Micro Rocket Lab

Limiting and Excess Reactants

Introduction

> *"It will free man from the remaining chains, the chains of gravity which still tie him to his planet."*
>
> *—Wernher von Braun*

The combustion reaction of hydrogen and oxygen is used to produce the explosive energy needed to power the space shuttle. The reaction is also being engineered to serve as a source of continuous energy for fuel cells in electric vehicles. What factors determine the explosiveness of the reaction of hydrogen with oxygen? In this lab, we will generate microscale quantities of hydrogen and oxygen and test their explosive nature, first separately, then in mixtures of various proportions. The goal—to find the most "powerful" gas mixture and use it to launch a rocket across the room!

Concepts

- Mole ratio
- Combustion
- Stoichiometry
- Limiting reactants

Background

Hydrogen, the most abundant element in the universe, is a colorless, odorless gas. It is combustible, which means that it burns quite readily. Hydrogen gas is conveniently generated in the lab by the reaction of zinc metal with hydrochloric acid.

Oxygen, the most abundant element on Earth, is also a colorless, odorless gas. Oxygen gas supports combustion, that is, it must be present for combustible materials to burn. Small-scale quantities of oxygen gas are conveniently generated in the lab by the decomposition of hydrogen peroxide. The decomposition reaction of hydrogen peroxide requires a catalyst to initiate the reaction. A variety of different catalysts, including manganese, manganese dioxide, potassium iodide, and even yeast, have been used in this reaction. In this lab, yeast will be used to catalyze the decomposition of hydrogen peroxide and generate oxygen gas.

Experiment Overview

The purpose of this microscale experiment is to generate hydrogen and oxygen and determine the optimum ratio for their combustion reaction to give water. The optimum ratio will be used to calculate the mole ratio for the reaction of hydrogen and oxygen in a balanced chemical equation. The concept of limiting reactants will be used to explain the results obtained with various hydrogen/oxygen gas mixtures.

Pre-Lab Questions

1. Write the balanced chemical equation for the single-replacement reaction of zinc and hydrochloric acid to generate hydrogen gas.
2. Write the balanced chemical equation for the yeast-catalyzed decomposition of hydrogen peroxide to generate oxygen gas and water. *Note:* Since a catalyst is not really a reactant or product, it is usually written over the arrow.

Materials

Hydrochloric acid, HCl, 3 *M*, 15 mL
Hydrogen peroxide, H_2O_2, 3%, 15 mL
Yeast suspension, 2%, 5 mL
Zinc, mossy, Zn, about 5 g
Beaker, 250-mL
Graduated cylinder, 10-mL
Marker (permanent pen)
One-hole rubber stoppers, to fit test tubes, 4
Paper towels
Piezo sparker (optional)
Pipets, Beral-type, graduated, 4
Safety matches
Spatula
Test tube rack
Test tubes, small, 4
Wood splint

Safety Precautions

Hydrochloric acid is toxic by ingestion and inhalation and is corrosive to skin and eyes. Hydrogen peroxide is a skin and eye irritant. Avoid contact of all chemicals with skin and eyes and notify your teacher immediately in the case of a spill. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Construct Gas Generators

1. Microscale gas generators consist of a small test tube, a rubber stopper, a gas delivery tube, and a gas collection bulb. See Figure 1a.
2. Cut four Beral-type pipets as shown in Figure 1b to obtain four gas-collecting bulbs and four gas-delivery tubes. Discard the middle part of the pipet stem. It is important that the gas-collecting bulbs all have similar lengths. Trim the lengths so they are equal.
3. Place the gas delivery tube into the tops of rubber stoppers as shown in Figure 1a. The narrow end of the gas delivery tube should be above the stopper.

