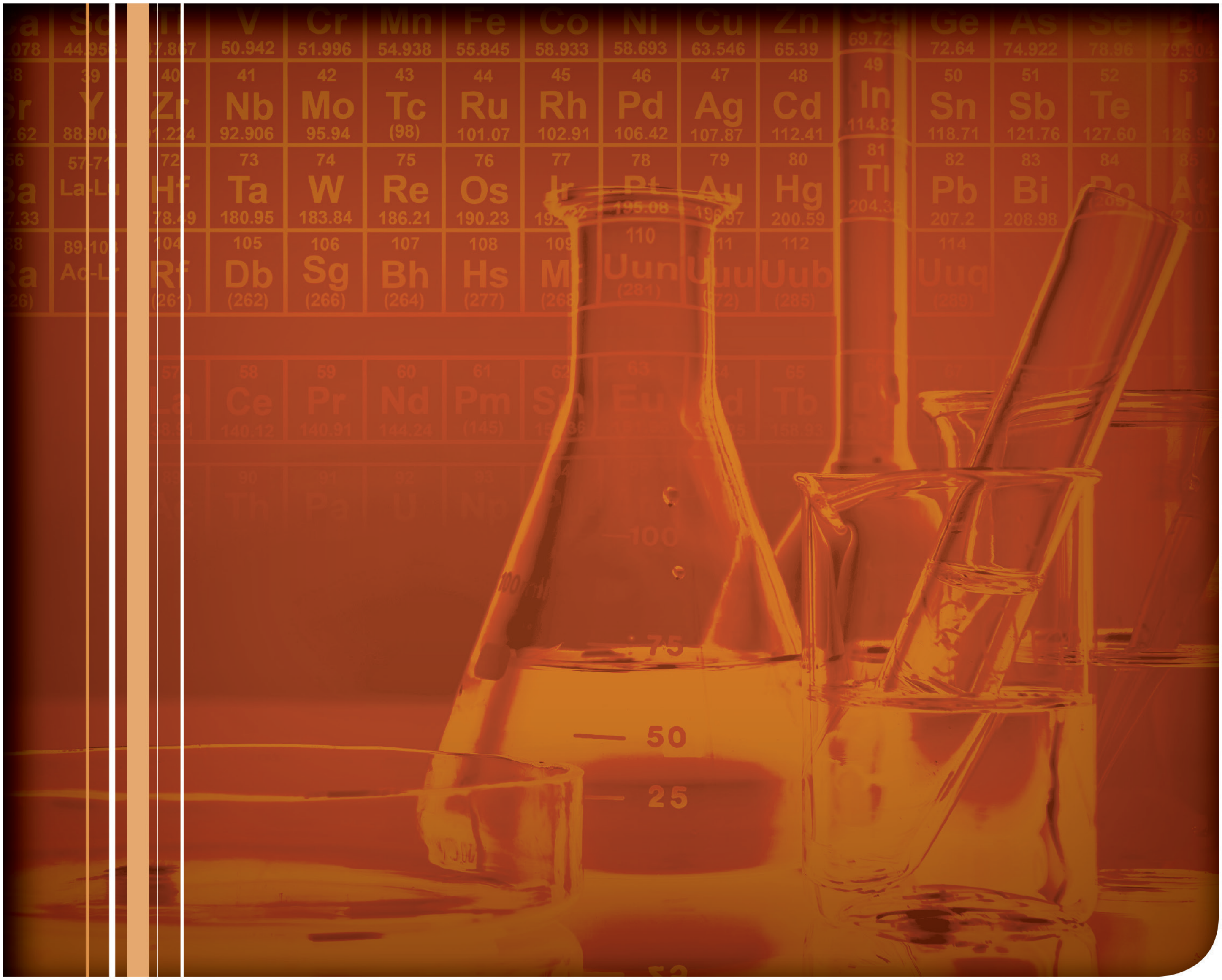

Investigating Chemical Reactions

Investigation Manual

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DISTANCE LEARNING

INVESTIGATING CHEMICAL REACTIONS

Contents

Overview

The common types of chemical reactions are studied and performed in this investigation, including synthesis, decomposition, single replacement, double replacement, and combustion. Chemical products are predicted for each reaction based on observations and chemical tests. A balanced chemical equation will be written for each reaction. After the investigation, a series of known reactions will be presented to classify and balance.

