environment.*

   Glass #2 – *Sodium hydroxide is a base. Phenolphthalein is pink in a basic solution.*

   Glass #3 – *Sulfuric acid is an acid. Phenolphthalein is colorless in an acidic solution.*

   Glass #4 – *The acidic solution reacts with the sodium bicarbonate to create bubbles of carbon dioxide gas.*

   Glass #5 – *Barium ions react with sulfate ions to form barium sulfate, which is a white precipitate.*

   Glass #6 – *Sodium hydroxide is a base. Phenolpthalein is pink in a basic solution.*

3. Write a balanced chemical equation for the reactions that occurred in Glass #4 (“7-Up”) and Glass #5 (“milk”).

   $HCO_3^-(aq) \rightarrow CO_3^{2-}(aq) + H^+(aq) \rightarrow CO_2(g) + H_2O(l)$

   $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

The *Water to Grape Juice to Milk—Chemical Demonstration Kit* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP4867	Water to Grape Juice to Milk—Chemical Demonstration Kit

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

Name: ______________________________

Water to Grape Juice to Milk Worksheet

Discussion Questions

1. Draw the setup for this demonstration. Label each glass with its contents and note the appearance the solution had in each glass.

2. Explain the color change, and any other observations, for each glass.

   Glass #1—

   Glass #2—

   Glass #3—

   Glass #4—

   Glass #5—

   Glass #6—

3. Write a balanced chemical equation for the reactions that occurred in Glass #4 ("7-Up") and Glass #5 ("milk").

Hydrolysis of Salts — Acidic, Basic, or Neutral?

A Colorful Overhead Demonstration

Introduction

Show the effects of hydrolysis of salts on the acid–base properties of a solution with this colorful demonstration that can be done on an overhead projector.

Concepts

- Acids and bases
- pH
- Salt hydrolysis

Background

Acidic and basic properties of aqueous solutions depend on the concentrations of hydrogen ions [H^+] and hydroxide ions [OH^-]. Water (the solvent in an aqueous solution) dissociates to a small extent into hydrogen ions (H^+) and hydroxide ions (OH^-) according to Equation 1.

$$H_2O \rightleftharpoons H^+(aq) + OH^-(aq) \qquad \textit{Equation 1}$$

When the concentration of H^+ is equal to the concentration of OH^-, the solution is neutral (pH = 7). When H^+ ions exceed OH^- ions, the solution is acidic (pH < 7). When OH^- ions exceed H^+ ions, the solution is basic (pH > 7). For example, an aqueous solution of HCl or H_2SO_4 has a greater concentration of H^+ ions and is therefore acidic. An aqueous solution of NaOH or NH_4OH has a greater concentration of OH^- ions and is therefore basic.

Salts, on the other hand, may undergo hydrolysis in water to form acidic, basic, or neutral solutions. *Hydrolysis* of a salt is the reaction of the salt with water or its ions. A *salt* is an ionic compound containing a cation other than H^+ and an anion other than OH^- (or O^{2-}). The broad range of cations and anions that combine to form salts (such as $NaNO_2$, NH_4I, $CuSO_4$, or NaBr) makes it more difficult to predict whether the resulting salt solution will be acidic, basic, or neutral.

In a dilute salt solution, a soluble salt dissociates completely into its ions. Thus, a water solution labeled "NaBr" actually contains Na^+ ions and Br^- ions (Equation 2).

$$NaBr(s) \rightarrow Na^+(aq) + Br^-(aq) \qquad \textit{Equation 2}$$

The acid–base properties of a salt such as NaBr are determined by the behavior of its ions. To decide whether a water solution of NaBr is acidic, basic, or neutral, the effect of the Na^+ and Br^- ions on the pH of water must be considered. Some ions have no effect on the pH of water, some ions are acidic because they produce H^+ ions in water, and others are basic because they produce OH^- ions in water. In this demonstration, five salts will be tested. The salts will be dissolved in water, the pH of the resulting solutions will be measured, and chemical equations will be written.

Materials (for each demonstration)

Aluminum chloride, $AlCl_3 \cdot 6H_2O$, 1 g*
Ammonium chloride, NH_4Cl, 1 g*
Sodium bicarbonate, $NaHCO_3$, 1 g*
Sodium chloride, NaCl, 1 g*
Sodium phosphate, $Na_3PO_4 \cdot 12H_2O$, 1 g*
Universal indicator solution, 3–5 mL*
Water, boiled, distilled or deionized
Beaker, 250-mL
Graduated cylinder, 25-mL
Hot plate or Bunsen burner
Marking pen
Overhead projector
Overhead transparency sheet
Petri dishes (tops or bottoms), 5*
Spatulas, 5
Stirrers, 5*
Universal indicator color card*

**Materials included in kit.*

Safety Precautions

Aluminum chloride, ammonium chloride, and sodium phosphate are slightly toxic by ingestion and are body tissue irritants. Do not substitute anhydrous aluminum chloride due to its violent reaction with water. Universal indicator solution is an alcohol-based flammable liquid. 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. Place approximately 150 mL of distilled or deionized water in a beaker.
2. Using a hot plate or Bunsen burner, boil the water for about 10–15 minutes to remove any dissolved carbon dioxide. (*Note:* The pH of the water should be near 7.) Cover the beaker and allow the water to cool.
3. Rinse five Petri dishes with distilled water to ensure that they are not contaminated.

Procedure

1. Place five Petri dishes on an overhead transparency sheet on the overhead projector (or on the demonstration table). Label the transparency with the formulas of the five salts to be used.
2. Add 15–20 mL of boiled distilled or deionized water to each Petri dish (enough to fill the dishes half way).
3. Add 15 drops of universal indicator solution to each Petri dish to achieve a neutral green color. (*Note:* If the solution in any of the dishes is not green after adding the indicator, rinse out the dish with DI water and start again as there must have been some contamination.)
4. Using a different spatula for each solid, add about 1 gram of salt to each Petri dish in the following order:

Petri Dish	Salt	Solution Color	pH
1	Aluminum chloride	Red	3
2	Ammonium chloride	Orange-yellow	5
3	Sodium chloride	Green	7
4	Sodium bicarbonate	Blue	9
5	Sodium phosphate	Purple	12

5. Stir to dissolve each solid using a separate wood stirrer for each.
6. Note the pH of each solution by comparing the solution color to the universal indicator color card.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Each of the salts may be disposed of down the drain or in the solid waste disposal according to Flinn Suggested Disposal Methods #26a or #26b.

Tips

- This kit contains enough chemicals to perform the demonstration at least seven times. The quantities provided in the kit are as follows—10 grams (7 g needed) of each of the five salts (aluminum chloride, ammonium chloride, sodium bicarbonate, sodium chloride, and sodium phosphate), 35 mL of universal indicator solution, 5 reusable Petri dishes, 35 wood stirrers, and a universal indicator pH card.
- After reading the discussion, decide if you wish to first perform the demonstration and then discuss the observations. Or you may wish to first have students look at and evaluate the cations and anions of the salts and make predictions as to the acidic or basic nature of the salt solutions. Then perform the demonstration to test their predictions.
- An overhead transparency of the universal indicator color card, the *Universal Indicator Overhead Color Chart* (Flinn Catalog No. AP5367), is available for use on the overhead projector.

Discussion

Results from this demonstration show that aluminum chloride and ammonium chloride form acidic solutions in water (pH < 7); sodium chloride forms a neutral solution (pH = 7); sodium bicarbonate and sodium phosphate form basic solutions (pH > 7). *Hydrolysis* refers to the reaction of a substance with water or its ions. The chemical equations for the reactions are shown below. The equation for the dissociation of the salts are shown first followed by the net equations that produce either H^+ (if acidic), OH^- (if basic), or neither (if neutral). Note: Spectator ions are omitted from the net equations.

Aluminum chloride

$AlCl_3{\cdot}6H_2O(s) \rightarrow Al(H_2O)_6^{3+}(aq) + 3Cl^-(aq)$

$Al(H_2O)_6^{3+}(aq) \rightarrow \mathbf{H^+}(aq) + Al(H_2O)_5(OH)^{2+}(aq)$ *Acidic*

Ammonium chloride

$NH_4Cl(s) \rightarrow NH_4^+(aq) + Cl^-(aq)$

$NH_4^+(aq) \rightarrow \mathbf{H^+}(aq) + NH_3(g)$ *Acidic*

Sodium chloride

$NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$

$Na^+(aq) + Cl^-(aq) \rightarrow$ No further reaction *Neutral*

Sodium bicarbonate

$NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$

$HCO_3^-(aq) + H_2O(l) \rightarrow H_2CO_3(aq) + \mathbf{OH^-}(aq)$ *Basic*

Sodium phosphate

$Na_3PO_4(s) \rightarrow 3Na^+(aq) + PO_4^{3-}(aq)$

$PO_4^{3-}(aq) + H_2O(l) \rightarrow HPO_4^{2-}(aq) + \mathbf{OH^-}(aq)$ *Basic*

While acidic or basic properties of salt solutions can be measured in the laboratory, the acidic or basic nature of a salt can also be predicted by considering the properties of its ions. In general, as shown in Table 1, neutral anions are those derived from strong acids and neutral cations are those derived from strong bases. Acidic cations include all cations except those of the alkali metals and the heavier alkaline earths. Acidic anions include the HSO_4^- and $H_2PO_4^-$ anions. Basic anions include any anion derived from a weak acid; there are no common basic cations.