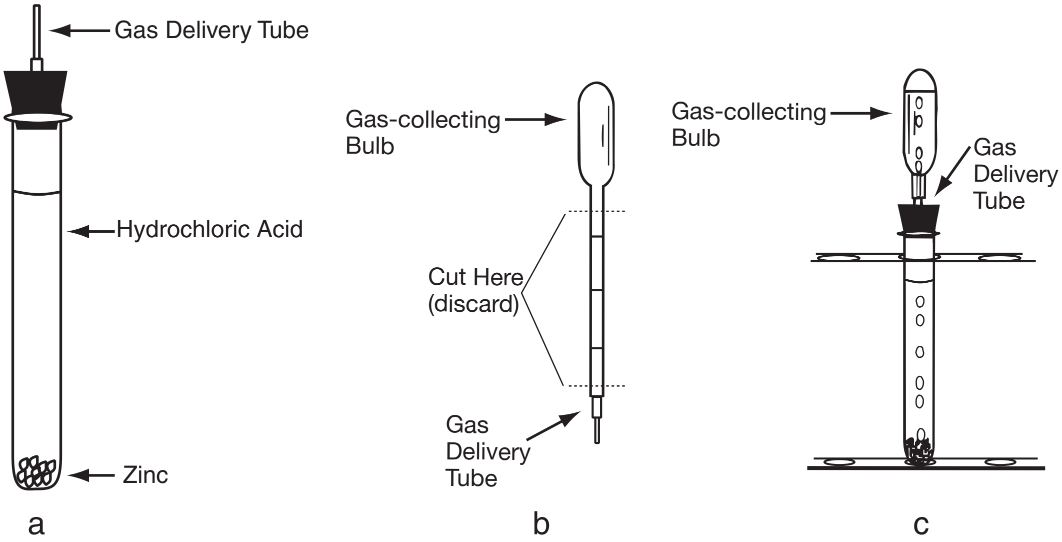


Figure 1. Constructing a Gas Generator

4. Prepare two hydrogen gas generators by placing about four pieces of mossy zinc into the bottom of two small test tubes.
5. Prepare two oxygen gas generators by placing about 5-10 drops of yeast suspension into the bottom of the other two small test tubes.
6. Set the test tubes in a test tube rack over several layers of paper towels.

Calibrate Gas Collection Bulbs

7. Fill a 250-mL beaker about one-half full with tap water.
8. Immerse one of the cut-off pipet bulbs under water. Fill the bulb completely with water and remove it from the beaker.
9. Squeeze the water out of the pipet bulb into an empty graduated cylinder to measure the total volume (V) of water in the bulb.
10. Divide the contents of the pipet bulb into six, equal-volume increments by following steps 11 and 12. By doing so, the water level lines will be correct on the gas collection bulb.
11. Refill the pipet bulb, then squeeze out one-sixth of the total volume (V/6) into an empty graduated cylinder. Release the squeeze and use a permanent pen to mark the water level on the side of the bulb.
12. Squeeze out a second V/6 volume, mark the level again, and repeat for the remainder of the water. This should serve to divide the bulb into six, equal-volume increments. See Figure 2.
13. Once the first pipet bulb has been calibrated, the rest of the pipet bulbs can be copied to save time. Simply rest a wood splint across the bulb, with the end of the splint flush with the end of the bulb, and mark off the splint at the same places that the bulb is marked. Then use the splint as a template to mark the rest of the bulbs.

Collect and Test Hydrogen and Oxygen Gases

14. Add 3 M hydrochloric acid to the mossy zinc in one of the hydrogen gas generators until the liquid level is about 1 cm below the mouth of the test tube. Cap the tube with the gas delivery stopper. *Note:* Wait about one minute before proceeding to step 15. This will allow time for the air to be purged from the test tube. See Figure 1a.
15. Completely fill a marked pipet bulb with water and place the bulb over the gas delivery tube to collect hydrogen gas by water displacement. As the bubbles enter the pipet bulb, the water will flow out of the bulb and down the sides of the test tube to the paper towels. (Figure 1c.)
16. As soon as the bulb is filled with hydrogen, remove it from the gas delivery tube and immediately place a finger over the mouth of the bulb to prevent the collected gas from leaking out.
17. Hold the gas bulb so the opening is pointed upward and have a classmate quickly strike a match over the opening of the bulb. After the match is lit, remove finger and allow the hydrogen gas escape into the flame. Record the results of this “pop-test” in the data table.
18. Add 3% hydrogen peroxide to the yeast suspension in one of the oxygen gas generators until the liquid level is about 1 cm below the mouth of the test tube. Cap the tube with the gas delivery stopper. *Note:* Wait about one minute before proceeding to step 19.
19. Repeat steps 15–17 to collect *oxygen gas* and test its properties. Record the results of its “pop-test” in the data table.