Objectives

- Describe common types of chemical reactions.
- Predict products from common chemical reactions, including synthesis, decomposition, single replacement, double replacement, and combustion.
- Write balanced chemical equations.
- Classify chemical reactions by type.
- Identify heat as a possible product or reactant.

Time Requirements

Preparation .... 10 minutes
Activity 1: Synthesis Reaction .... 20 minutes
Activity 2: Decomposition Reaction .... 15 minutes
Activity 3: Single-Replacement Reaction .... 20 minutes
Activity 4: Double-Replacement Reaction .... 15 minutes
Activity 5: Combustion Reaction .... 10 minutes
Activity 6: Precipitation Reaction .... 15 minutes
Activity 7: Combustion Reaction .... 5 minutes

Key

Background

Knowing how to recognize common types of chemical reactions allows a chemist to accurately predict the products of a given reaction. Chemical reactions can be grouped into the following five common reaction types: (1) synthesis, (2) decomposition, (3) single replacement, (4) double replacement, and (5) combustion.

1. Synthesis Reactions

Synthesis means to combine or put together. These reactions are sometimes referred to as combination reactions. In a synthesis reaction, two or more reactants combine to make a single new product.

$$A + B \rightarrow AB$$

Examples of synthesis reactions:

$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g) + \text{Heat}$

$H_2O\ (l) + SO_3\ (g) \rightarrow H_2SO_4\ (aq)$

2. Decomposition Reactions

Decomposition means to break down. In a decomposition reaction, a single reactant compound breaks down to form two or more new products.

$$AB \rightarrow A + B$$

Examples of decomposition reactions:

$H_2CO_3\ (aq) \rightarrow H_2O\ (l) + CO_2\ (g)$

$CaCO_3\ (s) \xrightarrow{\textbf{Heat}} CaO\ (s) + CO_2\ (g)$

$2NI_3 \rightarrow N_2\ (g) + 3I_2\ (s)$

3. Single-Replacement Reactions

Single-replacement reactions occur when a single element in one reactant replaces a similar single element in another reactant. This reaction is sometimes called a displacement or substitution reaction.

$$A + BC \rightarrow AC + B$$

Examples of single-replacement reactions:

$Zn\ (s) + CuSO_4\ (aq) \rightarrow ZnSO_4\ (aq) + Cu\ (s)$

$Fe_2O_3\ (s) + 2Al\ (s) \rightarrow 2Fe\ (s) + Al_2O_3\ (s) + \text{Heat}$

4. Double-Replacement Reactions

In double-replacement reactions, two ionic compounds exchange ions to produce two new ionic compounds. This reaction is sometimes called a metathesis reaction. The reactants are usually aqueous solutions, and the driving force is the formation of a precipitate, gas, or liquid product. When the product is a precipitate, the reaction is called a precipitation reaction.

$$AB + CD \rightarrow AD + CB$$

Examples of double-replacement reactions:

$NaCl\ (aq) + AgNO_3\ (aq) \rightarrow NaNO_3\ (aq) + AgCl\ (s)$

$BaCl_2\ (aq) + Na_2SO_4\ (aq) \rightarrow BaSO_4\ (s) + 2NaCl\ (aq)$

continued on next page

Background continued

One type of double-replacement reaction is an acid-base reaction, in which a reaction occurs between an acid and a base. A hydronium ion (H^+) reacts with a hydroxide ion (OH^-) to form water, and the cation and anion form an aqueous salt.

Examples of acid–base reactions:

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

$H_2SO_4\ (aq) + 2NH_4OH\ (aq) \rightarrow (NH_4)_2SO_4\ (aq) + H_2O\ (l)$

5. Combustion Reactions

Combustion reactions involve a single element or compound that combines with oxygen gas to release heat and light. This rapid oxidation is commonly called burning.

Examples of single-element combustion reactions:

$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g) + \text{Energy}$

$2Mg\ (s) + O_2\ (g) \rightarrow 2MgO + \text{Energy}$

Hydrocarbons are prime examples of compounds that react with oxygen gas by combustion. Hydrocarbons are a significant portion of the fossil fuels that are burned to produce energy. Complete combustion of hydrocarbon fuels produces carbon dioxide, water vapor, and energy.

