Reaction in a Bag

Scientific Method Demonstrations

Introduction

Careful observation is the foundation of science, leading to questions about what we have observed—how, what, why? The answers to these questions are sought in experiments, which may be described as observations made under controlled conditions. Observation and experiment are twin pillars of the scientific method.

Concepts

- Scientific method
- Observation
- Chemical reactions
- Chemical versus physical change
- Experiment
- Scientific design

Background

The scientific method is often presented as a rigid series of steps. The scientific method, however, is not a rigid path, it is a process—a process of discovery! Discovery begins when we make observations and then try to understand what we have observed by asking key questions. The process of discovery continues when we design experiments to test possible answers to these questions.

Chemistry is defined as the study of matter—what it is made of, its structure and properties, and the changes that it undergoes. Observations of the properties of matter often arise from the interaction of many different variables. Experiments need to be designed in such a way that the effects of different variables on the behavior of a substance can be studied independently. This is done by making observations under controlled conditions, where only one variable at a time is changed. Controlled experiments make it possible to separate the factors that are responsible for different observations.

The three substances used in this demonstration are all common chemicals. Sodium bicarbonate, or baking soda, is used as a food additive in baking. It is also used as a natural deodorant to remove odor-causing chemicals in refrigerators and in carpets. Calcium chloride ("road salt") is a salt-like compound that is used as a de-icer for sidewalks and roads. Phenol red is a naturally occurring dye that is used as an indicator—it changes color under different conditions. *Note:* Phenol red is a solution of the dye dissolved in water. Water should be considered as a fourth substance (variable) in the overall reaction, and its effect should also be examined.

When three substances—solid calcium chloride, solid sodium bicarbonate, and a solution of phenol red in water—are mixed, a series of changes is observed. These observations include temperature changes, color changes, and changes in state. How can we learn more about the individual interactions responsible for each observation? Imagine that each substance in the mixture represents a variable. By changing only one variable at a time, it should be possible to determine the contribution of each substance to the changes observed for the overall reaction.

Materials

Calcium chloride, $CaCl_2$, solid, 100 g
Phenol red solution, 0.02%, 70 mL
Sodium bicarbonate, $NaHCO_3$, solid, 40 g
Water, distilled or deionized, 70 mL
Beakers, 50-mL, 2
Beakers, 100-mL, 2
Graduated cylinder, 10-mL
Pen, labeling
Pipet, Beral-type, thin-stem
Sealable, zipper-lock plastic bags, 10
Teaspoon and tablespoon scoops
Wash bottle filled with distilled or deionized water
Student Data Tables, A and B

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Safety Precautions

Calcium chloride is slightly toxic by ingestion. Phenol red is a dye solution and will stain skin and clothing. Be careful to mix the chemicals in the amounts called for in the procedure. Adding too much of the solids may result in excessive release of gases that are difficult to contain and may cause chemical splashing. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

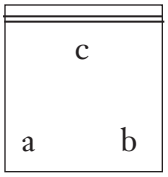
Demonstration Overview

The purpose of this inquiry-based demonstration is to have students make observations about the changes that occur when several substances are mixed. The students are then challenged to design controlled experiments to identify the substances responsible for the observed changes.

Procedure

Part A. The Overall Reaction

1. Make copies and distribute Data Table A and Data Table B to each student.
2. Label two 100-mL beakers "calcium chloride" and "sodium bicarbonate," respectively. Fill each beaker about one-half full with the appropriate solid.
3. Obtain both a teaspoon and tablespoon scoop to dispense the sodium bicarbonate and calcium chloride, respectively. Store the scoops in their respective beakers. It is essential each scoop is only used with the same chemical it originally contacted.
4. Obtain 40 mL each of phenol red and distilled water in separate, labeled, 50-mL beakers. Use a 10-mL graduated cylinder to dispense the liquids as needed in the following steps. After using the cylinder for the phenol red solution, be sure to rinse it with distilled or deionized water before using it again to dispense distilled water. A thin-stem pipet may also be used to dispense the liquid.
5. Have students observe and describe the appearance of calcium chloride, sodium bicarbonate, and phenol red solution, then record the observations in Data Table A.
6. Place the following three substances ***in separate locations*** in a sealable plastic bag that is lying flat on a table.
   a. 1 tablespoon of calcium chloride
   b. 1 teaspoon of sodium bicarbonate
   c. 10 mL of phenol red indicator solution