Collect and Test Oxygen/Hydrogen Gas Mixtures

20. Completely fill a marked pipet bulb with water and place it over the oxygen gas generator to collect oxygen.
21. When the bulb is one-sixth full of gas, quickly remove it from the oxygen tube and place it over the hydrogen gas generator.
22. Continue collecting hydrogen until the bulb is filled with gas. This bulb should contain a 1:5 ratio of oxygen and hydrogen.
23. Remove the bulb, cap it with a finger, and determine its relative loudness in the “pop-test,” as described above for hydrogen and oxygen. Develop a scale to describe how loud this mixture is compared to pure hydrogen and pure oxygen. Record the result in the data table.
24. Repeat steps 20–23 to collect and test other volume ratios (2:4, 3:3, 4:2, 5:1) of oxygen and hydrogen (see the data table). Always collect oxygen first, followed by hydrogen. Record all results in the data table.
25. Rank the gas mixtures on a scale from zero to 10 to describe their relative loudness in the “pop-test.” Let the most “explosive” mixture be a 10, the least reactive gas a zero.

26. Collect various gas mixtures as many times as necessary to determine the optimum ratio of oxygen and hydrogen for combustion. *Note:* The pop-test is obviously subjective, but by repeating it several times with each possible mixture, it should be possible to determine the most explosive (loudest) gas mixture.
27. When the reaction in one of the gas generators slows down so much that it is no longer useful, fill the second gas generating tube with liquid (either HCl or H_2O_2, as appropriate) and use it instead.

Rocket Launches!

28. Collect the optimum (loudest) gas mixture one more time, and bring it to the instructor. Your instructor will place the bulb on a rocket launch pad and ignite it with a piezo sparker. How far does the micro mole rocket travel?
29. Collect the optimum mixture again, but this time leave about 1 mL of water in the bulb. With your instructor's consent, launch the micro mole rocket.
30. *(Optional)* Think of other design factors that might make the rockets travel farther. Try them!

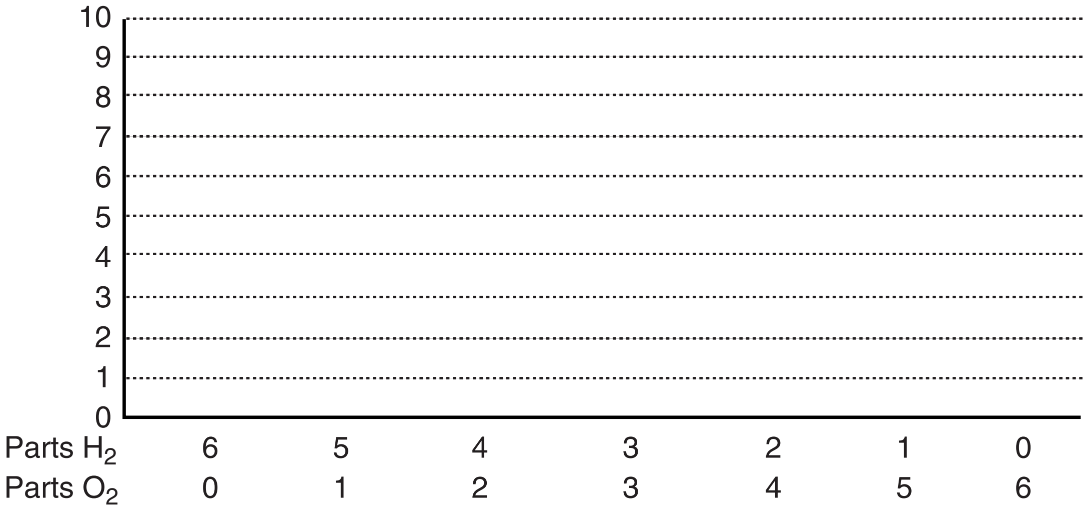
Micro Rocket Lab

Data Table

“Pop-test” Properties of H_2 Gas	
“Pop-test” Properties of O_2 Gas	
Pop-test Properties of O_2:H_2 Gas Mixtures	
Oxygen:Hydrogen Mole Ratio	**Relative Loudness**
1:5	
2:4	
3:3	
4:2	
5:1	

Post-Lab Questions

1. Draw a bar graph to illustrate the relative loudness produced by pop-testing various oxygen/hydrogen gas mixtures.



2. Explain the relative loudness of pure oxygen and pure hydrogen in the pop-test.

3. Write a balanced chemical equation for the combustion reaction of hydrogen and oxygen to give water.

4. Complete the following sentence to describe the number of moles of each reactant involved in the combustion of hydrogen: ______ moles of hydrogen react with _______ moles of oxygen to give _______ moles of water.

