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Catalog No. AP6444
Publication No. 6444

Stoichiometry Balloon Races

Chemical Demonstration Kit

Introduction

Most stoichiometry calculations in the classroom are performed using exact (stoichiometric) mole ratios of reactants and products. In real life, however, many commercial processes for preparing compounds are carried out using an excess amount of one reactant (and thus a limiting amount of another reactant). This demonstration uses the well-known reaction of sodium bicarbonate and acetic acid to illustrate the concepts of limiting and excess reactants. By comparing the amount of carbon dioxide generated when varying amounts of sodium bicarbonate react with a given amount of acetic acid, students will be able to immediately identify the limiting and excess reactant in each case.

Concepts

- Stoichiometry
- Mole ratio
- Limiting reactant
- Excess reactant

Materials (for each demonstration)

Acetic acid, CH_3COOH, 2 M, 60 mL*
Sodium bicarbonate, $NaHCO_3$, 10.5 g*
Balance, centigram (0.01-g precision)
Balloons, 6*
Erlenmeyer flasks, 125-mL, 6
Graduated cylinder, 25- or 50-mL
Permanent marker
Powder funnel*
Spatula
Weighing dishes, 6*

**Materials included in kit.*

Safety Precautions

Acetic acid is a skin and eye irritant. Avoid contact with eyes and skin. 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. Label six Erlenmeyer flasks 1–6. Using a graduated cylinder, add 10 mL of 2 M acetic acid to each flask.
2. Obtain six weighing dishes and label them 1–6.
3. Measure the appropriate amount of sodium bicarbonate into each weighing dish, according to Table 1.

Table 1.

Sample	**1**	**2**	**3**	**4**	**5**	**6**
Mass NaHCO3	0.50 g	1.00 g	1.50 g	2.00 g	2.50 g	3.00 g

4. Obtain six balloons. Stretch the balloons and blow them up at least once. Then let out as much air as possible.
5. Use a powder funnel to add the first sodium bicarbonate sample (#1) to one of the balloons.

6. Flatten out the balloon to remove any extra air and then carefully stretch the neck of the balloon over the mouth of Erlenmeyer flask #1. Do not allow the solid to drop into the flask at this time.
7. Repeat steps 5 and 6 with the other sodium bicarbonate samples #2–6.

Procedure

1. Introduce the concepts of limiting and excess reagents by asking students how many complete automobiles can be assembled if the following parts are available: 140 car bodies, 520 tires, 200 engines, and 270 headlights.
2. Which automobile part is present in a quantity that "limits" the total number of complete automobiles that may be assembled? Is the limiting part the same as the part that is present in the least number? Explain. *Note:* The tires are the limiting parts in this example, even though there are more tires than anything else. There are also not enough headlights for all the car bodies.
3. Show students the balloon/flask assemblies and ask them to predict what will happen when the sodium bicarbonate is added to the acetic acid in the flask. Write the reaction equation on the board.
4. Line up flasks 1–6 from right to left on the lecture desk. Lift each balloon in turn and shake it to allow the solid to fall into the solution. Make sure the neck of each balloon stays firmly attached to the flask.
5. The reactions will be immediate and vigorous. The white solids will dissolve, the solutions will start to bubble and fizz, and the balloons will become inflated.
6. Allow the reactions to proceed until the bubbling stops. Swirl the flasks, if necessary. Compare the size of the inflated balloons and whether all the solid has dissolved in each case. *(The balloon size should increase fairly uniformly for flasks 1–4, and then stay constant. It may be hard to tell the difference between flasks 3, 4, 5, and 6.)*
7. Discuss the observations and carry out the necessary calculations to explain the results (See Table 2). Identify the limiting reactant and the excess reactant in each case.

Table 2.

Flask	Acetic Acid		Sodium Bicarbonate		Moles CO_2 Produced (Theoretical)
	Volume	Moles	Mass	Moles	
1	10 mL	0.020	0.50 g	0.0060	0.0060
2	10 mL	0.020	1.00 g	0.0119	0.0119
3	10 mL	0.020	1.50 g	0.0179	0.0179
4	10 mL	0.020	2.00 g	0.0238	0.0200
5	10 mL	0.020	2.50 g	0.0298	0.0200
6	10 mL	0.020	3.00 g	0.0357	0.0200

Disposal

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

Tips

- Enough materials have been included in this kit to perform the demonstration at least seven times.
- Use new balloons each time the demonstration is performed. Once used, the balloons will become stretched, and their inflated sizes may vary considerably from the expected size.
- Unreacted (undissolved) sodium bicarbonate will be visible in flasks 4, 5, and 6. The solid, although normally water soluble, does not dissolve in the final solution.
- Add a few drops of universal indicator to each flask and observe the color changes as the pH of the solution changes over the course of the reaction.