Table 1. Acid–Base Properties of Common Ions in Aqueous Solution

	Neutral		Basic		Acidic
Anion	Cl^- Br^- I^-	NO_3^- ClO_4^- SO_4^{2-}	$C_2H_3O_2^-$ F^- CO_3^{2-} S^{2-} PO_4^{3-}	CN^- NO_2^- HCO_3^- HS^- HPO_4^{2-}	HSO_4^- $H_2PO_4^-$
Cation	Li^+ Na^+ K^+	Ca^{2+} Ba^{2+}	none		Mg^{2+} Al^{3+} NH_4^+ transition metal ions

The information provided in Table 1 can be used to predict the acidic or basic nature of the salt; this can then be confirmed by experiment. The five salts tested in this demonstration are listed below. The acidic or basic nature of the cation and of the anion are given, together with a prediction of whether the salt solution will be acidic, basic, or neutral.

Salt	**Cation**	**Anion**	**Solution of Salt**
$AlCl_3{\cdot}6H_2O$	Al^{3+} (acidic)	Cl^- (neutral)	Acidic
NH_4Cl	NH_4^+ (acidic)	Cl^- (neutral)	Acidic
NaCl	Na^+ (neutral)	Cl^- (neutral)	Neutral
$NaHCO_3$	Na^+ (neutral)	HCO_3^- (basic)	Basic
$Na_3PO_4{\cdot}12H_2O$	Na^+ (neutral)	PO_4^{3-} (basic)	Basic

Connecting to the National Standards

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

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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, chemical reactions.

Answers to Worksheet Results Table

Petri Dish	Salt	Solution Color	pH	Acid, Base, or Neutral
1	Aluminum chloride	*Red*	*3*	*Acid*
2	Ammonium chloride	*Orange-yellow*	*5*	*Acid*
3	Sodium chloride	*Green*	*7*	*Neutral*
4	Sodium bicarbonate	*Blue*	*9*	*Base*
5	Sodium phosphate	*Purple*	*12*	*Base*

Answers to Discussion Questions

1. Explain what happened to the salts in the water and what caused the acid-base properties of the solutions.

   The salts underwent hydrolysis, which is the reaction of a salt with water or its ions. The ions determine the acid–base properties of the resulting solutions. Some ions have no effect on the pH of the water, while some produce H^+ ions, and others produce OH^- ions.

2. Salt hydrolysis can be described in two chemical equations, the first showing the dissociation of the salt, and the second net equation showing the production of H^+ or OH^- ions. Write the two equations for each salt in this demonstration. If neither H^+ nor OH^- ions are produced, write "no reaction" for the second equation.

   a. $AlCl_3{\cdot}6H_2O(s) \rightarrow Al(H_2O)_6^{3+}(aq) + 3Cl^-(aq)$
   $Al(H_2O)_6^{3+} \rightarrow H^+(aq) + Al(H_2O)_5(OH)^{2+}(aq)$
   Note to teachers: *You may have to tell students that the aluminum forms a complex ion with water.*

   b. $NH_4Cl(s) \rightarrow NH_4^+(aq) + Cl^-(aq)$
   $NH_4^+(aq) + H_2O(l) \rightarrow H^+(aq) + NH_3(g)$

   c. $NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$
   No reaction

   d. $NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$
   $HCO_3^-(aq) + H_2O(l) \rightarrow H_2CO_3(aq) + OH^-(aq)$

   e. $Na_3PO_4(s) \rightarrow 3Na^+(aq) + PO_4^{3-}(aq)$
   $PO_4^{3-}(aq) + H_2O(l) \rightarrow HPO_4^{2-}(aq) + OH^-(aq)$

Acknowledgment

Flinn Scientific would like to thank John Wass, Western Branch H.S., Chesapeake, VA for bringing this demonstration to our attention to share with other teachers.

Materials for *Hydrolysis of Salts—Acidic, Basic or Neutral? A Colorful Overhead Demonstration* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP6187	Hydrolysis of Salts —Acidic, Basic, or Neutral? A Colorful Overhead Demonstration
AP5367	Universal Indicator Overhead Color Chart

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

Name: ______________________________

Hydrolysis of Salts Worksheet

Results Table

Petri Dish	Salt	Solution Color	pH	Acid, Base, or Neutral
1	Aluminum chloride			
2	Ammonium chloride			
3	Sodium chloride			
4	Sodium bicarbonate			
5	Sodium phosphate			

Discussion Questions

1. Explain what happened to the salts in the water and what caused the acid–base properties of the solutions.

2. Salt hydrolysis can be described in two chemical equations, the first showing the dissociation of the salt, and the second net equation showing the production of H^+ or OH^- ions. Write the two equations for each salt in this demonstration. If neither H^+ nor OH^- ions are produced, write "no reaction" for the second equation.

   a. $AlCl_3{\cdot}6H_2O(s) \rightarrow$

   b. $NH_4Cl(s) \rightarrow$

   c. $NaCl(s) \rightarrow$

   d. $NaHCO_3(s) \rightarrow$

   e. $Na_3PO_4(s) \rightarrow$

Surface Tension Jar

A Surface Tension Demonstration

Introduction

Surface tension is a force—a force powerful enough to prevent water from spilling out of an open jar when it is turned upside-down! A fine mesh screen hidden inside the lid of the jar provides hundreds of tiny surface tension “membranes” that, in addition to air pressure, will support the weight of the water.

Science Concepts

- Surface Tension
- Cohesion
- Air pressure
- Properties of water

Materials (for each demonstration)

Jar with screw-on ring lid*
Laminated card*
Screen*
Liquid detergent (optional)
Plastic tub or bucket
Tap water

**Materials included in kit.*

Safety Precautions

Although this activity is considered nonhazardous, please observe all normal laboratory safety guidelines.

Procedure

1. Place the screen inside the lid of the jar, and screw the lid tightly onto the jar.
2. Pour tap water through the screen until the jar is about three-quarters full.
3. Place a laminated card over the top of the jar and hold the card down tightly with one hand. *The water will form an adhesive seal with the laminated paper.*
4. Quickly invert the jar 180° over a sink or other container, such as a plastic tub or bucket.

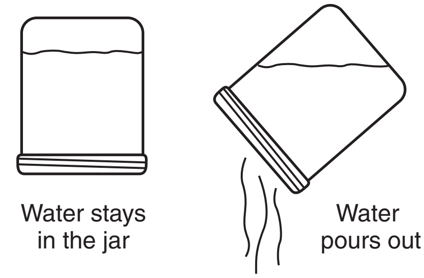


Figure 1.

5. While holding the jar steady, remove your hand from the laminated card. *The card will remain in place over the mouth of the jar! The water forms a tight adhesive seal and external air pressure holds the card in place.*
6. Carefully slide the card out from under the jar with one hand while holding the jar steady with the other hand. *A little water may spill out, but most of the water will stay in the jar! The mesh screen provides a surface for the formation of hundreds of tiny surface-tension “membranes” that, in addition to air pressure, will support the weight of the water.*
7. Tilt the jar a few degrees to allow air to enter the jar. The water will immediately spill out of the jar—gravity still works!
8. *(Optional)* After performing the demonstration once for the students, ask for a student volunteer to repeat the demonstration. Dip a finger into detergent that is hidden from view and inconspicuously run the finger over the screen after the jar has been filled with water. *When the student inverts the jar, the laminated card may stick for a short time due to the counter-force of air pressure acting on the outside of the card. When the card is removed, however, the water will rush out. The detergent interferes with the hydrogen-bonding network in water, which drastically reduces the surface tension of water and modifies its adhesive properties.*

9. Alternatively, you may show students that the demonstration will work without the laminated card, simply by covering the jar mouth with your hand and then quickly removing it.

Disposal

None required—save all materials for future use.

Tips

- If the jar is inverted while the screen is uncovered, all of the water will pour out.
- To make the demo more dramatic, do not allow students to see the screen before inverting the jar—let them think the mouth of the jar is open. Alternatively, do the demonstration over a student's arm if they do not mind getting wet in the event that the surface tension is broken.
- Experiment with different materials in place of the screen. Be creative—try a larger mesh material, such as the type from a produce bag, a fine mesh with smaller openings than the screen included in the kit, cloth, aluminum foil with holes, filter paper, etc.
- Test whether the demonstration will work with different amounts of water in the jar. Fill the jar completely, add only enough water to cover the screen, etc.