When the reactants in a mixture are present in the exact mole ratio given by the balanced chemical equation, all of the reactants should be used up when the reaction is over. There will be no "leftover" reactants. However, if one of the reactants is present in an amount greater than its mole ratio, then that reactant cannot react completely, and some of it will be left over at the end of the reaction.

5. Use the mole ratio of hydrogen to oxygen from Question #4 to determine what happens when various hydrogen/oxygen gas mixtures are allowed to burn. Complete the following table to indicate which reactant (H_2 or O_2) is present in excess, and how much of it will be left over after the combustion reaction is complete. *Note:* The second mixture has been completed as an example.

Parts H_2	6	5	4	3	2	1	0
Parts O_2	0	1	2	3	4	5	6
Which reactant is present in excess?		**H_2**					
How much of that reactant is left over?		**3**					

6. Which oxygen/hydrogen gas mixture produced the most explosive mixture? Explain why this mixture was most explosive.

7. Why do the hydrogen and oxygen gas mixtures in the collection bulb not react as soon as they are collected? *Note:* Consider the role of the match and the properties of gas molecules at room temperature.

Teacher's Notes

Micro Rocket Lab

Materials Included in Kit

Hydrochloric acid, HCl, 3 *M*, 250 mL
Hydrogen peroxide, H_2O_2, 3%, 250 mL
Yeast, Baker's (active), 1 packet*
Zinc, mossy, Zn, 100 g
Pipets, Beral-type, graduated, 60
Wood splints, 15

Additional Materials Needed (for each lab group)

Beaker, 250-mL
Graduated cylinder, 10-mL
Marker (permanent pen)
Paper towels
Piezo sparkers (optional)[†]
Rubber stoppers, to fit test tubes, 4
Safety matches
Spatula
Test tube rack
Test tubes, 13 × 100 mm, 4
Water

*The yeast suspension should be freshly prepared for each class section.

[†] See the *Supplementary Information* section for instructions on how to prepare a piezo sparker using an empty butane barbecue-type lighter. Piezo sparkers may be used instead of matches to test the combustion properties of the gas mixtures.

Pre-Lab Preparation *(for a class of 30 students working in pairs)*

Yeast Suspension, 2%: Add 100 mL of lukewarm tap water to 2 g of active, dry yeast. Prepare fresh before use.

Safety Precautions

Hydrochloric acid is toxic by ingestion and inhalation and is corrosive to skin and eyes. Zinc metal dust may be present on the bottom of the mossy zinc bottle. Zinc dust is flammable; avoid contact with flames and other sources of ignition. Do not use zinc dust in this experiment. If zinc is dusty, rinse it with distilled water to remove the dust. Hydrogen peroxide is a skin and eye irritant. Avoid contact of all chemicals with skin and eyes and carefully clean up any spills. Wear chemical splash goggles and chemical-resistant gloves and apron. Remind students to wash hands thoroughly with soap and water before leaving the laboratory. Please consult current Material Safety Data Sheets for additional safety, handling, and disposal information.

Disposal

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

Lab Hints

- This lab should take approximately 50 minutes for students to complete. Many students may want to experiment, however, with different variables to see how far their rockets will travel.
- The loudness test is obviously arbitrary. Nonetheless, the results are remarkably consistent from class to class. Students tend to anticipate that the 3:3 mixture will be the loudest, and this could certainly bias their results. Encourage students to pop-test their mixtures in a blind and random fashion, and also to repeat all of the tests at least once. Have one student in the group collect a gas mixture, without telling the other student in the group what the gas ratio is. Let the "blind" partner do the pop-test and judge the result. The partners should then switch roles and repeat the process to collect a

second set of data.