Examples of hydrocarbon combustion reactions:

$C_2H_5OH\ (l) + 3O_2\ (g) \rightarrow 2CO_2\ (g) + 3H_2O\ (g) + \text{Energy}$

$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (g) + \text{Energy}$

Evidence for the occurrence of chemical reactions includes precipitate formation, gas evolution, pH change, heat release or absorption, or color change. Any one of these events can indicate a chemical reaction. If a chemical reaction results in the production of a gaseous product, then simple chemical tests can be used to confirm gaseous reaction products. These chemical tests are also chemical reactions.

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Standard Tests for Gaseous Products

Oxygen Gas: To test for oxygen gas, insert a glowing splint into a container of collected gas (Figure 1). If the splint bursts back into flame, the test is positive for oxygen gas. Oxygen supports combustion, and the oxygen-rich environment inside the container causes the glowing splint to burn. Sometimes the glowing splint can create a small pop when first exposed to the oxygen.

Hydrogen Gas: To test for hydrogen gas, insert a flaming splint into a container of collected gas held at a 45-degree angle (Figure 2). If a loud pop or barking sound is heard, the test is positive for hydrogen gas. The hydrogen gas will react with oxygen in the atmosphere when ignited as follows:

$$2H_2\ (g) + O_2\ (g) \rightarrow 2H_2O\ (g) + \text{Energy}$$

Carbon Dioxide Gas: To test for carbon dioxide gas, bubble the collected gas through limewater. If a precipitate forms, the test is positive for carbon dioxide gas. The carbon dioxide gas [CO_2 (g)] reacts with the limewater [$Ca(OH)_2$ (aq)] to produce insoluble $CaCO_3$ and water as follows:

$$CO_2\ (g) + Ca(OH)_2\ (aq) \rightarrow CaCO_3\ (s) + H_2O\ (l)$$

A glowing or burning splint will extinguish in carbon dioxide, but this is not a decisive test. In addition to carbon dioxide, there are other gasses that also do not support combustion.

Figure 1.

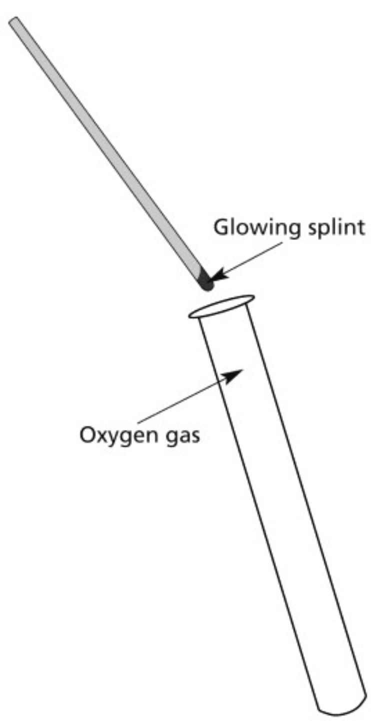
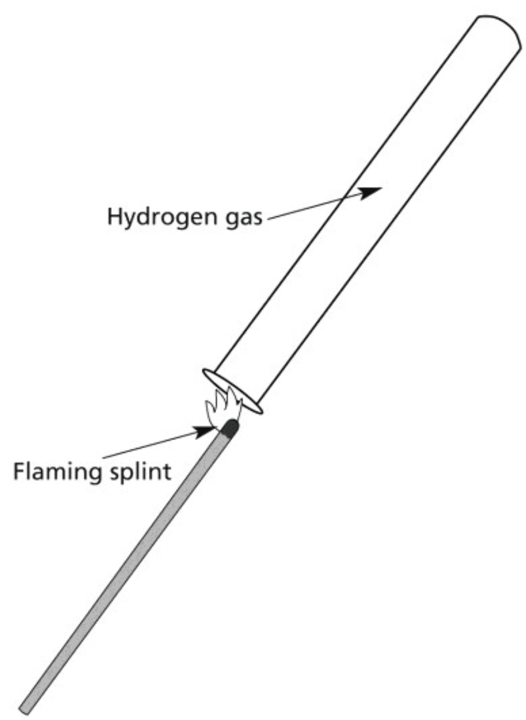


Figure 2.