Discussion

There are two main questions in this demonstration. What force(s) hold the laminated card in place under the inverted jar (step 5)? What force(s) prevent the water from spilling out when the card is removed (step 6)? In order to understand why this demonstration works, it helps to know also when the demonstration will not work! The demonstration does not work, for example, with alcohols, even though their properties are similar to water. The demonstration also does not work if the air pressure outside the jar is reduced (by placing the inverted jar inside a bell jar and applying a vacuum).

Water is a unique liquid—the surface tension of water is substantially greater than that of alcohols and other liquids. Surface tension is a net attractive force that tends to "pull" adjacent surface molecules inward toward the rest of the liquid. Surface tension is a result of uneven attractive forces experienced by molecules at the surface of a liquid versus those in the rest of the liquid. Molecules in the liquid are bound to neighboring molecules all around them. Molecules at the surface, however, have no neighboring molecules above them. Because the forces acting on the surface molecules are not balanced in all directions, the surface molecules are drawn inward toward the rest of the liquid.

When the jar is first inverted, a small amount of water probably leaks out from the jar. This creates a slight partial vacuum in the space above the water in the jar. The water in the jar also forms a tight adhesive "seal" with the card—in addition to forming strong intermolecular cohesive forces with other water molecules, water also forms strong adhesive forces to many other molecules or materials. External air pressure, acting in all directions, applies a net upward force on the card and the water and prevents the water from spilling out of the jar.

When the card is removed, the surface tension of water provides an additional force keeping the water in the inverted jar. The high surface tension of water arises because of strong hydrogen bonding among water molecules. As an analogy, the surface tension of water may be thought of as an invisible, "elastic" film that expands as needed to counteract the force of gravity and prevent the water from spilling out of the jar. The numerous tiny holes in the mesh screen provide a larger total surface area for the formation of thousands of invisible surface membranes.

When the jar is tilted, the forces become off-balanced and there is no longer a greater pressure on the outside of the jar. The surface tension "breaks" and the water spills out of the jar.

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 A: Science as Inquiry

Content Standard B: Physical Science; properties and changes of properties in matter, understanding of motions and forces.

Content Standards: Grades 9–12

Content Standard A: Science as Inquiry

Content Standard B: Physical Science; structure and properties of matter, motions and forces.

Acknowledgment

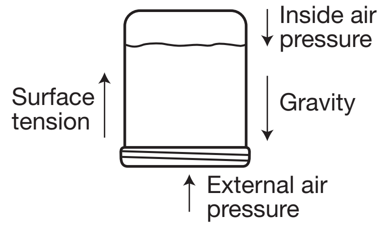
Special thanks to Patrick Funk, Pickerington High School, Pickerington OH, for providing the idea and the instructions for this activity to Flinn Scientific.

Reference

Floating water experiment http://www.stevespanglerscience.com (accessed June 30, 2004)

Answers to Worksheet Questions

1. Draw a sketch of the inverted jar filled with water. Use arrows to show the direction of the following forces acting on the water: Gravity, external air pressure, pressure of air inside the jar, and surface tension.



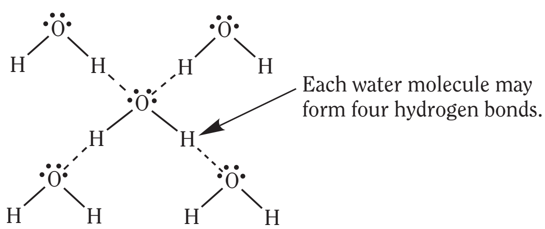
2. When the jar is inverted with the card in place, a small amount of water leaks out of the jar. Assuming that the card prevents air from entering the jar, how does the air pressure inside the jar change when water leaks out?

   The air pressure inside the jar decreases, creating a partial vacuum.

3. If there is even a trace of soap or detergent in the water in the jar, the demonstration will not work. What effect does soap have on the surface tension of water? How does this relate to how soaps work?

   Adding soap or detergent drastically reduces the surface tension of water by interfering with hydrogen bonding among water molecules. One way that soaps work is by improving the "wettability" of surfaces (skin, clothing, etc.). Water's extremely high surface tension prevents it from spreading out across and penetrating into a material. Soap lowers the surface tension of water and helps it diffuse into the pores on these surfaces.

4. Draw the structure of a water molecule and show by means of a diagram the hydrogen bonds between water molecules. How many hydrogen bonds does each water molecule form?



The *Surface Tension Jar—A Surface Tension Demonstration* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP6648	Surface Tension Jar—A Surface Tension Demonstration

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

Name: ___________________________________

Surface Tension Jar Demonstration Worksheet

1. Draw a sketch of the inverted jar filled with water. Use arrows to show the direction of the following forces acting on the water: Gravity, external air pressure, pressure of air inside the jar, and surface tension.

2. When the jar is inverted with the card in place, a small amount of water leaks out of the jar. Assuming that the card prevents air from entering the jar, how does the air pressure inside the jar change when water leaks out?

3. If there is even a trace of soap or detergent in the water in the jar, the demonstration will not work. What effect does soap have on the surface tension of water? How does this relate to how soaps work?

4. Draw the structure of a water molecule and show by means of a diagram the hydrogen bonds between water molecules. How many hydrogen bonds does each water molecule form?

Electrochemistry: Build Your Own Hand-held Battery

AP* Chemistry Investigation

A Guided-Inquiry Wet/Dry Experiment

Introduction

Experience and learn the concepts you need to help you succeed on the AP* Chemistry exam with this guided-inquiry activity! This activity covers topics from Big Idea 3 in the AP Chemistry curriculum. Complete a thorough homework set before lab day to delve into the basic principles of electrochemistry, involving the similarities and differences between galvanic and electrolytic cells. Then, you are tasked with the challenge to build your very own hand-held battery out of a few simple materials. The object of the challenge is to successfully assemble the battery materials so the illumination of a red LED component completes the task. You'll love this safe and fun activity while gaining a deeper understanding of electrochemistry and its real-world connection to batteries!

Concepts

- Half-cell reaction
- Galvanic cell vs. electrolytic cell
- Oxidation–reduction reactions
- Standard reduction potential

Background

Galvanic Cells

An electrochemical cell results when an oxidation reaction and a reduction reaction occur, and the resulting electron transfer between the two processes occurs through an external wire. The oxidation and reduction reactions are physically separated from each other and are called *half-cell reactions*. A half-cell can be prepared from almost any metal in contact with a solution of its ions. Since each element has its own electron configuration, each element develops a different electrical potential, and different combinations of oxidation and reduction half-cells result in different voltages for the completed electrochemical cell.

The *standard reduction potential* is the voltage that a half-cell, under standard conditions (1 M, atm, 25 °C), develops when it is combined with the standard hydrogen electrode, that is arbitrarily assigned a potential of zero volts. A chart of reduction half-cell reactions, arranged in order of decreasing standard reduction potential, shows the relative ease of reduction of each substance listed. The more positive the reduction potential, the easier the reduction. A spontaneous cell (a battery) can be constructed if two half-cells are connected internally using a salt bridge, and externally using a metallic connector. In an electrochemical cell, the reaction listed in the standard reduction potential chart with the more positive voltage occurs as a reduction, and the reaction listed with the less positive voltage reverses and occurs as an oxidation reaction. The cell voltage can be found by adding the voltages listed in the table, with the value of the voltage for the oxidation reaction becoming the negative of its reduction reaction voltage.

As an example, consider a cell made up of copper and aluminum half-cells.

$$Cu^{2+}(aq) + 2\,e^- \rightarrow Cu(s) \qquad E° = 0.34\text{ V}$$
$$Al^{3+}(aq) + 3\,e^- \rightarrow Al(s) \qquad E° = -1.66\text{ V}$$

The copper reaction has the more positive potential and remains a reduction reaction. The aluminum reaction with the less positive (more negative) potential is reversed and becomes an oxidation reaction. Its potential is now an oxidation potential:

$$Al(s) \rightarrow Al^{3+}(aq) + 3\,e^- \qquad E° = +1.66\text{ V}$$

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The reduction potential and the oxidation potential are added to find the cell voltage:

$$3Cu^{2+}(aq) + 2Al(s) \rightarrow 3Cu(s) + 2Al^{3+}(aq)$$

$$E°_{cell} = E°_{reduction} + E°_{oxidation}$$

$$E°_{cell} = 0.34\text{ V} + 1.66\text{ V} = 2.00\text{ V}$$

A positive value for $E°_{cell}$ indicates the oxidation–reduction reaction, as written, is *spontaneous*.

A cell representation such as the following: $Zn(s) \mid Zn^{2+}(1.0\text{ M}) \parallel Cu^{2+}(0.0010\text{ M}) \mid Cu(s)$ means that a cell is constructed of zinc metal dipping into a 1.0 M solution of Zn^{2+}. The symbol "|" refers to a phase boundary. The symbol "‖" indicates a salt bridge between the zinc ion solution and the copper ion solution. The second half-cell is copper metal dipping into a 0.0010 M solution of copper ions. The anode is on the left (where oxidation occurs) and the cathode is on the right (where reduction occurs).