- The target at which the rockets are launched can be a bulls-eye or goalpost drawn on the chalkboard or, better yet, ano open box at one end of the room. Although the rockets are very soft and safe, students should avoid aiming the rockets at one another, and they should be reminded to keep their goggles on at all times. The rockets should not be scaled up. Do not attach any hard objects to the rocket.
- The concentrations of hydrochloric acid and hydrogen peroxide were selected to give an even rate of gas generation. The hydrogen gas generator will almost certainly slow down to an inefficient rate before all of the gas mixtures can be collected and tested. The oxygen gas generator tends to be a bit more constant and will probably remain active for at least 30 minutes. It is recommended, however, that each group prepare two gas generators for both oxygen and hydrogen in advance. That way, if one of the generators slows down, the group can easily switch to the other generator without losing too much momentum.
- Instruct students to use mossy zinc pieces and not zinc dust. Zinc metal dust may be present on the bottom of the mossy zinc bottle. Zinc dust is flammable; avoid contact with flames and other sources of ignition. Rinsing the mossy zinc with distilled water will remove most of the dust.
- Have students practice filling the bulb completely with water. Squeeze the bulb to remove as much air as possible, then fill with water. Turn the bulb upside down and squeeze to remove the remaining air and again fill to the top with water.
- Manganese, manganese dioxide, and potassium iodide may also be used as catalysts for the decomposition of hydrogen peroxide. In our experience, yeast provided the longest-lived oxygen gas generator.
- If the first pop test does not work, wait about a minute and recollect the gas. The generating gas must first purge the air out of the test tube.
- Some students may wonder why pure hydrogen gives a positive, albeit very faint, pop-test result. Hydrogen by itself, of course, should not react. The slight popping sound occurs as hydrogen escaping from the bulb mixes with oxygen in the air. For each volume of H_2 expelled from the bulb, an equal volume of air is drawn back in. Eventually, a combustible H_2/O_2 mixture is produced in the bulb and the flame backfires into the bulb.

Tips

- Why do the micro mole gas rockets travel considerably farther when some water is left in the bulb? It's rocket science! The water gives the expanding water vapor produced in the reaction something to push against—it is a propellant.
- Review Avogadro's Law before beginning this experiment. It provides the foundation for the experiment as written, namely, that the volume ratios of the gases are equal to their mole ratios.
- In schools where "micro mole rockets" have become a tradition, students look forward with anticipation to trying to beat the class and school records for distance traveled by a rocket. The gymnasium, after all, showcases track records, and the pool swim records—why shouldn't the chemistry lab showcase micro mole rocket records? Streamlining the pipet-bulb rockets with fins and a nose cone greatly increases the distances the rockets will travel.
- A wonderful extension of this lab would be to run the reaction in reverse. Generate hydrogen and oxygen together via the electrolysis of water and demonstrate that the gases are indeed produced according to the stoichiometric mole ratio. Call, write, or e-mail Flinn Scientific to request a complimentary copy of our ChemFax #10461,"Microscale Electrolysis."

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

1. Write the balanced chemical equation for the single-replacement reaction of zinc and hydrochloric acid to generate hydrogen gas.

   $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

2. Write the balanced chemical equation for the yeast-catalyzed decomposition of hydrogen peroxide to generate oxygen gas and water. *Note:* Since a catalyst is not really a reactant or product, it is usually written over the arrow.

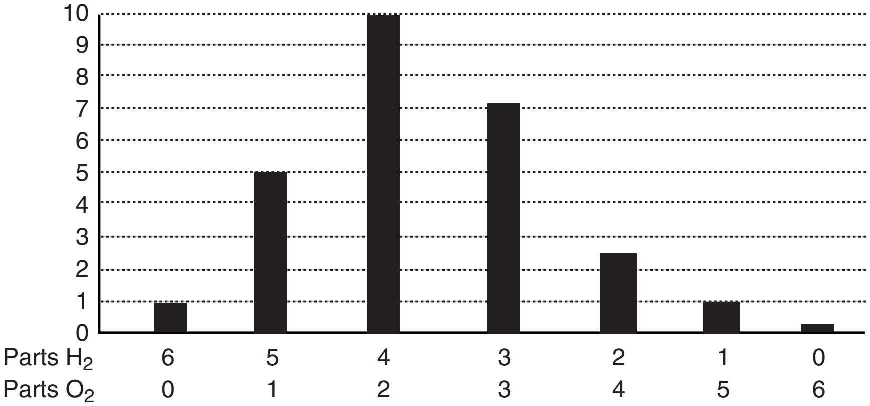
   $2H_2O_2(aq) \xrightarrow{yeast} 2H_2O(l) + O_2(g)$

Sample Data Table *Student data will vary.*

“Pop-test” Properties of H_2 Gas	*A faint “pop” sound was heard and the flame was extinguished.*
“Pop-test” Properties of O_2 Gas	*The flame flared slightly, but there was no “pop” or explosion.*
Pop-test Properties of O_2:H_2 Gas Mixtures	
Oxygen:Hydrogen Mole Ratio	**Relative Loudness**
1:5	*Moderate “pop” sound. Rating = 5*
2:4	*Explosion produced very loud “pop” and small recoil action. Rating = 10*
3:3	*Loud “pop.” Rating = 7*
4:2	*Weak “pop.” Rating = 2.*
5:1	*Faint “pop.” Rating = 1.*