- Excess reactants are used commercially in cases where reactions are reversible and thermodynamically unfavorable. An example of a gas-phase inorganic reaction is the synthesis of ammonia from nitrogen and hydrogen. Excess nitrogen is used to drive the reaction to completion. The synthesis of organic esters from organic alcohols and acids is another example of commercial processes that are normally carried out in the presence of excess reactants.
- Carry out the demonstration using sodium carbonate instead of sodium bicarbonate. The maximum amount of CO_2 evolution will be observed at a lower mass of sodium carbonate, due to the 2:1 mole ratio for reaction of acetic acid with sodium carbonate.
- This reaction also works well using 20–25 mL of 1 M acetic acid.

Discussion

Equation 1 summarizes the reaction between sodium bicarbonate and acetic acid.

$$NaHCO_3(s) + CH_3CO_2H(aq) \rightarrow NaCH_3CO_2(aq) + CO_2(g) + H_2O(l) \qquad \textit{Equation 1}$$

The sodium bicarbonate and acetic acid react in a 1:1 ratio. Sodium bicarbonate is the limiting reactant in Flasks 1–3. In Flasks 3–6, the acetic acid is the limiting reactant.

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 Questions

Data Table

Flask	Acetic Acid		Sodium Bicarbonate		Limiting Reagent	Moles CO_2 Produced (Theoretical)
	Volume	Moles	Mass	Moles		
1	10 mL	0.020	0.50 g	*0.0060*	*Sodium bicarbonate*	*0.0060*
2	10 mL	0.020	1.00 g	*0.0119*	*Sodium bicarbonate*	*0.0119*
3	10 mL	0.020	1.50 g	*0.0179*	*Sodium bicarbonate*	*0.0179*
4	10 mL	0.020	2.00 g	*0.0238*	*Acetic acid*	*0.0200*
5	10 mL	0.020	2.50 g	*0.0298*	*Acetic acid*	*0.0200*
6	10 mL	0.020	3.00 g	*0.0357*	*Acetic acid*	*0.0200*

1. Calculate the number of moles of sodium bicarbonate that were present in each flask. Use the space below to work out the answer. Record your answer in the Data Table.

   Student work will vary. Answers are in the Data Table.

2. Write a balanced chemical equation for the reaction between sodium bicarbonate and acetic acid. Use the equation to determine the ideal mole ration for the reaction.

   $NaHCO_3(s) + CH3CO2H(aq) \rightarrow NaCH_3CO_2(aq) + CO_2(g) + H_2O(l)$

3. Decide which chemical was the limiting reagent, and therefore how many moles of carbon dioxide were produced, in each flask. Record your answers in the Data Table.

   Answers are in the Data Table.

Reference

This activity is from *Flinn ChemTopic™ Labs,* Volume 7, Molar Relationships and Stoichiometry. Cesa, I., Ed., Flinn Scientific; Batavia, IL, 2002.

Stoichiometry Balloon Races—Chemical Demonstration Kit is available from Flinn Scientific, Inc.

Catalog No.	Description
A0095	Acetic Acid, 1 M, 1 L
S0043	Sodium Bicarbonate, Lab Grade, 500 g
GP3040	Erlenmeyer Flasks, 125-mL
AP1900	Balloons, 12″, Mixed Colors, Pkg/20

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

Name: ______________________________

Stoichiometry Balloon Races Demonstration Worksheet

Data Table

Flask	Acetic Acid		Sodium Bicarbonate		Limiting Reagent	Moles CO_2 Produced (Theoretical)
	Volume	Moles	Mass	Moles		
1	10 mL	0.020	0.50 g			
2	10 mL	0.020	1.00 g			
3	10 mL	0.020	1.50 g			
4	10 mL	0.020	2.00 g			
5	10 mL	0.020	2.50 g			
6	10 mL	0.020	3.00 g			

Discussion Questions

1. Calculate the number of moles of sodium bicarbonate that were present in each flask. Use the space below to work out the answer. Record your answer in the Data Table.

2. Write a balanced chemical equation for the reaction between sodium bicarbonate and acetic acid. Use the equation to determine the ideal mole ration for the reaction.

3. Decide which chemical was the limiting reagent, and therefore how many moles of carbon dioxide were produced, in each flask. Record your answers in the Data Table.

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Publication No. 6443

Stoichiometry and Solubility

Mole Ratios and Chemical Formulas Demonstration Kit

Introduction

Double replacement reactions are generally considered to be irreversible. The formation of an insoluble precipitate provides a driving force that makes the reaction proceed in one direction only. The purpose of this demonstration is to find the optimum mole ratio for the formation of a precipitate in a double replacement reaction and use this information to predict the chemical formula of the precipitate.