Electrolytic Cells

When an electric current is passed through an aqueous solution containing an electrolyte (Na_2SO_4), the water molecules break apart or decompose into their constituent elements, hydrogen and oxygen. The overall reaction occurs as two separate, independent half-reactions. Reduction of the hydrogen atoms to elemental hydrogen (H_2) occurs at the cathode (–), while oxidation of the oxygen atoms in water to elemental oxygen (O_2) occurs at the anode (+). Each half-reaction is accompanied by the production of OH^- or H^+ ions as shown below:

$$\text{Cathode: } 4e^- + 4H_2O \rightarrow 2H_2(g) + 4OH^-$$

$$\text{Anode: } 2H_2O \rightarrow O_2(g) + 4H^+ + 4e^-$$

Experiment Overview

Gain pre-lab preparation by completing the following homework set to gain conceptual understanding of galvanic and electrolytic cells. Then, hit the ground running on lab day and build your own hand-held battery from simple components. You will have time to do a post hand-held battery build analysis. Draw and label your observations in your lab notebook. Did you build an electrolytic cell or a galvanic cell? Prove it.

Pre-Lab Homework Assignment

Complete the following homework set and turn in any graphs or figures you were asked to create. Use a separate sheet of paper, if necessary.

Redox Reactions

1. Identify equations *a–d* as redox or nonredox. Explain.

   a. $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

   b. $Zn^{2+}(aq) + Al(s) \rightarrow Zn(s) + Al^{3+}(aq)$

   c. $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

   d. $HF(g) + H_2O(l) \rightleftharpoons H_3O^+ + F^-(aq)$

2. Identify the oxidation half-reaction and the reduction half-reaction in *a–c*.

   a. $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

   b. $2Al(s) + 3CuCl_2(aq) \rightarrow 2AlCl_3(aq) + 3Cu(s)$

   c. $Zn(s) + V^{3+}(aq) \rightarrow V^{2+}(aq) + Zn^{2+}(aq)$

3. Go back to 2, *a–c* and identify:

   a. The oxidizing and reducing agents.

   b. The species that is oxidized and the species that is reduced.

Electrolytic Cell

A student setup a Hoffman apparatus electrolysis experiment as shown in Figure 1. The Hoffman electrolysis apparatus is a type of electrolytic cell where an electric current passes through an aqueous solution containing an electrolyte. As a result, water molecules decompose into their constituent elements. Two independent half-reactions are observed at the cathode and the anode. For a free demonstration video on the Hoffman apparatus, visit flinnsci.com.

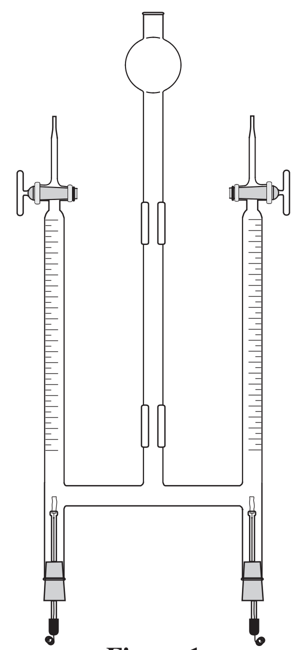


Figure 1.

4. The student added 0.5 M sodium sulfate electrolytic solution to the mouth of the Hoffman apparatus and then connected the battery leads to the electrodes. She immediately witnessed bubble formation and collected two gases on each side of the assembly. Answer questions *a–d*.

   a. Why did the student choose 0.5 M sodium sulfate for this experiment? Are there other electrolytic solutions she may test?

b. Report the overall reaction and the independent half reactions. Identify the gases collected. Predict the volumes of each gas collected in the apparatus.

c. Identify the cathode and anode and report where each occurs in the half reactions from question 4b.

d. Can the student use the Hoffman apparatus without the battery? In other words, will the decomposition (formation of gases) spontaneously occur?

5. The student carefully opened each stopcock and collected each gas in separate test tubes. She inserted a lit wood splint into each.

   a. Predict what occurred to the lit wood splint of the gas collected at the anode.

   b. Predict what occurred to the lit wood splint of the gas collected at the cathode.

6. As an extension, 1-mL of universal indicator solution was added to the sodium sulfate solution while the Hoffman apparatus was connected. Predict the observations. *Hint:* Look up the exhibited color changes of universal indicator solution at various pH values.

Galvanic Cell

See Figure 2 for the second experiment setup, a galvanic cell. In a galvanic cell, a spontaneous chemical reaction releases energy in the form of electricity (moving electrons).

7. Using arrows, label the parts of the galvanic cell in Figure 2 and answer questions *a–d*. Use this list of key words: electrodes, electrode storage/compartment, cathode, anode, and salt bridge.

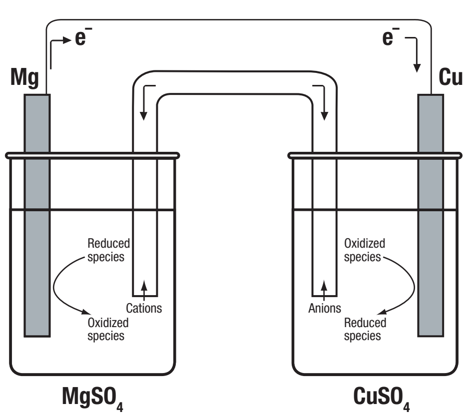


Figure 2. Galvanic Cell

a. What would happen to the cell if the salt bridge was removed?

b. Write the half-reactions that are taking place.

c. Write the cell notation.

d. Calculate the standard cell potential, E°.

8. Seek educational resources and provide an example of a replacement electrode if the copper electrode was not available in Figure 2.

9. The materials to build your very own hand-held battery include: 2 small squares of filter paper, 1 M copper(II) sulfate solution, 1 M sodium sulfate solution, magnesium ribbon, and an LED with copper tape attached to the positive terminal. Again, the challenge is to build a hand-held battery by successfully arranging the components to light the LED. *Helpful tips:*

   a. Think safety, first. Make sure you have the proper PPE available to perform this lab, i.e., goggles, apron, and gloves.

   b. Make a list of the equipment and glassware needed for this lab.

   c. Once you successfully complete the experiment, draw a hand-held battery figure in your notebook and label the parts of your battery, i.e. the cathode, anode etc. Write the reactions occurring.

   d. How does this battery differ from those practiced in the homework set? How is it similar?

   e. What are the half-cell reactions?

   f. Inspect the separate components of the hand-held battery after connecting it and lighting the LED. Describe any observations.

Safety Precautions

The copper(II) sulfate solution is harmful if swallowed and causes serious skin and eye irritation. The sodium sulfate solution may be harmful if in contact with skin. Magnesium ribbon is a flammable solid. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.

Teacher's Notes
Electrochemistry: Build Your Own Hand-held Battery
AP* Chemistry Investigation
A Guided-Inquiry Wet/Dry Experiment

Materials Included in Kit *(for 12 groups of students)*

Copper(II) sulfate solution, $CuSO_4$, 1 M, 500 mL

Sodium sulfate solution, Na_2SO_4, 1 M, 375 mL

Copper foil conductive adhesive, Cu, 12″ piece, 2

Filter paper, 100 sheets

LEDs, clear, red, 24

Magnesium ribbon, Mg, 6 ft, 1

Sand paper, 1 (shared)

Additional Materials Required *(for each lab group)*

Weigh boats, medium, 24

Beakers, 50-mL, 24

Tweezers, 12

Scissors, 12

Graduated cylinders, 10-mL, 12

Deionized or distilled water

Time Required

This laboratory activity was specifically written, per teacher request, to be completed in one 50-minute class period. It is important to allow time between the *Pre-Lab Homework Assignment* and the *Lab Activity*. Prior to beginning the homework, show the students the hand-held battery materials—this will get the procedure thought process rolling.

Pre-Lab Preparation and Complete *Build Your Own Hand-held Battery* Procedure

1. Gently polish both LED terminals with the sand paper on all LEDs to be used by the students.
2. Cut 24 copper conductive adhesive tape pieces 2 cm in length.
3. Cover the positive terminal (the longer terminal) with the 2 cm piece of the adhesive conductive tape of each LED to be used by the students.
4. Cut 24 pieces of rectangular shaped filter paper. The sodium sulfate filter paper is the salt bridge and should be bigger in size than the copper(II) sulfate filter paper.
   a. Cut the 12 pieces to be submerged in copper(II) sulfate in about ½ cm^2 in size.
   b. Cut 12 pieces to be submerged in the sodium sulfate solution in about 1 cm^2 in size.

Build Your Own Hand-held Battery Procedure

Lead the students through steps 1–3 after providing the materials. At step 4, allow them to determine the correct component arrangements to successfully light the LED.