Answer to Post-Lab Questions *(Student answers will vary.)*

1. Draw a bar graph to illustrate the relative loudness produced by pop-testing various oxygen/hydrogen gas mixtures.



2. Explain the relative loudness of pure oxygen and pure hydrogen in the pop-test.

Pure oxygen does not produce a noise in the “pop-test.” Oxygen supports combustion, but is not itself combustible. Hydrogen produces only a faint pop as it combusts with the available oxygen in the air.

3. Write a balanced chemical equation for the combustion reaction of hydrogen and oxygen to give water.

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

4. Complete the following sentence to describe the number of moles of each reactant involved in the combustion of hydrogen: ***Two*** moles of hydrogen react with ***one*** mole of oxygen to give ***two*** moles of water.

When the reactants in a mixture are present in the mole ratio given by the balanced chemical equation, all of the reactants should be used up when the reaction is over. There will be no “leftover” reactants. However, if one of the reactants is present in an amount greater than its mole ratio, then that reactant cannot react completely, and some of it will be left over at the end of the reaction.

5. Use the mole ratio of hydrogen to oxygen from Question #4 to determine what happens when various hydrogen/oxygen gas mixtures are allowed to burn. Complete the following table to indicate which reactant (H_2 or O_2) is present in excess, and how much of it will be left over after the combustion reaction is complete. *Note:* The second one has been completed as an example.

Parts H_2	6	5	4	3	2	1	0
Parts O_2	0	1	2	3	4	5	6
Which reactant is present in excess?	*H_2*	**H_2**	*neither*	*O_2*	*O_2*	*O_2*	*O_2*
How much of that reactant is left over?	*6*	**3**	*none*	*1.5*	*3*	*4.5*	*6*

Note to teachers: *Some students pick up on this concept right away, while others struggle. For those students who are having trouble visualizing the idea of limiting and excess or leftover reactants, an effective teaching method is to have them write down the parts* H_2 *and* O_2 *as symbols. Five parts* H_2 *and 1 part* O_2 *would look like this:* $H_2\ H_2\ H_2\ H_2\ H_2\ O_2$*. Tell the students to cross off the symbols as they get used up in the reaction. But remember, they have to cross off two* H_2*'s for every* O_2 *they cross off! In the above case, we would get:*

$$H_2\ H_2\ H_2\ H_2\ H_2\ O_2$$

Hydrogen is present in excess and there are three parts left over at the end of the reaction.

6. Which oxygen/hydrogen gas mixture produced the most explosive mixture? Explain why this mixture was most explosive.

   The most explosive gas mixture contained two parts oxygen and four parts hydrogen. When this gas mixture was burned, there was nothing left over. It was the most efficient reaction, and thus the most explosive.

7. Why do the hydrogen and oxygen gas mixtures in the collection bulb not react as soon as they are collected? *Note:* Consider the role of the match and the properties of gas molecules at room temperature.

   Even if H_2 *and* O_2 *are both present in a combustible ratio, and the* H_2*–*O_2 *collisions are occurring at a considerable rate, the collisions are generally not occurring with enough energy at room temperature to form the activated complex. The reaction, therefore, does not occur at a detectable rate at room temperature. The flame or piezo sparker provides extra energy, in the form of heat or electricity, that makes the gas molecules move faster and increases the collision energy when they collide. The "energized" gas molecules have sufficient energy to form an activated complex and enable the reaction to begin. The minimum excess energy that must be supplied in the form of a flame or other source of ignition is called the activation energy for the 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
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 of atoms, structure and properties of matter, chemical reactions, motions and forces

Reference

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

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Micro Rocket Lab* activity, presented by Bob Becker, is available in *Limiting and Excess Reactants*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Micro Rocket Labs* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Micro Mole Rockets—Student Laboratory Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6374	Micro Mole Rockets—Student Laboratory Kit
AP6255	ChemTopic™ Labs, Vol. 7, Molar Relationships and Stoichiometry
H0034	Hydrochloric Acid Solution, 3 M, 500 mL
H0009	Hydrogen Peroxide, 3%, 473 mL
Y0008	Yeast, Baker's, Pkg/3
AP6286	Piezoelectric Igniter
AP1721	Beral-type Pipet, Graduated, Pkg/20

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

Supplementary Information

Piezo Sparker/Rocket Launcher

The piezo sparker/launch pad is quite simple to construct from an empty piezoelectric barbecue lighter (such as the Scripto™ brand "Aim-n-Flame"™). Most people tend to discard the lighter once the butane runs out, but the piezo sparking mechanism is still good and will last almost indefinitely.