Materials

Included in the materials kit:

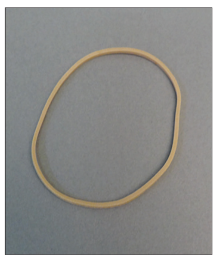
Limewater

1-hole rubber stopper, #4

1-hole rubber stopper, #00

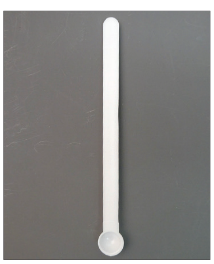
Plastic tubing

Steel-wool pad



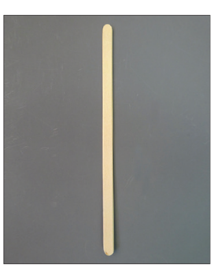
3 Rubber bands

Glass test tube, large (25 × 150 mm)



Minispoon

Dry yeast



Wooden splints

Needed from chemical set 1:

Hydrogen peroxide, 3% H_2O_2

White vinegar, acetic acid, 110 mL

Baking soda, $NaHCO_3$

Needed from chemical set 2:

Hydrochloric acid, 1 M HCl

Magnesium ribbon

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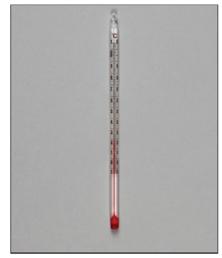
Needed from the equipment kit:

Graduated cylinder, 10 mL

Graduated cylinder, 50 mL

Beaker, 250 mL

Test-tube rack



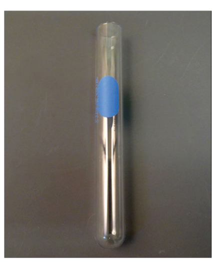
Thermometer

Electronic balance

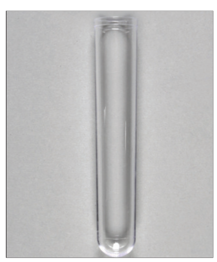
2 Pipets

Weighing boat

Candle

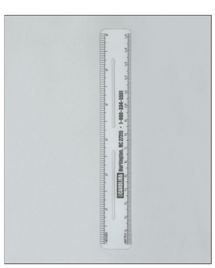


Glass test tube, small (13 × 100 mm)



Polystyrene test tube (17 × 100 mm)

Forceps



Ruler

Needed, but not supplied:
- Matches (or a lighter)
- Paper towels
- Scissors
- Small cup, 7 oz or greater
- Timer
- Water, purified (commercially available)
- Digital camera, or cell phone with camera capability

Reorder Information: Replacement supplies for the Investigating Chemical Reactions investigation can be ordered from Carolina Biological Supply Company, kit 580312.

Call 800-334-5551 to order.

Safety

Wear your safety goggles, chemical apron, and gloves at all times while conducting this investigation.

Read all the instructions for this laboratory activity before beginning. Follow the instructions closely, and observe established laboratory safety practices, including the use of appropriate personal protective equipment (PPE) as described in the Safety and Procedure sections.

Hydrogen peroxide, vinegar, and baking soda are not packaged for household consumption or use. They should be considered chemicals and kept away from children and pets.

Magnesium metal ribbon is a combustible metal. Keep chemical away from any heat or flame sources.

Vinegar and **hydrogen peroxide** cause skin and eye irritation.

Limewater, hydrogen peroxide, and **hydrochloric acid** are corrosive materials. Use these materials near a source of running water that can be used as a safety eyewash or safety shower if any corrosive material comes in contact with skin or eyes.

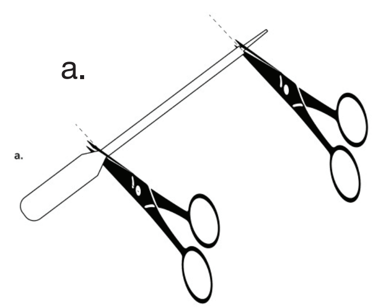
Do not eat, drink, or chew gum while performing this activity. Wash your hands with soap and water before and after performing the activity. Clean up the work area with soap and water after completing the investigation. Keep pets and children away from lab materials and equipment.

Glass test tubes are provided in the Investigating Chemical Reactions materials kit and are more resistant to heat and chemicals than the polystyrene (plastic) test tubes in the equipment kit. Use the glass test tubes as instructed in the Investigating Chemical Reactions manual. If a glass test tube breaks, carefully clean up the broken glass, and dispose of it in an appropriate way.