1. Measure 2 mL, each of the 1 M copper(II) sulfate solution and the 1 M sodium sulfate solution using a 10-mL graduated cylinder. Pour into separate medium sized weigh boats or small beakers (50-mL).
2. Using tweezers, dip the larger (1 cm^2) pre-cut filter paper into the sodium sulfate solution and the smaller (1/2 cm^2) pre-cut filter paper into the copper(II) sulfate solution. Dip long enough to completely coat each filter paper (about 10 seconds).
3. Place both on a separate weigh boat to let dry until the filter papers are damp with solution, not dripping. Students may hold each with tweezers and gently wave to decrease drying time.
4. While filter paper is drying, students make predictions. In their notebooks, students illustrate the experiment and identify the anode, cathode, the salt bridge, and evidence of electron flow; the lit LED. Students should include the half-cell reactions taking place.

5. See Figure 3 on how to correctly arrange the components. Lead the students into squeezing the LED between the thumb and index finger for component contact. Add a drop of DI water if necessary, but not too much to drown the battery. Darken the room or cup hand over LED to watch it light.

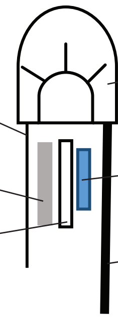


Figure 3. The correct arrangement of the hand-held battery. Squeeze with thumb and index finger on each side of the LED terminals to light the LED.

Safety Precautions

The copper(II) sulfate solution is harmful if swallowed and causes serious skin and eye irritation. The sodium sulfate solution may be harmful if in contact with skin. Magnesium ribbon is a flammable solid. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines. Remind students to wash their hands thoroughly with soap and water before leaving the laboratory. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

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. You may save all materials, including solutions, for future labs. Any leftover copper(II) sulfate and sodium sulfate solutions may be flushed down the drain with excess water according to Flinn disposal method #26b.

Alignment with AP* Chemistry Curriculum Framework—Big Idea 3

Enduring Understandings and Essential Knowledge

Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other. Classes of chemical reactions include synthesis, decomposition, acid–base, and oxidation–reduction reactions. (Enduring Understanding 3B)

3B3: In oxidation–reduction (redox) reactions, there is a net transfer of electrons. The species that loses electrons is oxidized, and the species that gains electrons is reduced.

Chemical and physical transformations may be observed in several ways and typically involve a change in energy. (Enduring Understanding 3C)

3C3: Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.

Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal. (Enduring Understanding 6A)

6A4: The magnitude of the equilibrium constant, *K*, can be used to determine whether the equilibrium lies toward the reactant side or product side.

Chemical equilibrium plays an important role in acid–base chemistry and in solubility. (Enduring Understanding 6C)

6C3: The solubility of a substance can be understood in terms of chemical equilibrium.

Learning Objectives

3.8 The student is able to identify redox reactions and justify the identification in terms of electron transfer.

3.12 The student can make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faraday's laws.

3.13 The student can analyze data regarding galvanic or electrolytic cells to identify properties of the underlying redox reactions.

6.7 The student is able, for a reversible reaction that has a large or small K, to determine which chemical species will have very large versus very small concentrations at equilibrium.

6.21 The student can predict the solubility of a salt, or rank the solubility of salts, given the relevant K_{sp} values.

Science Practices

2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

2.3 The student can estimate numerically quantities that describe natural phenomena.

4.3 The student can collect data to answer a particular scientific question.

5.1 The student can analyze data to identify patterns or relationships.

Lab Hints

- A pre-lab prep alternative to cutting filter paper squares: you may first dip the filter paper in the sulfate solutions, allow to dry, then cut into squares for use by the students.
- Depending the inquiry level of your students, they may perform all of the set-up steps from the *Pre-Lab Preparation.*

Teaching Tips

- Flinn Scientific has excellent video resources that enhance the teaching experience! Simply type in the key word electrolysis or Hoffman apparatus to pull up some great videos.
- The Colorful Electrolysis Demonstration is a great extension to this lab! This demonstration kit is available from Flinn (Catalog No. AP6467).

Answers to Pre-Lab Homework Assignment *(Student answers will vary.)*

Redox Reactions

1. Identify equations *a–d* as redox or nonredox. Explain.

   Electrons are gained or lost in redox reactions; a species is oxidized or reduced. 1 c and d are nonredox due to being acid base reactions.

   a. $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

   Redox

   b. $Zn^{2+}(aq) + Al(s) \rightarrow Zn(s) + Al^{3+}(aq)$

   Redox

   c. $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

   Nonredox

   d. $HF(g) + H_2O(l) \rightleftharpoons H_3O^+ + F^-(aq)$

   Nonredox

2. Identify the oxidation half-reaction and the reduction half-reaction in *a–c*.

   a. $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

   $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ (oxidation)

   $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ (reduction)

   b. $2Al(s) + 3CuCl_2(aq) \rightarrow 2AlCl_3(aq) + 3Cu(s)$

   $Al(s) \rightarrow Al^{3+} + 2e^-$ (oxidation)

   $Cu^{2+} + 2e^- \rightarrow Cu(s)$ (reduction)

c. $Zn(s) + V^{3+}(aq) \rightarrow V^{2+}(aq) + Zn^{2+}(aq)$

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ (oxidation)

$V^{3+}(aq) + 2e^- \rightarrow V^{2+}$ (reduction)

3. Go back to 2, *a–c* and identify:

   a. The oxidizing and reducing agents.

   2a. Zn is the reducing species and Cu^{2+} is the oxidizing species.
   2b. Al is the reducing species and Cu^{2+} is the oxidizing species.
   2c. Zn is the reducing species and V^{3+} is the oxidizing species.

   b. The species that is oxidized and the species that is reduced.

   2a. Zn is oxidized and Cu^{2+} is reduced.
   2b. Al is oxidized and Cu^{2+} is reduced.
   2c. Zn is oxidized and V^{3+} is reduced.

Electrolytic Cell

A student setup a Hoffman apparatus electrolysis experiment as shown in Figure 1. The Hoffman electrolysis apparatus is a type of electrolytic cell where an electric current passes through an aqueous solution containing an electrolyte. As a result, water molecules decompose into their constituent elements. Two independent half-reactions are observed at the cathode and the anode. For a free demonstration video on the Hoffman apparatus, visit flinnsci.com.

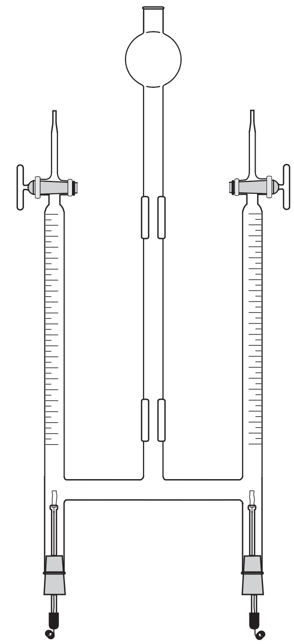


Figure 1.

4. The student added 0.5 M sodium sulfate electrolytic solution to the mouth of the Hoffman apparatus and then connected the battery leads to the electrodes. She immediately witnessed bubble formation and collected two gases on each side of the assembly. Answer questions *a–d*.

   a. Why did the student choose 0.5 M sodium sulfate for this experiment? Are there other electrolytic solutions she may test?

   Sodium sulfate is an electrolyte, it is conductive. The student can use solutions of potassium iodide or potassium chloride.

   b. Report the overall reaction and the independent half reactions. Identify the gases collected. Predict the volumes of each gas collected in the apparatus.

   Oxygen and hydrogen gases are produced/collected. Since hydrogen gas forms at twice the molar volume in the overall reaction, double the amount of hydrogen gas collects in the apparatus vs. oxygen gas.

   $4H_2O \rightarrow 4H_2 + 2O_2$

   Cathode: $4e^- + 4H_2O \rightarrow 2H_2(g) + 4OH^-$

   Anode: $2H_2O \rightarrow O_2(g) + 4H^+ + 4e^-$

   c. Identify the cathode and anode and report where each occurs in the half reactions from question 4b.

   See 4b.

   d. Can the student use the Hoffman apparatus without the battery? In other words, will the decomposition (formation of gases) spontaneously occur?

   No, electrolysis reactions require external power where a non-favorable redox reaction occurs.

5. The student carefully opened each stopcock and collected each gas in separate test tubes. She inserted a lit wood splint into each.

   a. Predict what occurred to the lit wood splint of the gas collected at the anode.

   Oxygen gas is flammable, so it ignited the wood splint.

   b. Predict what occurred to the lit wood splint of the gas collected at the cathode.

Hydrogen gas is also flammable, so it ignited the wood splint as well.

6. As an extension, 1-mL of universal indicator solution was added to the sodium sulfate solution while the Hoffman apparatus was connected. Predict the observations. Hint: Look up the exhibited color changes of universal indicator solution at various pH values.

   Beautiful colors will result. At the cathode: solution will be purple/blue due to the production of basic hydroxide ions. At the anode: solution will be pink/red due to the production of acidic protons.

Galvanic Cell

See Figure 2 for the second experiment setup, a galvanic cell. In a galvanic cell, a spontaneous chemical reaction releases energy in the form of electricity (moving electrons).