Concepts

- Stoichiometry
- Double replacement reaction
- Mole ratio
- Solubility rules

Materials (for each demonstration)

Copper(II) chloride solution, $CuCl_2$, 0.05 M, 210 mL*
Iron(III) nitrate solution, $Fe(NO_3)_3$, 0.1 M, 210 mL*
Sodium hydroxide solution, NaOH, 0.1 M, 210 mL*
Trisodium phosphate solution, Na_3PO_4, 0.05 M, 210 mL*
Graduated cylinders, 50-mL, 4
Graduated cylinders, 100-mL, 14
Stirring rods, long, 2
Marker or labeling pen

**Materials included in kit.*

Safety Precautions

Copper(II) chloride, iron(III) nitrate, sodium hydroxide, and trisodium phosphate solutions are skin and eye irritants and are slightly toxic by ingestion. Avoid contact with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

Part A. Reaction of Iron(III) Nitrate with Sodium Hydroxide

1. Label seven 100-mL graduated cylinders 1–7.
2. Using a clean, 50-mL graduated cylinder, add the appropriate volume of iron(III) nitrate solution to each 100-mL graduated cylinder, as shown in Table 1.
3. Use a second 50-mL graduated cylinder to add the appropriate volume of sodium hydroxide solution to each 100-mL graduated cylinder, as shown in Table 1.

Table 1.

Cylinder	**1**	**2**	**3**	**4**	**5**	**6**	**7**
$Fe(NO_3)_3$, 0.1 M, mL	10	15	20	30	40	45	50
NaOH, 0.1 M, mL	50	45	40	30	20	15	10
Fe^{3+}:OH^- Mole Ratio	1:5	1:3	1:2	1:1	2:1	3:1	5:1
Volume of Precipitate	20	33	10	2	0	0	0

4. Use a large stirring rod to thoroughly mix the reactants. Observe the signs of chemical reaction in each cylinder. (Mixing the yellow-orange solution of iron(III) nitrate with the colorless sodium hydroxide solution gives a rust-colored precipitate and a pale yellow supernatant.)
5. Let the reaction mixtures sit undisturbed for at least 10 minutes to allow the precipitates to settle. During this time, write the reactants on the board and identify the possible products. Ask students to predict which ratio will result in the largest amount of precipitate.
6. After the precipitates have settled, record the volume of precipitate in each graduated cylinder.
7. What mole ratio gave the maximum amount of precipitate?

Part B. Reaction of Copper(II) Chloride with Sodium Phosphate

8. Label seven 100-mL graduated cylinders 1–7.
9. Using a clean, 50-mL graduated cylinder, add the appropriate volume of copper(II) chloride solution to each 100-mL graduated cylinder, as shown in Table 2.
10. Use a second 50-mL graduated cylinder to add the appropriate volume of sodium phosphate solution to each 100-mL graduated cylinder, as shown in Table 2.

Table 2.

Cylinder	**1**	**2**	**3**	**4**	**5**	**6**	**7**
$CuCl_2$, 0.05 M, mL	10	20	25	30	35	40	50
Na_3PO_4, 0.05 M, mL	50	40	35	30	25	20	10
Cu^{2+}:PO_4^{3-} Mole Ratio	1:5	1:2	2:3	1:1	3:2	2:1	5:1
Volume of Precipitate	30	40	45	50	55	50	42

11. Use a large stirring rod to thoroughly mix the reactants. Observe the signs of chemical reaction in each cylinder. (Mixing the blue solution of copper(II) chloride with the colorless sodium phosphate solution gives an aqua-colored precipitate and a colorless supernatant.)
12. Let the reaction mixtures sit undisturbed for at least 10 minutes to allow the precipitates to settle. During this time, write the reactants on the board and identify the possible products. Ask your students to predict which ratio will result in the largest amount of precipitate.
13. After the precipitates have settled, record the volume of precipitate in each graduated cylinder on the board.
14. What mole ratio gave the maximum amount of precipitate? Ask your students to explain.

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. Filter or decant the reaction mixtures from Parts A and B to collect the solid products. The solids may be packaged for landfill disposal according to Flinn Suggested Disposal Method #26a. The waste solutions may be rinsed of down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- This kit contains enough chemicals to perform the demonstration as written seven times: 1500 mL each of copper(II) chloride, iron(III) nitrate, sodium hydroxide and sodium phosphate.
- Carrying out the reactions in graduated cylinders makes it easy to measure the volume of precipitate and determine the optimum mole ratio. The reactions may also be carried out in large test tubes in a test tube rack. The quantities may also be scaled down to convenient test tube size.
- This demonstration works best if the precipitates are allowed to settle for at least 15 minutes before recording the volume of solid obtained.