1. Cut a 10-cm length of double solid speaker wire (24 gauge) and spread the two wires apart at one end to make a Y shape.
2. Strip about 1.5–2.0 cm of the insulation off the two split ends (Figure 3).
3. Place a small straw (use the same piece of pipet that was used for the gas generator nozzles) over the butane outlet nozzle in the tip of the lighter (Figure 4).
4. Now for the tricky part: Straighten out one of the two stripped ends and thread it into the butane nozzle hole. This may be a snug fit; twisting back and forth as you insert the wire helps it go in smoothly (Figure 5).
5. Lay the other stripped end along side the metal shaft of the lighter (Figure 6), and wrap with 2–3 layers of electrician's tape around the wire, leaving about 1 cm of wire exposed (Figure 7).
6. Bend over the end of this wire and wrap with two or three more layers of tape (Figure 8). Use hot melt glue to fill in the area around the nozzle and to keep the wire from slipping out of the nozzle. This piezo sparker may be used instead of matches to test the explosive reactions of the oxygen and hydrogen gas mixtures.
7. To use the piezo sparker as a rocket launch pad: Make a hole in the center of a film canister lid. Thread the protruding speaker wire through the hole in the lid, and hot melt glue it in place from behind (Figure 9). The lid will serve as a launch platform and prevent some of the water from spraying the shooter. You're finished!

Piezo Sparker/Rocket Launcher, cont'd.

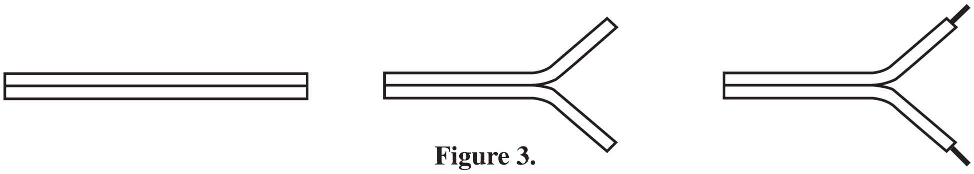


Figure 3.

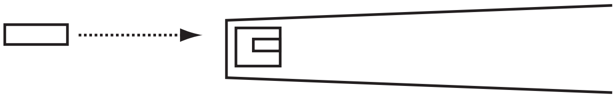
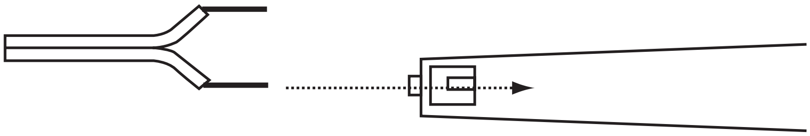


Figure 4.



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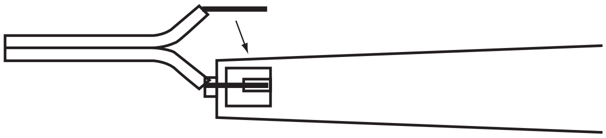

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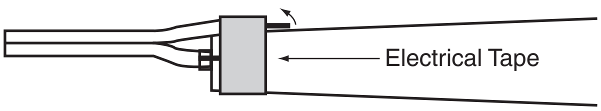

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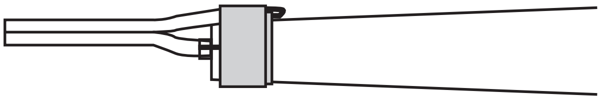

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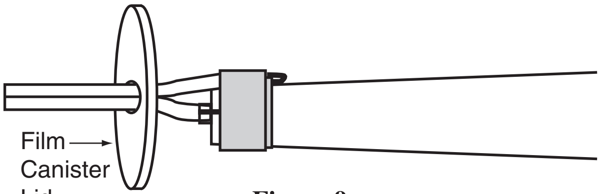

Figure 9.

Figures 3–9.