7. Using arrows, label the parts of the galvanic cell in Figure 2 and answer questions a–d. Use this list of key words: electrodes, electrode storage/compartment, cathode, anode, and salt bridge.

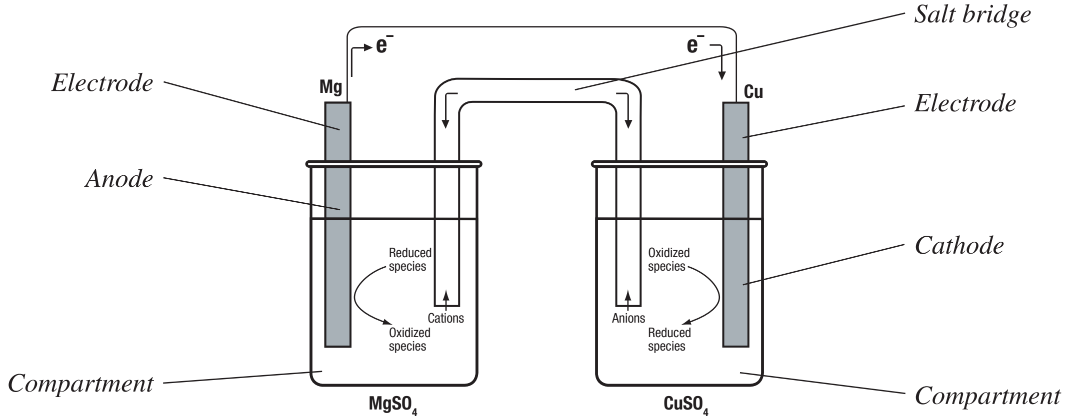


Figure 2. Galvanic Cell

a. What would happen to the cell if the salt bridge was removed?

Build-up of positive and negative charges would occur; salt bridges are needed for chemical neutrality.

b. Write the half-reactions that are taking place.

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

$Mg(s) \rightarrow Mg^{2+}(aq) + 2e^-$

c. Write the cell notation.

$Mg(s)\,|\,Mg^{2+}(1\ M)\,||\,Cu^{2+}\ (1\ M)\,|\,Cu(s)$

d. Calculate the standard cell potential, E°.

$E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode}$

$E^\circ_{cell} = 0.34 - (-2.37) = 2.71\ V$

8. Seek educational resources and provide an example of a replacement electrode if the copper electrode was not available in Figure 2.

   A standard, non-conductive electrode such as platinum or graphite are good options.

9. The materials to build your very own hand-held battery include: 2 small squares of filter paper, 1 M copper(II) sulfate solution, 1 M sodium sulfate solution, magnesium ribbon, and an LED with copper tape attached to the positive terminal. Again, the challenge is to build a hand-held battery by successfully arranging the components to light the LED. *Helpful tips:*

   a. Think safety, first. Make sure you have the proper PPE available to perform this lab, i.e., goggles, apron, and gloves.

   b. Make list of the equipment and glassware needed for this lab.

c. Once you successfully complete the experiment, draw a hand-held battery figure in your notebook and label the parts of your battery, i.e. the cathode, anode etc. Write the reactions occurring.

See Figure 3

d. How does this battery differ from those practiced in the homework set? How is it similar?

It is a galvanic cell—it does not require external power to work. The filter papers are the cell's compartments and there is not a magnesium sulfate solution present.

e. What are the half-cell reactions?

Cu tape was applied to the positive LED terminal of the battery as the conductive material to prevent reaction between Mg(s) and the bare LED terminal.

$Mg(s) \rightarrow Mg^{2+} + 2e^{-}$ *(oxidation, anode)*

$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$ *(reduction, cathode)*

f. Inspect the separate components of the hand-held battery after connecting it and lighting the LED. Describe any observations.

Student answers will vary. Dark spots are seen on the copper(II) sulfate filter paper, which is copper metal. Without the conductive tape, the LED terminals can darken due to oxidation of Mg(s).

References

Eggen, P.; Skaugrud, B. *An Easy-to-Assemble Three-Part Galvanic Cell. J. Chem. Educ.* **2015**, *92 (6)*, 1053–1055.

AP Chemistry Guided-Inquiry Experiments: Applying the Science Practices*; The College Board: New York, NY, **2013.**

The *Electrochemistry: Build Your Own Hand-held Battery AP* Chemistry Investigation— A Guided-Inquiry Wet/Dry Experiment* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP8496	Electrochemistry: Build Your Own Hand-held Battery AP* Chemistry Investigation—A Guided-Inquiry Wet/Dry Experiment

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

Safe Swimming with Sodium

Chemical Demonstration Kit

Introduction

No chemistry class is complete without the spectacular demonstration of alkali metals reacting with water. *Safe Swimming with Sodium* is a novel variation that is much safer to perform than the standard demonstration of simply dropping a small piece of the sodium metal into a beaker of water.

Concepts

- Alkali metals—reaction with water
- Density

Materials (for each demonstration)

Sodium metal, Na, 1 small piece*

Mineral oil, 200 mL*

Phenolphthalein, 0.5% solution, a few drops*

**Materials included in kit*

Water, 200 mL

Glass cylinder, approximately 500 mL

Ring stand and clamp

Lithium metal, Li, 1 small piece (optional)

Safety Precautions

Sodium metal is a flammable, corrosive solid and is dangerous when exposed to heat or flame. Sodium also reacts vigorously with moist air, water, or any oxidizer. The pre-cut pieces provided for this demonstration greatly reduce the potential hazard of the material. Sodium reacts with water to produce flammable hydrogen gas and a solution of sodium hydroxide. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please consult current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Clamp a hydrometer cylinder or large graduated cylinder to a ring stand for support.
2. Add about 200 mL of water to the cylinder along with a few drops of phenolphthalein solution.
3. Add 200 mL of mineral oil, forming a layer above the water. Tilt the cylinder to reduce mixing at the interface.
4. Drop a piece of sodium, about the size of a kernel of corn, into the cylinder and observe the reaction.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Do not dispose of anything until the sodium has completely reacted. The mineral oil can be stored and reused for future demonstrations and labs. The aqueous solution can be flushed down the drain with excess water according to Flinn Suggested Disposal Method #26a.

Tips

- The colorless water–phenolphthalein layer can be regenerated by the addition of a small amount of dilute acid, such as 1 M HCl. The setup can be used several times during the day.

- Sometimes during the first few reactions, the sodium metal may react very vigorously and briefly melt. If this occurs, the sodium becomes porous and “too light” to sink in the mineral oil. This piece of sodium will no longer swim—try another piece. This sometimes occurs because the mineral oil is wet or becomes wet during the setup.

Discussion

When added to the cylinder, sodium will sink in the mineral oil until it reaches the interface between the oil and water layers, at which time it reacts with water, forming hydrogen gas and sodium hydroxide, a strong base.

$$2Na(s) + 2H_2O(l) \rightarrow H_2(g) + 2NaOH(aq)$$

The evolution of hydrogen gas is evident, and hydrogen bubbles adhering to the sodium will carry it into the hydrocarbon layer, temporarily stopping the reaction. The amount of hydrogen and heat evolved is kept under control by this “swimming” behavior, making this demonstration quite safe. The piece of sodium repeatedly dives down to the water–hydrocarbon interface, reacts, then “swims” back up into the hydrocarbon layer until the reaction is complete. During the reaction, the piece of sodium is largely devoid of corrosion, allowing the students to view its gray, metallic appearance. The aqueous layer contains phenolphthalein and turns pink due to the production of a base, sodium hydroxide.

Density is an important physical property that can be used to separate materials or control reactions. Sodium has a density of 0.97 g/mL and sits at the interface of the water and oil layers. Lithium, in contrast, has a density of 0.54 g/cm^3, and will float on top of the hydrocarbon layer. (Try it!) The interface between two immiscible solvents is an effective site for controlling chemical reactions. Many industrial processes use this concept to react aqueous salts with nonpolar hydrocarbons.

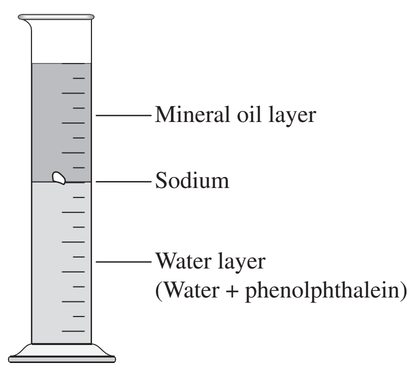
Connecting to the National Standards

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

Answers to Worksheet Discussion Questions

1. Draw the setup for this demonstration.



2. Describe what happened in the demonstration.

   When the sodium was added to the hydrometer, it sank through the layer of oil on the top until it reached the interface between the layer of oil and the layer of water. The sodium reacted with the water and then rose back into the layer of oil. The sodium sank once again and continued reacting when it reached the water. This process repeated several times, and eventually the layer of water turned pink.

3. Why does the sodium metal sit at the interface between the oil and the water?

   The density of sodium is greater than that of mineral oil but less than that of water.