- This demonstration illustrates the method of continuous variation. The best way to use this method is to graph the amount of product obtained in each reaction as a function of the mole ratio. Ideally, the amount of product should increase in a continuous manner, and then begin to decrease. To find the optimum mole ratio, draw two best-fit straight lines through the increasing and decreasing points on the graph. The optimum mole ratio should occur at the intersection of the two lines. **Notice that if this graphical method is used, it is not necessary to use the optimum mole ratio in a single run—the ratio is determined by extrapolation.** Thus, The 25/35 ratio of $CuCl_2$ and Na_3PO_4 is conveniently simplified to a 2:3 ratio instead of the actual 5:7 ratio.
- It is not necessary to do all the sample trials for this demonstration. Cylinders #6 and #7 can be eliminated in the iron(III) reaction and cylinders #1 and #7 for the copper(II) reaction—a maximum will still be observed in the graph.
- The continuous variation method may be extended to determine the optimum mole ratio and the chemical formula of the precipitate for any double replacement reaction. Keep a solubility chart and a table of common ion charges handy to help students predict the formulas of the products obtained in double replacement reactions.
- The iron(III) hydroxide demonstration provides somewhat surprising results, in that no precipitate is observed at high concentrations of iron(III) ions. This is due to the formation of soluble, polynuclear complex ions, evidenced by the appearance of a deep red-brown color. (Excess iron(III) ions should appear yellow in solution.) A definite hydroxide $Fe(OH)_3$ probably does not exsist, and the red-brown precipitate commonly called iron(III) hydroxide is best described as hydrous or hydrated iron(III) oxide.
- The color of the liquid above the precipitate may be used to illustrate the excess reagent in each case. In the copper series, the liquid in trials 1–4 are colorless, as $Cu(NO_3)_2$ is the limiting reagent. Excess copper nitrate is apparent from the blue liquid in trials 6 and 7.

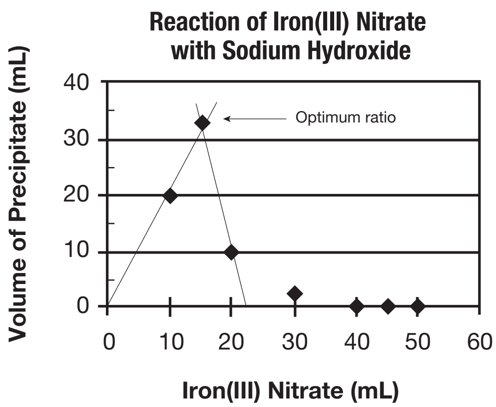
Discussion

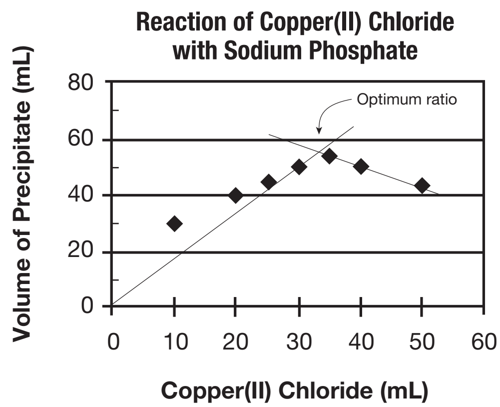
Equations 1 and 2 summarize the chemical reactions occurring in Parts A and B, respectively. The results of the experiments are illustrated graphically below.

$$Fe(NO_3)_3(aq) + 3NaOH(aq) \rightarrow Fe(OH)_3(s) + 3NaNO_3(aq) \qquad \textit{Equation 1}$$

$$3CuCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Cu_3(PO_4)_2(s) + 6NaCl(aq) \qquad \textit{Equation 2}$$

Graduated cylinder #2 should have the most precipitate for the iron(III) reaction and cylinder #5 should have the most precipitate for the copper(II) reaction.





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, chemical reactions

Answers to Worksheet Questions

Data Tables

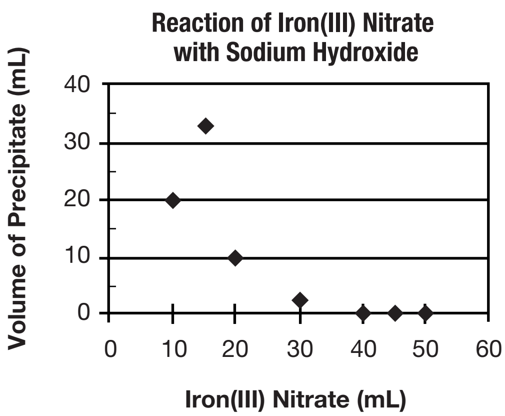
Cylinder	1	2	3	4	5	6	7
$Fe(NO_3)_3$, 0.1 M, mL	10	15	20	30	40	45	50
NaOH, 0.1 M, mL	50	45	40	30	20	15	10
Fe^{3+}:OH^- Mole Ratio	1:5	1:3	1:2	1:1	2:1	3:1	5:1
Volume of Precipitate	20	33	10	2	0	0	0