7. Squeeze out as much air as possible from the zipper-lock bag and seal it. Allow the contents to mix thoroughly.
8. Have the students approach and carefully observe (by means of sight and touch) the changes that take place in the zipper-lock bag. Have students record all their observations in Data Table A. *Note:* If the bag gets too tight due to the buildup of gas pressure, open the bag and then reseal it. Do NOT open the bag near your face or the face of any student!
9. The contents of the bag can be rinsed down the drain under running water. Rinse out the bag with water and dispose of the bag in the trash.
10. Have students discuss their observations.

    What questions arise concerning the changes that were observed during the reaction in the bag?

    Instruct students to consider at least *four questions* that could be investigated to determine the individual interactions that are responsible for the observed changes. For example, is water or a liquid necessary for the reaction to occur? Have students write their questions down in the spaces provided in Data Table A.

Part B. Control Experiments

1. Ask the students about the series of controlled experiments needed to determine which combinations of substances are responsible for each of the observed changes.

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2. Fill out the chart in Data Table B to indicate the substances used in each controlled experiment. Space has been provided for the nine possible control experiments. Fill out all nine combinations, although nine different tests are not needed to identify the substances responsible for the observed changes.
3. Use the same quantities of chemicals as in Part A and carry out the nine reactions in separate zipper-lock plastic bags. If water is tested in a controlled experiment, use the same amount of water as of phenol red solution in Part A.
4. After each demonstration experiment, have students observe the results, and then record their observations in the Data Table B.

Disposal

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

Tips

- If teaspoon and tablespoon measuring spoons are not available, plastic teaspoons will work well. Use three of these teaspoon-size amounts of calcium chloride in place of one tablespoon, as called for in the procedure. Plastic Solo™ cups can also be used instead of beakers to hold the reagents. If desired, the controlled experiments can be carried out in these plastic cups as well, although the temperature changes are easier to observe (feel) when the reactions are carried out in plastic bags.
- In order to maintain the introductory, "inquiry-based" quality of this demonstration, the procedure is qualitative rather than quantitative. Thus, the amounts of reagents are not massed and temperatures are not measured. The procedure can be adapted to a quantitative level, if desired, by massing the amounts of reagents used. An interesting extension in this case would be to find the ratio of reactants that produces the largest temperature change coupled with the greatest amount of gas. (These two trends may be at odds with one another.)
- It is not necessary to understand the precise chemical events that take place in this reaction in order to appreciate the essence of this activity, which is the nature of scientific inquiry. This activity provides a great introduction to develop the theme that the heart of science involves asking questions.
- The first part of this demonstration is a fun and easy way to introduce students to the study of chemistry—students can actually hold an experiment in their hands to see and feel what chemistry is all about. Students also learn to (1) observe phenomena and ask questions; (2) design a scientific study to answer their questions; (3) collect data; and (4) analyze data.
- The following information may be of interest to those students who are curious about what occurs. Do not present this information to the students prior to the activity! Calcium chloride produces heat (exothermic) when it dissolves in water, while sodium bicarbonate absorbs heat (endothermic) as it dissolves. Calcium chloride, baking soda, and water combine to produce carbon dioxide gas. Phenol red is an acid–base indicator that changes color in the presence of acids and bases. Sodium bicarbonate is a base, so it maintains the bright red (basic) color of phenol red at first. As sodium bicarbonate reacts with calcium chloride in water, acidic substances are produced and the color of the phenol red indicator changes from the basic form to its yellow, acidic form. Carbon dioxide is one of the acids produced—it dissolves in water and reacts to form carbonic acid, H_2CO_3, which makes the water acidic. As carbon dioxide is allowed to escape, the water may turn slightly orange or pink again.
- The products of the reaction include sodium chloride (NaCl), table salt; calcium carbonate ($CaCO_3$), the main component of chalk; and carbon dioxide (CO_2), the metabolic "waste" gas exhaled during respiration.
- The events that take place in the zipper-lock bag are part of a dynamic and complex reaction. Intermediate products may be formed and then react further to produce the final composition of the product mixture. The following equation pro vides a snapshot of the initial and final composition and does not show all of the possible intermediate products.