4. Why does the sodium metal suddenly "jump up" from the interface?

   When the sodium reacted with the water, it produced hydrogen gas and sodium hydroxide. Some of the bubbles of hydrogen gas adhered to the sodium and carried it back into the layer of mineral oil.

5. Why does the layer of water eventually turn pink?

   The sodium produced sodium hydroxide when it reacted with the water. Phenolphthalein, an acid–base indicator, had been added to the water layer. Since sodium hydroxide is a base, and phenolphthalein is clear in an acid but pink in a base, the water turned pink.

6. Write the balanced chemical equation for the reaction of sodium with water.

   $2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

Acknowledgment

Special thanks to Ken Lyle, St. Johns School, Houston, TX, for bringing this demonstration to our attention.

Reference

Alexander, M. D., *J. Chem. Ed.* **1992,** *69,* 418.

Materials for *Safe Swimming with Sodium—Chemical Demonstration Kit* are available from Flinn Scientific, Inc.

Catalog No.	Description
S0329	Sodium, bottle of 5 small pieces for demonstration
M0064	Mineral oil, light, 500 mL
P0115	Phenolphthalein indicator solution, 0.5%, 100 mL
AP8599	Hydrometer cylinder, 600-mL
L0057	Lithium, 2.5 g
AP8916	Safe Swimming with Sodium Chemical Demonstration Kit

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

Name: ____________________

Safe Swimming with Sodium Demonstration Worksheet

Discussion Questions

1. Draw the setup for this demonstration.

2. Describe what happened in the demonstration.

3. Why does the sodium metal sit at the interface between the oil and the water?

4. Why does the sodium metal suddenly “jump up” from the interface?

5. Why does the layer of water eventually turn pink?

6. Write the balanced chemical equation for the reaction of sodium with water.

Kool Chromatography

Column Chromatography Demonstration Kit

Introduction

Separate different colored dyes in grape Kool-Aid® using column chromatography, a popular method used in research and industry to separate, isolate, and purify components of mixtures.

Chemical Concepts

- Polarity
- Column chromatography

Materials Needed

Isopropyl alcohol solution, 70%, 500 mL*
Sep-Pak® C18 cartridge*
Grape Kool-Aid®, 1 packet*
Beakers, 600-mL, 2
Graduated cylinder, 100-mL
Microplate, 6-well*
Overhead projector
Syringe with luer lock tip, 12-mL*

**Materials included in kit.*

Safety Precautions

Isopropyl alcohol solution is a flammable liquid; keep away from open flame. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron.

Preparation

1. To prepare 500 mL of a 25% isopropyl alcohol solution, add 180 mL of 70% isopropyl alcohol solution to a 600-mL beaker and dilute to the 500-mL mark with distilled or deionized water.
2. To prepare 500 mL of a 5% isopropyl alcohol solution, add 35 mL of 70% isopropyl alcohol solution to a 600-mL beaker and dilute to the 500-mL mark with distilled or deionized water.
3. Prepare the Kool-Aid® according to the package instructions. Do not add sugar. The resulting solution is approximately 0.3 g of Kool-Aid powder per 100 mL of distilled or deionized water.
4. If the syringe has a tip cover, remove it before performing this demonstration.

Procedure

1. Pretreat the column by drawing 10 mL of the 70% isopropyl alcohol solution into the syringe. Twist the Sep-Pak® C18 cartridge snugly into place on the luer lock tip of the syringe. Using the plunger, expel the isopropyl alcohol solution out of the syringe back through the column.
2. Repeat Step 1 using 10 mL of distilled or deionized water in place of the 70% isopropyl alcohol solution.
3. Place the 6-well microplate on the overhead and pour grape Kool-Aid® into one of the wells. Remove the cartridge from the syringe and draw 10 mL of the grape Kool-Aid from the microplate into the syringe.
4. Place the cartridge back on the syringe and force the Kool-Aid through the column and into a clean well on the microplate. Notice the clear solution that elutes (or exits) from the column.

5. Again remove the cartridge from the syringe. If there is any grape Kool-Aid left in the syringe, rinse the syringe with 5% isopropyl alcohol first. Draw 10 mL of 5% isopropyl alcohol solution into the syringe and place the cartridge back on the syringe.
6. Force the 5% isopropyl alcohol solution through the column into a clean well on the microplate. Note the red-colored solution that exits the column.
7. Remove the cartridge from the syringe and draw 10 mL of 25% isopropyl alcohol solution into the syringe. Replace the cartridge.
8. Force the 25% isopropyl alcohol solution through the column into a clean well on the microplate. Note the blue-colored solution that elutes from the column.

Disposal

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

Tips

- The Sep-Pak® C18 cartridge has a short end and a long end. The cartridge can be used either direction. It is important to keep the flow going in one direction.
- The Sep-Pak C18 cartridge can be used to separate many mixtures of varying polarity. The demonstration becomes more visually appealing if the mixture has at least two colors that elute separately.
- An air pocket in the syringe will not affect the outcome of the demonstration.
- To store or reuse the Sep-Pak C18 cartridge, first clean the column by rinsing it with 10 mL of 70% isopropyl alcohol solution, then rinsing with 10 mL of distilled or deionized water. If cleaned properly after each use, the Sep-Pak C18 cartridge can be reused indefinitely.

Discussion

The ingredients of grape Kool-Aid® include sugar, citric acid, red dye, ascorbic acid, and blue dye. As the Kool-Aid passes through the very non-polar Sep-Pak C18 column, the polar molecules, such as citric acid, preferentially adhere to the polar solvent—water. The non-polar molecules, such as the dyes, spend very little time adhering to the polar solvent and therefore stay in the non-polar column. The 5% isopropyl alcohol solution is slightly non-polar. As the dilute alcohol solvent is passed through the column, the red dye, which is also slightly non-polar, is still more attracted to the solvent than it is to the column. The blue dye, however, is more non-polar than the red dye and is still attracted more strongly to the column than it is attracted to the solvent. Therefore, only the red dye is eluted from the sample by the 5% isopropyl alcohol solution. The 25% isopropyl alcohol solution is more non-polar than the 5% isopropyl alcohol solution. The more non-polar mixture now attracts the blue dye away from the column, causing it to flow out of the cartridge with the solvent.

Column liquid chromatography (LC) is often used in industry to separate mixtures and detect trace components of a mixture. High performance liquid chromatography (HPLC) has become the instrument-of-choice for many quantitative analyses. This demonstration and the concepts and processes involved can be compared directly to HPLC. As with HPLC there is a solvent delivery system (the syringe), an injector (the syringe), a column (Sep-Pak cartridge), and a detector (the human eye).

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

Answers to Worksheet Questions

1. Describe what happened in this demonstration.

   Water was drawn into a syringe, and then forced back out the syringe via an attached column cartridge. Grape Kool-Aid was then passed into the syringe and out through the column. The solution that left the syringe was colorless. Then 5% isopropyl alcohol was passes through the column. This time the exiting solution was red. Finally, 25% isopropyl alcohol was passed through the column. The exiting solution was blue.

2. The Sep-Pak C18 cartridge is very non-polar. Rank the three solutions used to separate the Kool-Aid, water, 5% isopropyl alcohol, and 25% isopropyl alcohol, in terms of their polarity from the most polar to the least polar.

   Water is the most polar of the solutions. 5% isopropyl alcohol is slightly less polar than water, and 25% isopropyl alcohol is the least polar, or the most non-polar, of the three solutions.

3. The ingredients of grape Kool-Aid are sugar, citric acid, ascorbic acid, blue dye, and red dye. Water, 5% isopropyl alcohol, and 25% isopropyl alcohol were passed through the column in that order. Based on what you know about the polarity of the solutions, explain what you observed during the demonstration.

   When the polar solvent, water, was passed through the column, the polar molecules naturally preferred the water to the cartridge. But the red and blue dyes, which are more non-polar, stayed in the column. When 5% isopropyl alcohol, which is slightly non-polar, was passed through the slightly non-polar red dye molecules adhered to the solvent. When, at last, the 25% isopropyl alcohol, the least non-polar of the solvents, passed through, the very non-polar blue dye was more attracted to this solution than the cartridge, and exited the cartridge with the alcohol.

4. High-performance liquid chromatography, also known as HPLC, is often used for quantitative analyses. HPLC requires the use of a solvent delivery system, an injector, a column, and a detector. This demonstration is comparable to HPLC. Therefore, what is the equivalent of each of those materials in this demonstration procedure?

   The syringe served both as the solvent delivery system and the injector. The Sep-Pak cartridge was the column, and people, primarily their eyes, were the detectors in this demonstration.

References

Vonderbrink, S. A. *Laboratory Experiments for Advanced Placement Chemistry;* Flinn Scientific: Batavia, IL, 1995; pp 149–153.

Bidlingmeyer, B. A.; Warren, F. V. *J. Chem Educ.* **1984,** *61,* 716–720.