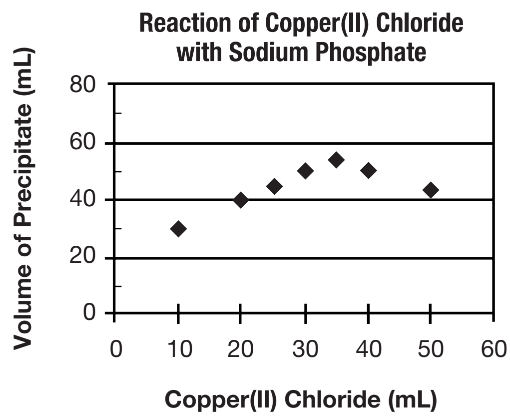
Cylinder	1	2	3	4	5	6	7
$CuCl_2$, 0.05 M, mL	10	20	25	30	35	40	50
Na_3PO_4, 0.05 M, mL	50	40	35	30	25	20	10
Cu^{2+}:PO_4^{3-} Mole Ratio	1:5	1:2	2:3	1:1	3:2*	2:1	5:1
Volume of Precipitate	30	40	45	50	55	50	42

*Actual ratio = 7 : 5. Optimum ratio obtained from graph.

Discussion Questions

1. Draw two graphs, showing the volume of precipitate produced for each cylinder in the iron(III) reaction and in the copper(II) reaction.





2. For each reaction, which cylinder and mole ratio produced the most precipitate?

   In the iron(III) reaction, Cylinder #2 had the most precipitate. Cylinder #2 contained 15 mL of iron(III) nitrate and 45 mL of sodium hydroxide. The mole ratio was 1:3. In the copper(II) reaction, Cylinder #5 had the most precipitate. Cylinder #5 contained 35 mL of copper(II) chloride and 25 mL of trisodium phosphate. The ideal mole ratio is 3:2.

3. Write two balanced chemical equations, one for each reaction.

   $Fe(NO_3)_3(aq) + 3NaOH(aq) \rightarrow Fe(OH)_3(s) + 3NaNO_3(aq)$

   $3CuCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Cu_3(PO_4)_2(s) + 6NaCl(aq)$

Reference

This activity is from *Flinn ChemTopic™ Labs,* Volume 7, *Molar Relationships and Stoichiometry*; Cesa, I., Ed; Flinn Scientific: Batavia, IL, 2002.

The *Stoichiometry and Solubility—Demonstration Kit* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP6443	Stoichiometry and Solubility—Demonstration Kit
GP2020	Graduated Cylinder, 100 mL
GP2056	Graduated Cylinder, Economy Choice, 100 mL

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

Name: ____________________

Stoichiometry and Solubility Demonstration Worksheet

Data Tables

Cylinder	1	2	3	4	5	6	7
$Fe(NO_3)_3$, 0.1 M, mL							
NaOH, 0.1 M, mL							
Fe^{3+}:OH^- Mole Ratio							
Volume of Precipitate							

Cylinder	1	2	3	4	5	6	7
$CuCl_2$, 0.05 M, mL							
Na_3PO_4, 0.05 M, mL							
Cu^{2+}:PO_4^{3-} Mole Ratio							
Volume of Precipitate							

Discussion Questions

1. Draw two graphs, showing the volume of precipitate produced for each cylinder in the iron(III) reaction and in the copper(II) reaction.

2. For each reaction, which cylinder and mole ratio produced the most precipitate?

3. Write two balanced chemical equations, one for each reaction.

Flame-Retardant Balloon

A Discrepant Event

Introduction

Show students a "special" balloon that doesn't pop when exposed to a flame. Students will come up with very clever ideas for why the balloon doesn't pop. But, when all is said and done, the "magic" is the result of important scientific principles involving specific heat capacity and heat transfer.

Concepts

- Specific heat capacity
- Heat transfer

Background

Rubber latex begins to melt and decompose at approximately 120 °C. Water boils at 100 °C. When a flame touches a balloon inflated with air, the rubber quickly weakens and the balloon pops. When a flame touches a balloon filled with water, the balloon will not pop. This is because most of the heat energy is transferred into the water instead of the rubber. Water has a large specific heat capacity, meaning it requires a relatively large amount of heat (compared to metals and plastics) to raise the temperature of the water by one degree Celsius. Water has a specific heat of 4.184 J/g·°C, whereas rubber and steel have specific heat capacities of approximately 1.6 J/g·°C, and 0.5 J/g·°C, respectively. The water in the balloon will continue to absorb the heat energy of the flame and the water temperature rises slowly. The temperature of the rubber is prevented from rising any faster than the temperature of the water. Since the temperature of the water will never rise above 100 °C, its boiling point, the temperature of the rubber will not rise above 100 °C until all the water has evaporated. Therefore, the section of the water-filled balloon that is touching the flame will not reach its melting or decomposition temperature, and the balloon does not pop.