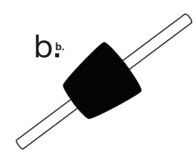
Preparation

1. Read through the procedure.
2. Obtain all materials.
3. Use a pair of scissors to cut a 1-cm piece of magnesium ribbon for Activity 3.
4. Assemble the gas-collection stopper for Activity 6.

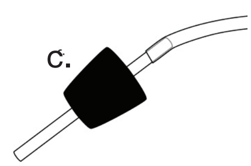
Figure 3.



a. Use scissors to remove the tip and bulb from a plastic disposable pipet to create a 2-inch plastic tube.



b. Insert the plastic pipette tube into the hole in the large #4 rubber stopper. Use the forceps to squeeze the tube and push it through the hole. A small drop of soap inside the dropper hole will help this process.



c. Connect airline tubing to the top (the larger end) of the plastic pipette tube extending from the top of the rubber stopper.

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Preparation continued

5. **Optional:** Wrap a rubber band around each glass test tube to prevent it from rolling off the table/workstation and potentially breaking.

Three different test tubes are used in this investigation. The materials kit contains a large glass test tube. The equipment kit contains a smaller glass test tube and poly-styrene (plastic) test tubes. Carefully read the instructions to ensure that the correct test tube (or tubes) is used during each activity.

ACTIVITY 1

A Synthesis Reaction

1. Measure 50 mL of white vinegar in the graduated cylinder, and then pour it into the small cup.
2. Measure the room temperature using a thermometer, and record the measurement in Data Table 1.
3. Place the thermometer and a rubber band on a paper towel.
4. While wearing protective gloves, tear or cut the steel-wool pad in half. Place one of the halves of steel wool on the paper towel. This half will be used later for comparison. Assume that this piece of steel wool remains at room temperature.
5. Place the other half of steel wool in the cup containing the white vinegar, and gently press it down to completely submerge it in the vinegar. Keep this steel wool submerged in the vinegar for 2 minutes.

Vinegar does not participate in the synthesis reaction. In this procedure, vinegar strips away the protective coating on the steel-wool pad, and provides an acidic environment that accelerates the subsequent chemical reaction.

6. Remove the steel wool from the cup, and carefully squeeze the excess vinegar back into the cup. **Keep the small cup of vinegar for use in Activity 4.**
7. Wrap the damp steel wool piece around the bulb of the thermometer, and secure it in place with the rubber band.

Figure 4

8. Place the steel-wool-wrapped thermometer on the paper towel.
9. Record the temperature of the damp steel wool. Start the timer.
10. Observe the synthesis reaction for 10 minutes. Record the temperature of the steel wool at 5 and 10 minutes after the start of the synthesis reaction. Enter your data into Data Table 1.

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ACTIVITY 1 continued

> The thermometer may have to be slid part-way out of the steel wool to observe the temperature scale, and then quickly slid back into the steel wool. Do not touch the bulb end of the thermometer during this procedure.

11. At 10 minutes after the start of the synthesis reaction, compare the appearance of the vinegar-treated steel wool to that of the dry steel wool. Record your observations in Data Table 1. Photograph your observations.
12. Remove the thermometer from the steel wool.
13. Rinse the thermometer and graduated cylinder with purified water, and dry with paper towels.
14. Discard paper towels, steel wool, and rubber band in the trash.

ACTIVITY 2

A Decomposition Reaction

1. Measure 10 mL of hydrogen peroxide (H_2O_2) solution in the graduated cylinder, and then pour it into the large glass test tube.
2. Place the large test tube containing H_2O_2 upright in a clean, empty, 250-mL beaker.
3. Use the plastic minispoon to measure two level spoonfuls of dry yeast; add both spoonfuls to the hydrogen peroxide solution in the large test tube. Start the timer.

> Yeast is not part of the decomposition reaction. Yeast contains a protein that catalyzes the reaction.

4. Observe the decomposition reaction for 1 minute, and record your observations in Data Table 1. Photograph your observations.
5. Gently swirl the contents of the large test tube for one minute and record your observations in Data Table 1.
6. Using the information described in “Standard Tests for Gaseous Products” predict the result of 6a and 6b.
    a. Insert a **glowing** splint into the large test tube. Record your observations in Data Table 1.
    b. Insert a **flaming** splint into the large test tube. Record your observations in Data Table 1.
7. After finishing Step 6, dispose of the contents of the large test tube down the drain.
8. Thoroughly rinse the 250-mL beaker and large test tube with purified water, and dry them with paper towels.

