Designing An Experiment Using Baking Soda and Vinegar

Introduction:

Kinetics is the study of chemical reaction rates. It is the study of how fast different chemicals react with one another to form new products. Some chemical reactions happen rapidly once the chemicals involved are allowed to mix, while other reactions occur relatively slow. For example, a very common kitchen experiment involves reacting baking soda (sodium bicarbonate) with household vinegar (a diluted solution of acetic acid, aka ethanoic acid).

The reaction between baking soda and vinegar is a two-step process summarized overall by the following word equation: baking soda (sodium bicarbonate) plus vinegar (acetic acid) yields carbon dioxide plus water plus sodium ion plus acetate ion

The chemical equation for the overall reaction is:

\[ \text{NaHCO}_3(s) + \text{CH}_3\text{COOH}(l) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l) + \text{Na}^+(aq) + \text{CH}_3\text{COO}^-(aq) \]

The first part of this two step reaction is double replacement reaction in which acetic acid in the vinegar reacts with sodium bicarbonate to form sodium acetate and carbonic acid:

\[ \text{NaHCO}_3(s) + \text{HC}_2\text{H}_3\text{O}_2(aq) \rightarrow \text{NaC}_2\text{H}_3\text{O}_2(aq) + \text{H}_2\text{CO}_3(aq) \]

During the second step, the Carbonic acid is undergoes a decomposition reaction to produce the carbon dioxide gas:

\[ \text{H}_2\text{CO}_3(aq) \rightarrow \text{H}_2\text{O}(l) + \text{CO}_2(g) \]

Learning Objectives:

Students will:

(a) design an experiment that investigates factors affecting rates of a chemical reaction (S2.1)
(b) determine/explain the causality of your investigation (S1.1)

Materials:

- Baking Soda
- Distilled Water
- Funnel
- Electronic Balance
- Parafilm
- Spoonula
- String
- 50mL Beakers (2)
- metric rulers
- Vinegar
- 20oz. plastic soda pop bottle
- Balloon
- Graduated cylinders: 100 mL and 10 mL
- Safety Goggles
- Stopwatch
- Digital thermometer
- Weighing boat
Hazard Information:

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Health Hazards</th>
<th>Physical Hazards</th>
<th>Environmental Hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Bicarbonate</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Vinegar (Acetic Acid)</td>
<td>Irritating to skin and eyes</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Waste:

<table>
<thead>
<tr>
<th>Description of Material (include concentration)</th>
<th>Quantity per group</th>
<th>Hazard</th>
<th>Disposal Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture of Baking Soda and Vinegar</td>
<td>120g baking soda &lt;500mL Vinegar</td>
<td>Low</td>
<td>Neutralize and Drain Disposal</td>
</tr>
<tr>
<td>Used Balloons</td>
<td>4 balloons</td>
<td>Low</td>
<td>Trash</td>
</tr>
</tbody>
</table>

Procedure:

Part 1 - Hypothesis Formation:
1.) Using a Spoonula, Place a heaping spoonful of baking soda into a 50mL beaker.
2.) Measure 5mL of vinegar using a graduated cylinder and place into a second 50mL beaker.
3.) Measure the temperature of the vinegar using a digital thermometer. Record in the Data Section.
4.) Pour the measured 5mL of vinegar into the 50mL beaker containing baking soda.
5.) Record all observations in the space provided.
6.) As soon as the reaction is complete, measure the temperature of the vinegar/baking soda solution. Record this temperature in the Data Section.
7.) Each group will be assigned one of two variables: Temperature, or Volume of gas produced. Record your variable in the Data Section.
8.) Form a hypothesis about what you think will happen when you mix baking soda and vinegar in various amounts. Be sure to address your variable in the hypothesis. State in terms of increasing or decreasing the amount of vinegar.
Part 2- Experimental Design

1.) You will design an experiment that tests your hypothesis for the assigned variable. If you are testing change in temperature, you will need to measure the increase/decrease in temperature during the reaction. If you are measuring volume of gas produced, you will need to use a soda bottle and balloon to collect gas and measure the circumference of the balloon.

2.) Each group will complete 4 trials of varying amounts of vinegar.

3.) Each trial will use 30 grams of baking soda.

4.) Design your experiment by filling in the Experiment Table in the Data Section with the amount of vinegar to be used in each trial.

5.) Write a brief step by step procedure of how you will conduct your experiment. Show your teacher and get permission before beginning next step.

Part 3- Run Your Procedure/ Data Collection

1.) Conduct your approved experiment.

2.) Record all observations and experimental data in the Experiment Table of the Data Section.

3.) Answer all Data Analysis questions.