The *Kool Chromatography—Column Chromatography Demonstration Kit* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP8950	Kool Chromatography— Column Chromatography Demonstration Kit

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

Name: ________________________________

Kool Chromatography Worksheet

Discussion Questions

1. Describe what happened in this demonstration.

2. The Sep-Pak C18 cartridge is very non-polar. Rank the three solutions used to separate the Kool-Aid, water, 5% isopropyl alcohol, and 25% isopropyl alcohol, in terms of their polarity from the most non-polar to the most polar.

3. The ingredients of grape Kool-Aid are sugar, citric acid, ascorbic acid, blue dye, and red dye. Water, 5% isopropyl alcohol, and 25% isopropyl alcohol were passed through the column in that order. Based on what you know about the polarity of the solutions, explain what you observed during the demonstration.

4. High-Performance liquid chromatography, also known as HPLC, is often used for quantitative analyses. HPLC requires the use of a solvent delivery system, an injector, a column, and a detector. This demonstration is comparable to HPLC. Therefore, what is the equivalent of each of those materials in this demonstration procedure?

Polyurethane Foam System

The Preparation of Polyurethane Foam

Introduction

Try this amazing demonstration! Simply mix two liquids together and watch as the mixture expands 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)*
Acetone (optional)
Disposable cups (clear plastic, if available), 2
**Materials included in kit.*

Disposable glove, clear (optional)
Food coloring (optional)
Paper towels or newspaper
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 Material 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. Please consult your current *Flinn Scientific Catalog/Reference Manual* for proper disposal procedures.

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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.
- 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).

$$\underset{\text{Polyether polyol}}{\mathrm{HO{-}R{-}OH}} + \underset{\text{Diisocyanate}}{\mathrm{O{=}C{=}N{-}R'{-}N{=}C{=}O}} \longrightarrow \underset{\text{Polyurethane}}{\left[\mathrm{{-}O{-}R{-}O{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}\overset{\displaystyle H}{\overset{|}{N}}{-}R'{-}\overset{\displaystyle H}{\overset{|}{N}}{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}}\right]_n} \qquad \textit{Equation 1}$$

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.)

$$\underset{\text{Diisocyanate}}{\mathrm{O{=}C{=}N{-}R'{-}N{=}C{=}O}} + \underset{\text{Water}}{\mathrm{H_2O}} \longrightarrow \mathrm{HO{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}\overset{\displaystyle H}{\overset{|}{N}}{-}R'{-}\overset{\displaystyle H}{\overset{|}{N}}{-}\overset{\displaystyle O}{\overset{\|}{C}}{-}OH} \longrightarrow \mathrm{H{-}\overset{\displaystyle H}{\overset{|}{N}}{-}R'{-}\overset{\displaystyle H}{\overset{|}{N}}{-}H + CO_2(g)} \qquad \textit{Equation 2}$$

Connecting to the National Standards

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

Unifying Concepts and Processes: Grades K–12

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, chemical reactions

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.

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).

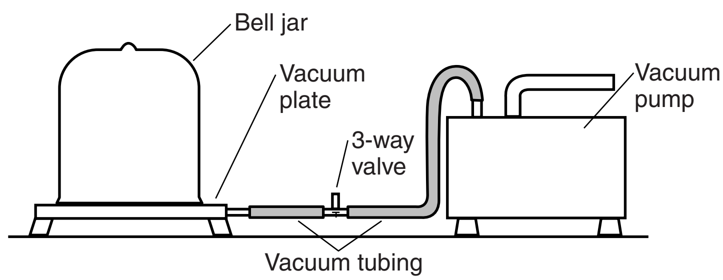

Figure 1.

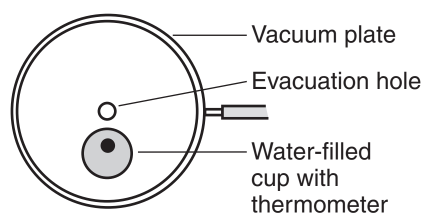

Figure 2.

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?

Ralphie, The Drinking Bird

Evaporation and Boiling

FLINN SCIENTIFIC CHEM FAX!

Introduction

Watch a glass bird that "drinks" from a cup for hours to demonstrate important chemical properties.

Concepts

- Evaporative cooling
- Gas pressure

Materials

Drinking bird

Cup of water (a coffee mug works well)

Safety Precautions

When setting up and beginning this demonstration, watch the drinking bird very closely. If it falls, it will break. The liquid inside the drinking bird is flammable and is poisonous by ingestion.

Procedure

1. Assemble the drinking bird by placing the metal prongs into the tops of the legs. Be sure that the beak is facing the same way as the feet.
2. The metal pivot should be approximately halfway between the bottom bulb and the red-colored neck of the drinking bird. The metal pivot should also be bent slightly so that the bird tends to lean forward. This will keep the drinking bird from doing backflips (and breaking!).
3. Submerge the entire head of the drinking bird into a full cup of tap water.
4. Set the bird next to the cup, facing it so the beak can "drink" from the cup. Observe.
5. The liquid inside the drinking bird will rise up the tube until the bird is top-heavy. The bird will then tip over as if it is drinking the water. In the horizontal position, air bubbles enter the tube and the liquid drains into the bottom bulb. Now the bottom-heavy bird rights itself, only to begin the process again.

Discussion

The bird's drinking action is based on evaporative cooling and its effect on gas pressure. The process takes place in a number of steps.

1. The bird's head is dipped into the water.
2. As water evaporates it causes a cooling effect on the upper bulb.
3. The vapor pressure in the upper bulb is lowered due to the decrease in temperature.
4. The higher vapor pressure in the lower bulb and the position of the tube in the lower bulb causes the liquid inside the bird to be forced up the tube.
5. The drinking bird becomes top-heavy causing it to tip over.
6. When the bird is in the horizontal position, gas bubbles enter into the tube—this equilibrates the pressures and allows the liquid to drain back into the lower tube. (Figure B.)
7. The bird rights itself and the process begins again.

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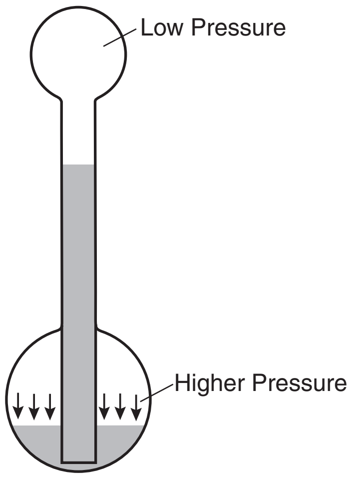

Figure 1A. Pressure differences forces liquid up the tube.

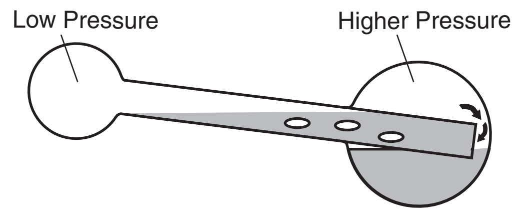

Figure 1B. Tipped over position allows gas into tube.

Evaporation is an endothermic process—*water* evaporation can be represented by the following chemical equation:

$$H_2O(l) + \text{Energy} \rightarrow H_2O(g)$$

Adding energy in the form of heat to water will cause it to evaporate more quickly (as in heating up a tea kettle). In the absence of an outside source of heat, the water will take energy from the surrounding water molecules. The evaporating water molecules then leave behind water that has less energy (i.e., it is cooler). This cooling effect is very small for a large container of water with very little surface area for evaporation. However, the cooling effect is very high when the amount of water is small and the surface area for evaporation is high; such as in this demonstration or when sweat evaporates from your skin.

In the case of the drinking bird, evaporative cooling on the outside of the bulb reduces the temperature inside the bulb. Pressure and temperature are directly related when volume is held constant. Therefore, the temperature reduction lowers the pressure in the upper bulb. The pressure in the lower bulb pushes the liquid up the tube and starts the process described above.

A common question is “When will the bird stop drinking?” There are three situations where the bird will stop drinking: (1) When there is not enough water left in the cup to wet the bird’s head, (2) When the relative humidity is 100%. This is verified by placing a bell jar over the cup and bird. In this case, the bird will stop drinking within a few minutes. When the bell jar is removed, the bird will resume drinking, (3) When the demonstration is performed in a room with high relative humidity. If this occurs, the bird can be made to drink by adding a small amount of alcohol (either methyl or ethyl) to the water in the cup.

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 of atoms, structure and properties of matter, chemical reactions,

References

Atkins, P. W. *Physical Chemistry;* W. H. Freeman: New York, 1990.

Gesser, H. D. *J. Chem. Ed.* **1996,** *73*, 355.

Gesser, H. D. *J. Chem. Ed.* **1999,** *76*, 757.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Ralphie*, *The Drinking Bird* activity, presented by Bob Lewis, is available in *Evaporation and Boiling* and in *Teaching with Toys*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Ralphie*, *The Drinking Bird* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP9292	Drinking Bird

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