ACTIVITY 3

A Single-Replacement Reaction

1. Cut a 1-cm strip off of the longer strip of magnesium.
2. Insert the 1-cm strip of magnesium a few millimeters into the hole on the smaller tapered end of the small, #00 1-hole rubber stopper as shown in Figure 5.

continued on next page

Figure 5.

3. Fill the 250-mL beaker with tap water to within 3 centimeters from the rim.
4. Using the 10-mL graduated cylinder, measure 3 mL of 1 M HCl, and add it to the small glass test tube.
5. Add 50 mL of purified water to the 50-mL graduated cylinder.
6. Hold the small glass test tube containing the HCl at a 45-degree angle.
7. Use the plastic pipette to slowly add the water from the graduated cylinder to the test tube containing the HCl. Try to layer the water on top of the HCl by gently pipetting the water down the side of the glass test tube.

> The objective is to contain the solution of hydrochloric acid at the bottom of the test tube to prevent the reaction from starting too quickly in Step 9.

8. Continue filling the glass test tube by repeating Step 6 until the water level is within one centimeter from the top of the test tube.
9. Hold the glass test tube over the beaker, and then carefully insert the stopper fitted with the magnesium strip into the opening of the glass test tube. Allow any overflow water to drain into the beaker.
10. Place your forefinger over the hole in the rubber stopper, carefully invert the test tube, and then place the inverted test tube into the beaker of water, allowing it to rest in the beaker at a 45-degree angle as seen in Figure 6. Start the timer.

Figure 6.

11. Observe the single-replacement reaction for 10 minutes. Record your observations in Data Table 1.

> As the glass test tube fills with gas, water escapes through the hole in the rubber stopper. Once the water is completely expelled from the glass test tube, bubbles will begin to emerge from the hole in the rubber stopper. When this happens, pick up the glass test tube, and hold it vertically with the rubber stopper at the bottom.
>
> The gases in the test tube are lighter than air, so keep the test tube inverted (with the opening pointing downward).

Carefully remove the stopper, and place the opening of the inverted glass test tube on a level surface. A tube full of a gas has been collected.

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ACTIVITY 3 continued

12. Refer to the section describing the standard tests for confirming gases ("Standard Tests for Gaseous Products"). Pick up the glass test tube and hold it, still inverted, at a 45-degree angle.
13. Insert a flaming splint into the opening of the glass test tube. Record your observations in Data Table 1.
14. Thoroughly rinse the 250-mL beaker, rubber stopper, and glass test tube with purified water. Dry each of them with a paper towel.

ACTIVITY 4

A Double-Replacement Reaction

1. Locate the cup containing 50 mL of vinegar that was saved from Activity 1.
2. Use a weighing boat to measure 10 g of baking soda (sodium bicarbonate, $NaHCO_3$) on the balance.
3. Pour the baking soda into the small cup containing the vinegar.
4. Loosely cover the cup with a small piece of paper towel to retain more of the gas in the cup. Start the timer.
5. Observe the double-displacement reaction for 1 minute. Photograph your observations.
6. Gently swirl the contents of the cup to complete the reaction. Remove the small piece of paper towel covering the top of the cup, and observe the contents.
7. Record your observations in Data Table 1.
8. Refer to the section describing the standard tests for confirming gases ("Standard Tests for Gaseous Products").
   a. Insert a glowing splint into the small cup. Record your observations in Data Table 1.
   b. Insert a flaming splint into the small cup. Record your observations in Data Table 1.
9. Keep the small cup containing vinegar and baking soda to use in Activity 5.
10. Keep the weighing boat used for measuring the baking soda to use in Activity 6.

ACTIVITY 5

A Combustion Reaction

1. Light the candle with a match (or a lighter). The fuel that supports burning of the wick is paraffin.

CAUTION: Hold the test tube opening a centimeter above the flame to capture all the gases. Hold the test tube at the opposite end away from the flame, so that you do not burn your fingers.

2. Hold the small glass test tube in an inverted position (with the opening facing downward) over the candle wick for 30 seconds. This collects the gases released by the burning candle. After 30 seconds, move the inverted test tube away from the flame. Keep the test tube inverted.
3. Record your observations of the gasses collected in the small test tube in Data Table 1. Photograph your observations.
4. Locate the small cup containing the vinegar and baking soda from Activity 4.