Materials

Balloons, medium or large size, opaque, 2

Beaker or graduated cylinder, 50-mL

Candle, match, or butane lighter

Pipet, Beral-type

Water, 25 mL

Safety Precautions

Although latex (in balloons) is considered nonhazardous, not all health aspects of this substance have been thoroughly investigated. Latex may be an allergen. Use caution when handling the candle, match, or butane lighter to pop the balloon. Rubber balloon pieces may turn into projectiles after the balloon pops. Wear chemical splash goggles.

Preparation

1. Measure 25 mL of water using a graduated cylinder or beaker.
2. Use a Beral-type pipet to add the 25 mL of water to one of the opaque balloons.
3. Inflate the other balloon with air until it is approximately the same size as the water filled balloon.
4. Tie off the ends of both balloons.

Procedure

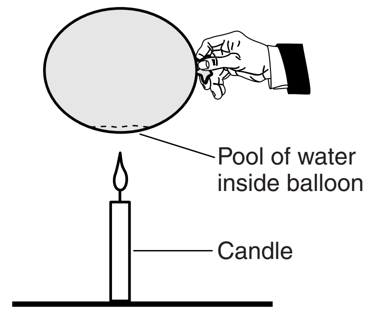


Figure 1.

1. Ignite a candle and place it upright on a tabletop. Or, simply light a butane lighter.
2. Touch the lowest point of the air filled balloon to the flame. The balloon should instantly pop.
3. Relight the candle if necessary.
4. Touch the lowest point of the water filled balloon to the flame. Make sure to touch the lowest point on the balloon to the flame because the water will collect in this region (see Figure 1). The balloon will not pop! *(The rubber will scorch and turn black, however.)*
5. Continue to hold the balloon over the flame for 10–20 seconds. The balloon will not pop.
6. Have students discuss their observations and suggest possible reasons for why the balloon does not pop.

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 balloon fragments may be placed in the trash according to Flinn Suggested Disposal Method #26a.

Tips

- Practice this demonstration before performing to determine the best quantity of water to use for different balloon sizes. Also, practice placing the balloon over the flame to make it appear as if the two balloons are identical. Do not make it obvious that you are placing the water-filled balloon over the flame at a “specific” location on the balloon. Students may quickly question whether there is something in the balloon that prevents it from popping.
- Do not use a Bunsen burner or propane burner for this demonstration. The flame will be too large and hot and will quickly pop the balloon containing water.
- Thick, opaque, colored balloons work best because the water inside the balloon will not be visible.

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 A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, interactions of energy and matter.

Materials for *Flame Retardant Balloon—A Discrepant Event* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1900	Balloons, Latex, Pkg/20
AP8960	Butane Safety Lighter
AP1935	Book Matches

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

Soda Can Calorimeter

Energy Content of Food

FLINN SCIENTIFIC SCIENCE FAX!

Introduction

Have you ever noticed the nutrition label located on the packaging of the food you buy? One of the first things listed on the label are the calories per serving. How is the calorie content of food determined? This activity will introduce the concept of calorimetry and investigate the caloric content of snack foods.

Concepts

- Calorimetry
- Conservation of energy
- First law of thermodynamics

Background

The law of conservation of energy states that energy cannot be created or destroyed, only converted from one form to another. This fundamental law was used by scientists to derive new laws in the field of *thermodynamics*—the study of heat energy, temperature, and heat transfer. The *First Law of Thermodynamics* states that the heat energy lost by one body is gained by another body. Heat is the energy that is transferred between objects when there is a difference in temperature. Objects contain heat as a result of the small, rapid motion (vibrations, rotational motion, electron spin, etc.) that all atoms experience. The temperature of an object is an indirect measurement of its heat. Particles in a hot object exhibit more rapid motion than particles in a colder object. When a hot and cold object are placed in contact with one another, the faster moving particles in the hot object will begin to bump into the slower moving particles in the colder object making them move faster (vice versa, the faster particles will then move slower). Eventually, the two objects will reach the same equilibrium temperature—the initially cold object will now be warmer, and the initially hot object will now be cooler. This principle is the basis for *calorimetry*, or the measurement of heat transfer.

In the 1770s, Joseph Black (1728–1799) was one of the first scientists to conduct calorimetry experiments with different materials. He discovered that not all materials are equal when it comes to heat transfer. He concluded that different materials have their own unique ability to retain heat energy. Some materials, like water, can gain a large amount of heat energy without a significant change in temperature, while other materials, such as metals, will have a more dramatic temperature change for the same amount of heat energy gained. This property is based mainly on the structure of the material, the size of the atoms and molecules, and the interactions between them. This is known as the *specific heat* of the substance. The specific heat is defined as the heat energy required to raise the temperature of one gram of a substance by one degree Celsius. The unit of energy commonly associated with heat is called a *calorie*. Water has a defined specific heat of 1 cal/g °C so it takes one calorie of energy to raise the temperature of one gram of water by one degree Celsius. (The reverse is also true, remove one calorie of heat from one gram of water, and the temperature will decrease by one degree Celsius.) With the specific heat of a substance known, the amount of heat energy gained or lost by a substance can then be calculated if the temperature change is measured.