$$CaCl_2(aq) + 2NaHCO_3(aq) + \text{phenol red (basic form)} \rightarrow$$

$$CaCO_3(s) + 2NaCl(aq) + H_2O\,(aq) + CO_2(g) + \text{phenol red (acidic form)}$$

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- This demonstration does not require any knowledge of chemistry content beyond the scientific method. Teachers who have already covered physical and chemical changes, however, may find it natural to discuss these additional concepts as well. Which observations are due to physical changes and which to chemical changes? Challenge students to propose additional experiments to prove that dissolving the individual solids in water represent physical changes, but that reacting the two solids together in water produces a chemical change.

Post-Demonstration Discussion

Review the following questions with the class.

1. Based on the results of the control experiments, what interaction among the four substances seems to be responsible for the observed temperature change in the overall reaction?

   Mixing calcium chloride with water (either alone or in a solution of phenol red) produced the same temperature change as was observed for the overall reaction. A great deal of heat was produced and the mixture felt very hot to the touch.

2. Was there a temperature effect observed in any of the individual control experiments that was NOT observed in the overall reaction of the four chemical substances? Explain.

   When sodium bicarbonate was mixed with water (either alone or in a solution of phenol red), some of the solid dissolved and the solution felt slightly cool to the touch. This temperature decrease, due to the solution absorbing heat energy, was not observed in the overall reaction.

3. What color change was observed in the overall reaction of the substances? Do the control experiments provide any evidence concerning the interaction(s) responsible for the observed color change?

   In the overall reaction in Part A, the color changed from red to yellow. Mixing either of the solids with phenol red did not produce a color change. A slight color change was noted when phenol red was mixed with water. The red color faded to a paler shade of red-orange. The control experiments suggest, but do not prove, that the color change to yellow in the overall reaction is due to the production of a new substance with new acid–base properties.

4. Does the formation of gas bubbles occur independently of the observed temperature and color changes? Explain.

   The formation of gas bubbles occurs independently of the color change, that is, it was observed in a controlled experiment with three substances, calcium chloride, sodium bicarbonate, and water in the absence of the phenol red indicator. It is possible, therefore, that the gas bubbles make the solution turn yellow. Gas bubbles were always observed along with the large temperature increase, which was also observed when calcium chloride alone reacted (dissolved) with water. It is not possible, therefore, to conclude whether a temperature increase was also associated with the production of the gas.

5. What control experiments were done to evaluate if a liquid is necessary for the observed effects in Part A? Does any reaction occur in the absence of water?

   The two solids were mixed without any liquid (phenol red or water) present. No evidence of any reaction was observed. The two solids seemed to retain their individual appearance in the mixture of the two.

6. Is there any evidence that a new chemical substance is produced in the overall reaction of the four substances mixed in Part A? Explain. What interaction among the four components must be responsible for new substance?

   The strongest evidence for the production of a new chemical substance comes from the formation and release of gas bubbles when calcium chloride and sodium bicarbonate are mixed together in a liquid. Since the fizzing is not observed when either solid alone dissolves in water, even though the temperature changes, there is a good likelihood that the gas represents a new chemical substance. In order to answer this question precisely, however, it would be necessary to isolate the gas and study its properties. If it has different properties than any of the other substances, then it is a new chemical substance. The color change to yellow also suggests that a new substance is produced (it may be the gas!) which has different acid–base properties than the reactants. The new substance must be formed from "rearranging" the elements in the two solids, because either solid alone with water or phenol red failed to give either gas bubbles or a color change.

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7. Let's assume that the chemical identity of calcium chloride is not changed when it is mixed with water. Suggest an experiment that could be done to prove or disprove this hypothesis.

   If calcium chloride is still present in solution after the solid has dissolved in water, it should be possible to isolate it after all of the water has been removed by evaporation. Heat the solution until the water has evaporated and then test the properties of the remaining solid.