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5. Slowly add another 50 mL of white vinegar to the small cup.
6. Carefully pour the gasses that are generated over the candle flame.
7. Record your observations in Data Table 1.

Convection currents may have removed gas. Adding additional vinegar will regenerate the gas.

To pour the gases, hold the small cup over the candle, and tilt it as far as possible while keeping the vinegar and baking soda retained inside the cup.

8. If necessary, extinguish the candle flame.
9. Pour the remaining vinegar and baking soda solution down the drain, and flush with excess water.
10. Thoroughly rinse the small cup with purified water, and dry it with a paper towel.

ACTIVITY 6

A Precipitation Reaction

1. Locate the gas-collection stopper with the plastic pipet tube that was constructed during the Preparation steps (Figure 3).
2. Use the weighing boat, and measure 5 g of baking soda using the electronic balance. Add this 5 g of baking soda to the large test tube.

It is easier to pour the baking soda into the large test tube by carefully folding the weighing boat diagonally, which creates a spout.

3. Place the large test tube containing the baking soda into the 250-mL beaker.
4. Measure 10 mL of white vinegar in the 50-mL graduated cylinder. Pour this 10 mL of vinegar into the polystyrene test tube.

The polystyrene test tube is thinner and shorter than the large test tube, so it fits completely inside the large test tube.

5. Place the polystyrene test tube containing the vinegar into the large test tube containing the baking soda. Both test tubes should be in upright positions (with the openings facing upward).
6. Carefully insert the gas-collection stopper into the large test tube, which is resting in the beaker. The plastic tubing will hang freely out of the beaker.
7. Add limewater to the small glass test tube until the tube is approximately one-half full.

Limewater contains calcium hydroxide, $Ca(OH)_2$, dissolved in water.

8. Place the glass test tube containing the limewater in the cardboard test-tube rack.
9. Tilt the large test tube horizontally, so that vinegar pours out of the polystyrene test tube into the larger test tube, and reacts with the baking soda.
10. As soon as the reaction starts, stop adding vinegar to the reaction and quickly place the free end of the plastic tubing into the limewater solution in the small test tube.

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ACTIVITY 6 continued

The vinegar and baking soda react to generate carbon dioxide gas. The gas is then bubbled into the limewater. The first gas to come out of the tube will be mostly air until the large test tube fills up with the carbon dioxide gas. Place the end of the plastic tube as far into the limewater solution as possible to increase the reaction time.

11. As the generation of carbon dioxide slows, again tilt the large test tube to pour more vinegar into the baking soda. Be careful that the plastic tubing remains immersed in the limewater. Repeat this step until all the vinegar is consumed.
12. Observe the limewater solution and record your observations in Data Table 1.
13. Swirl the large test tube to complete the reaction of all the vinegar and baking soda.
14. When no more gas is generated, remove the plastic tubing from the limewater solution. Start the timer. Allow the limewater solution to sit, undisturbed, for 5 minutes.
15. After 5 minutes, record any additional observations in Data Table 1. Photograph your observations.

ACTIVITY 7

A Combustion Reaction

1. Gently pull apart the unused half of the steel-wool pad from Activity 1. Use approximately 1/4 of the remaining steel-wool pad for this activity.

The steel wool is tightly packed; by pulling the fibers apart, more surface area is exposed. The steel-wool fibers should be visible and separated from one another.

2. Light the candle.
3. Hold the steel wool with the forceps over a cookie sheet or large plate.

CAUTION: The cookie sheet will catch any burning particles from the steel wool and protect the counter top or table.

4. Attempt to ignite the steel-wool fibers with the flame of the candle.
5. Record any observations in Data Table 1.

Disposal and Cleanup

1. Ensure that each used wooden splint is extinguished by dipping each used splint into water.
2. Discard weighing boat, wooden splints, paper towels, and nitrile gloves in the trash.
3. Wash and dry the beaker, test tubes, graduated cylinders, minispoon, rubber stopper, small cup, forceps, and thermometer.
4. Clean and sanitize the work space.

Data Table 1: Experimental Data and Observations

Activity	Observations and Data
1. Synthesis reaction	
2. Decomposition reaction	
3. Single-replacement reaction	
4. Double-replacement reaction	
5. Combustion reaction	
6. Precipitation reaction	
7. Combustion reaction	

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