In this experiment, the specific heat of water and its change in temperature will be used to determine the caloric content of a food sample. The normal unit for measuring the energy content in food is called a Calorie (with an uppercase C). A Calorie is really a kilocalorie, or 1000 calories (lowercase c). During calorimetry, food burns and its stored energy is quickly converted into heat energy and products of combustion (carbon dioxide and water). The heat energy that is released is then transferred into the water above it in the calorimeter. The temperature change in the water is then measured and used to calculate the amount of heat energy released from the burning food. The heat energy is calculated using Equation 1.

$$Q = mC\Delta T \qquad \textit{Equation 1}$$

where

Q = heat energy
m = mass of the water
C = specific heat of the water
ΔT = change in water temperature, $T_{final} - T_{initial}$
("Δ" is the Greek letter Delta which means "change in")

Materials

Balance (0.01-g precision)
Cork stopper
Butane safety lighter
Graduated cylinder, 50-mL
Metal ring with clamp
Pin, large straight
Ruler, metric
Snack foods (cheese puffs, popcorn, marshmallows, etc.)
Soda can, empty and clean
Stirring rod, glass
Support stand
Thermometer
Water, distilled or tap, 50 mL

Safety Precautions

Wear safety glasses when performing this or any lab that uses chemicals, heat or glassware. Care should be taken when handling or placing food onto the pin point. Allow the food sample to cool before touching or discarding it. Use a glass stirring rod to stir the liquid; never stir with a thermometer. Students should not be allowed to eat the snack foods once they are brought into the lab. This lab should be performed in a well-ventilated room. Wash hands thoroughly with soap and water before leaving the laboratory.

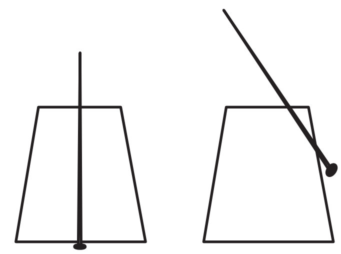


Figure 1.

Procedure

1. Push the pin through the cork so that the pin head is flush with the cork. If the pin is large enough, try to go through the center. If this is hard to do, try to insert the pin at an angle through the side and top of the cork (see Figure 1). *Note:* This setup will now be referred to as the "Food Holder."
2. Place a food sample on the food holder. Measure and record the combined mass of the food holder and sample. Place the food holder on the base of a support stand.
3. Using a graduated cylinder, measure and add 50.0 mL of water to an empty, clean soda can.
4. Bend the tab on the soda can and slide a glass stirring rod through the hole. Suspend the can on a support stand using a metal ring (see Figure 2). Adjust the height of the can so that it is about 2.5 cm above the food holder.
5. Insert a thermometer into the can. Measure and record the initial temperature of the water.
6. Light the food sample and center it under the soda can. Allow the water to be heated until the food sample stops burning. Record the maximum (final) temperature of the water in the can.
7. Measure and record the final mass of the food holder and sample.
8. Allow the can and pin to cool, and then clean the bottom of the can and remove any food residue from the food holder.
9. Repeat steps 1–8 two more times with two different snack food samples.

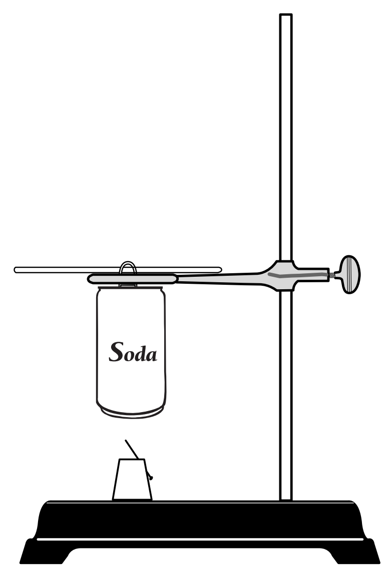


Figure 2.

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. Burned food samples should be allowed to cool and may be disposed of in the trash according to Flinn Suggested Disposal Method #26a.

Sample Data Table *(Student data may vary.)*

Data Table — The Experiment

Food Sample	Initial Mass (food sample and holder), g	Final Mass (food sample and holder), g	Initial Temperature of Water, °C	Final Temperature of Water, °C
Cheese Puff	*4.18 g*	*4.08 g*	*21.8 °C*	*27.1 °C*
Marshmallow	*6.08 g*	*6.00 g*	*22.0 °C*	*23.6 °C*
Onion Ring	*4.87 g*	*4.74 g*	*23.0 °C*	*30.1 °C*

Analysis and Calculations *(The sample calculations are for a cheese puff.)*

1. Determine the change in temperature of the water by subtracting the initial water temperature from the final water temperature.