8. Temperature changes are sometimes used as evidence to indicate that a chemical reaction, which produces a new chemical substance, has occurred. Comment on using this observation as a "test" of a chemical reaction.

   Temperature changes alone do not provide clear evidence that a chemical reaction has occurred. Temperature changes can also accompany a physical change, such as when a solid dissolves in water.

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 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, chemical reactions
Content Standard G: History and Nature of Science, nature of scientific knowledge

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Reaction in a Bag* activity, presented by Jeff Hepburn, is available in *Scientific Method Demonstrations*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Reaction in a Bag* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in *A Reaction in a Bag—An Inquiry-Based Demonstration* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6607	A Reaction in a Bag—An Inquiry-Based Demonstration
C0016	Calcium Chloride, $CaCl_2$, 500 g
P0100	Phenol Red Indicator Solution, 0.02%, 100 mL
S0042	Sodium Bicarbonate, $NaHCO_3$, 500 g

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

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A Reaction in a Bag

Observation and Experiment

Data Table A. *The Overall Reaction*

What are properties of the individual substances?	
Chemical	**Observations**
Calcium Chloride	
Sodium Bicarbonate	
Phenol Red	
What happens when the substances are mixed together?	
Observations	
What interactions are responsible for the observed changes?	
Questions	

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Data Table B. *Control Experiments*

Place a check in the appropriate box to show which chemicals were mixed in each experiment.

Number	Calcium Chloride	Sodium Bicarbonate	Phenol Red	Water	Observations
1					
2					
3					
4					
5					
6					
7					
8					
9					

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Sample Data *(Student answers will vary.)*

Data Table A. *The Overall Reaction*

What are properties of the individual substances?	
Chemical	**Observations**
Calcium Chloride	White, granular solid, "chunky", odorless substance
Sodium Bicarbonate	White, powdery solid, very finely-divided, odorless substance
Phenol Red	Bright red, odorless, clear liquid
What happens when the substances are mixed together?	
Observations	There is an immediate color change from red to yellow as the four substances are mixed. The solids initially "disappear" into solution and the bag gets very hot; a great deal of heat is produced. Many tiny gas bubbles are released and the mixture looks like it is fizzing. Slight fizzing noise is heard. The bag begins to expand and feel "tight" as gas pressure builds up. The final mixture is a "chalky" yellow liquid.
What interactions are responsible for the observed changes?	
Questions	1. Is a liquid necessary for the overall reaction to occur? 2. Is the color change due to simple mixing of the reactants? 3. What interaction is responsible for the observed temperature change? 4. Does the production of gas arise from a new chemical substance being formed? 5. Does the formation of gas bubbles accompany the observed temperature or color changes?

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Data Table B. *Control Experiments*

Place a check in the appropriate box to show which chemicals were mixed.

Number	Calcium Chloride	Sodium Bicarbonate	Phenol Red	Water	Observations
1	✓	✓			No reaction. White solids retain their individual appearance after mixing.
2	✓		✓		White solid mostly dissolves; final mixture is slightly cloudy. Bag is quite hot. Final color is red (no change from initial indicator color.)
3	✓			✓	White solid "disappears" into solution and dissolves. Bag feels quite hot. Final solution is colorless but slightly cloudy.
4		✓	✓		White solid begins to disappear into solution, but does not dissolve completely. Final solution is cloudy or "chalky" pink (white solid and red liquid). Bag is cool to the touch.
5		✓		✓	White solid partially dissolves. Bag gets noticeably cool to the touch. Final solution is chalky white.
6			✓	✓	Liquids mix, form one solution. Color changes to paler red, almost orange color.
7	✓	✓		✓	Solution bubbles and fizzing noise is heard. Bag expands and feels tight. Bag is warm (hot) to the touch. Solids combine or react with each other; final mixture is chalky white.
8	✓		✓	✓	White solid dissolves. Bag feels hot to the touch. Color changes to paler shade of red.
9		✓	✓	✓	White solid partially dissolves. Cup feels slightly cold. Final mixture is chalky and pink due to white solid and red liquid.

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