Part 4- Sharing Your Results With the Class

1.) On the white board, display your results in the following order

<table>
<thead>
<tr>
<th>Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis</td>
</tr>
<tr>
<td>Table of Data</td>
</tr>
<tr>
<td>Did the data support your hypothesis, yes or no?</td>
</tr>
<tr>
<td>How do you know?</td>
</tr>
</tbody>
</table>
Data and Results:

Hypothesis:

1.) Temperature of vinegar before reaction _____________________ °C

2.) Observations of Reaction (Not all spaces need to be used)
   - _______________________________________________________________
   - _______________________________________________________________
   - _______________________________________________________________
   - _______________________________________________________________
   - _______________________________________________________________

3.) Temperature of vinegar/baking soda mixture after reaction _____________________ °C

4.) Variable Assigned ____________________________

5.) Form a hypothesis about the assigned variable. State in terms of increasing or decreasing the amount of vinegar used.
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________
Experimental Design:
Variable being tested __________________________

Table 1: Experiment Table

<table>
<thead>
<tr>
<th></th>
<th>Amount of Baking Soda Used, g</th>
<th>Amount of Vinegar Used, mL</th>
<th>Circumference of Balloon, cm OR Change in Temperature, °C</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>30g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td>30g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td>30g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 4</td>
<td>30g</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Written Procedure:
6.) Did the results of your experiment support your hypothesis? ________ Why or Why not?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

7.) Did you observe a relationship between amount of vinegar used and change in temperature/circumference of balloon? State the relationship in your own words.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

8.) Provide one source of error that may have effected the results of your experiment and explain how you could correct for this source of error.

Source of Error: __________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Possible Way to Correct Error: __________________________________________________________________

________________________________________________________________________

References:
Stacy Dawson, Oswego City School District,
http://staff.oswego.org/sdawson/cms/docs/stations/station%202.pdf
TEACHER INFORMATION

Regents Core

Teacher Tips:

This tends to be a messy lab, with eruptions and spills. Starting with a clean workspace that can easily be wiped down after lab makes clean up easier.

30 grams of baking soda will react with over 100mL of Vinegar. While approving experimental procedures, suggest values close to, but below 100mL of vinegar for students testing volume of gas produced.

The easiest method for the volume of gas produced is to place the vinegar in the soda bottle, and the baking soda in the balloon. Attach the balloon to the bottle, hold onto and lift the balloon so the baking soda falls into the bottle. This helps to prevent gas loss.

The excess baking soda used in the experiment makes the waste procedure simple. Combine all student waste into one container, slowly so that there is not an overflow, and test pH with pH paper. It should be slightly basic, but close to neutral (around a pH of 8). Drain dispose and rinse out container thoroughly to remove excess baking soda.

Preparation:

Having multiple containers for baking soda and vinegar will reduce bottlenecking at balances and during the student designed experimental portion of the lab.

Answers to Questions

-Common sources of error
  - Volume of gas produced:
    - Loss of gas during the reaction. This can be prevented by following the procedure outlined in tips, and by securing the balloon tightly.
    - Not all baking soda reacted. The baking soda is in excess in this experiment, so it will not all react, but if there is baking soda remaining in the balloon, inverting the bottle to pour fluid into the balloon and then allowing it to enter the bottle again will resolve this issue.

  Temperature change:
    - Gain of heat from surroundings: The surrounding room will provide heat to the endothermic reaction, causing the measured temperature loss to be less than it should be. This can be slowed by using a double insulated cup instead of a beaker. A true calorimeter will work even better.
WASTE

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>CAS Number</th>
<th>Health Hazards</th>
<th>Physical Hazards</th>
<th>Environmental Hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Bicarbonate</td>
<td>144-55-8</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Acetic Acid, &lt;5%</td>
<td>64-19-7</td>
<td>Irritant</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

1. How has this lab been modified to make it “greener”?

The experiment uses benign, readily available, inexpensive materials. All waste can be neutralized and drain disposed.

2. Which of the 12 principles of Green Chemistry were employed to make this lab greener? Please check all that apply.

- ☑ Prevention  It’s better to prevent waste than to treat or clean up waste afterwards.
- ☐ Atom Economy  Design synthetic methods to maximize the incorporation of all materials used in the process into the final product.
- ☑ Less Hazardous Chemical Syntheses  Design synthetic methods to use and generate substances that minimize toxicity to human health and the environment.
- ☐ Designing Safer Chemicals  Design chemical products to affect their desired function while minimizing their toxicity.
- ☑ Safer Solvents and Auxiliaries  Minimize the use of auxiliary substances wherever possible make them innocuous when used.
- ☑ Design for Energy Efficiency  Minimize the energy requirements of chemical processes and conduct synthetic methods at ambient temperature and pressure if possible.
- ☑ Use of Renewable Feedstocks  Use renewable raw material or feedstock rather whenever practicable.
- ☐ Reduce Derivatives  Minimize or avoid unnecessary derivatization if possible, which requires additional reagents and generate waste.
- ☐ Catalysis  Catalytic reagents are superior to stoichiometric reagents.
- ☑ Design for Degradation  Design chemical products so they break down into innocuous products that do not persist in the environment.
- ☐ Real-time Analysis for Pollution Prevention  Develop analytical methodologies needed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
- ☑ Inherently Safer Chemistry for Accident Prevention  Choose substances and the form of a substance used in a chemical process to minimize the potential for chemical accidents, including releases, explosions, and fires.¹