   $\Delta T = T_{final} - T_{inital} = 27.1\ °C - 21.8\ °C = 5.3\ °C$

2. Calculate the heat gained by the water using Equation 1 from the Background section. The mass of water used is 50.0 g and the specific heat of water (C) is 1.0 cal/g °C. These values will give you the heat gained in calories.

   $Q = m \times C \times \Delta T = 50.0\ g \times 1.0\ cal/g°C \times 5.3\ °C = 265\ cal.$

3. Convert the heat gained from calories to food Calories (kilocalories) by dividing the answer above by 1000.

   265 cal. ÷ 1000 = 0.265 Cal.

4. Determine how much of the food burned by subtracting the final mass of the cork/pin/food assembly from the initial mass.

   4.18 g – 4.08 g = 0.10 g

5. Calculate the energy content per gram of the food sample. This is done by dividing the heat gain of the water (in Calories), by the change in mass of the food sample.

   0.265 Cal. ÷ 0.1 g = 2.65 Cal./g

Note to Teacher: *The total energy content in Calories per gram for all the foods will be lower than the actual energy content listed on their nutrition label. This is due to the simplicity of the calorimeter used in this experiment. However, if the foods are ranked from highest energy content to lowest energy content based on the class results, the relative ranking should be the same as an actual ranking from the nutrition labels. You might want to summarize the results obtained above (in Cal/g) for three foods to show this is true.*

NGSS Alignment

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

Disciplinary Core Ideas: Middle School

- MS-PS1 Matter and Its Interactions
  - PS1.A: Structure and Properties of Matter
- MS-PS3 Energy
  - PS3.A: Definitions of Energy
  - PS3.B: Conservation of Energy and Energy Transfer
  - PS3.C: Relationship between Energy and Forces

Disciplinary Core Ideas: High School

- HS-PS1 Matter and Its Interactions
  - PS1.A: Structure and Properties of Matter
- HS-PS3 Energy
  - PS3.A: Definitions of Energy
  - PS3.B: Conservation of Energy and Energy Transfer
  - PS3.C: Relationship between Energy and Forces

Science and Engineering Practices

- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking

Crosscutting Concepts

- Cause and effect
- Energy and matter

Tips

- A butane safety lighter (Flinn Catalog No. AP8960) is recommended instead of matches because it may take about 10 seconds for the food to ignite.
- For further concept development, try the Flinn Scientific “Calorimetry Basics—Specific Heat Laboratory Kit” (Catalog No. AP5952).
- Have students pin the food piece at one of the ends so that the piece “points up” and the length is parallel to the pin.
- It may take about 10 seconds to get the food ignited, so some heat related to the burning food will be lost during this process. A small flame on the food will spread and engulf it over time.
- Be sure that when the food sample burns, it is close to but not touching the soda can. If it is too close to the bottom of the can, it may extinguish too early due to a lack of oxygen.
- Black carbon soot will deposit on the bottom of the can when the food burns. For best results, this soot should be wiped off with a little water and a paper towel between trials.
- Have students try different samples of food in order to compare the caloric contents of different foods. *Note:* Avoid sugar cookies, pretzels, soda crackers or other food samples with a high sugar content. They tend to get soft as they burn and may fall off the pin. Walnuts, pecans, popped corn, and Cheetos® (or other puffed snacks) are good choices.
- Good ventilation is required since burning food can generate a large amount of smoke. Allow some time between trials so that the smoke has time to dissipate.

References

Cesa, I. *Flinn ChemTopic™ Labs, Volume 10, Thermochemistry;* Batavia, IL, 2002; pp 39–49.

Kotz, J. C.; Treichel, Jr., Paul. *Chemistry and Chemical Reactivity*, 3rd Ed.; Saunders College: New York, 1996; pp 264–271.

Tipler, P. A. *Physics for Scientists and Engineers*, 3rd Ed., Vol. 1; Worth: New York, 1990; pp 518–524, 534–537.

Materials for *Soda Can Calorimeter* are available from Flinn Scientific, Inc.

Catalog No.	Description
OB2141	Flinn Scientific Electronic Balance (0.01-g precision)
AP8308	Cork Stopper, Size 8
AP8960	Butane Safety Lighter
GP2044	Graduated Cylinder, Borosilicate Glass, Plastic Base, 50 mL
AP8232	Metal Ring Support with Rod Clamp
AB1039	Pin, 20 Dissection
GP5075	Stirring Rod, Glass
AP8228	Support Stand
AP6049	Flinn Digital Pocket Thermometer

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

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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.

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