The Bottomless Bottle Explosion

Properties of Hydrogen

Introduction

Generate hydrogen gas using aluminum metal and sodium hydroxide and ignite. Something interesting will happen! When an empty, bottomless soda bottle is filled with hydrogen and the gas ignited, the hydrogen will burn with the flame decreasing in size. After awhile, the reaction will whistle. Suddenly, the hydrogen will explode with water vapor condensing on the inside surface of the bottle.

Concepts

- Hydrogen gas
- Combustion
- Stoichiometric ratio

Materials

Calcium chloride, anhydrous or Drierite®
Sodium hydroxide solution, NaOH, 5.5 M, 50 mL
Aluminum foil
Bottle, water or soda, tall
Butane safety lighter
Cotton puff
Drying tube
Ring stand and clamp
Rubber tubing, 3–4 ft, 3⁄16″ ID × 1⁄16″ wall
Stoppers, one-hole, to fit flask, bottle, and drying tube
Tubing, 5–6 mm, 1½″ long piece
Tubing, Pyrex® glass, 2″ long piece
Volumetric flask, 500-mL

Safety Precautions

This is not a demonstration for the inexperienced teacher. The production of the hydrogen is dangerous. Hydrogen is a very flammable and potentially explosive gas but can be safely handled with proper safety procedures. Never generate hydrogen in a closed system; always make sure there are no plugs or blockages in the system. Remove all sources of sparks, flames, and heat from the area where hydrogen gas is produced or used. Sodium hydroxide is very corrosive to all body tissues, especially eyes. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. The reaction between sodium hydroxide and aluminum starts slowly and then proceeds rapidly with the production of excessive heat. If the reaction is allowed to proceed too vigorously, it will produce both steam and hydrogen gas and may even boil up out of the reaction flask. Slow the reaction by immersing the reaction flask into an ice water bath. Keeping the reaction cool and producing a slow, steady stream of hydrogen is both safer and produces a drier gas. Do not scale this procedure up. Avoid telling your students that one of the ingredients is sodium hydroxide. The reaction is easily performed and sodium hydroxide (lye) is too readily available. Hydrogen filled bottles and caustic sodium hydroxide can be a problem in untrained hands. Many teachers prepare the hydrogen gas before class and store the hydrogen gas in a balloon until use. Hydrogen gas will be vented from the bottom of the bottle as it is generated and is extremely flammable. Be absolutely certain that there are no flames or operating electrical equipment nearby. Follow all laboratory safety guidelines. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information. Remember to wash hands thoroughly with soap and water before leaving the laboratory.

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Procedure

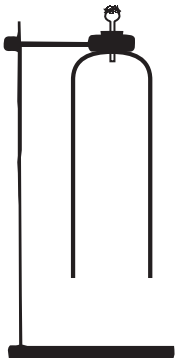

Figure 1.

1. Cut the bottom off a tall, narrow water or soda bottle. Plug the top of the bottle with a one-hole stopper containing a short piece of glass tubing. Assemble the apparatus by clamping the bottle to a ring stand. Attach a 3–4 foot long piece of 3/16″ ID latex tubing from the bottle and to a drying tube attached to a rubber stopper (see Figure 1).
2. Tear a 6–8″ long sheet of 12″ wide aluminum foil into four or five pieces. Fold and roll each piece into a cigar shaped tube with a diameter small enough to fit into the volumetric flask.
3. Add the aluminum foil to the volumetric flask followed by 50 mL of 5.5 M sodium hydroxide solution. Seal the flask with a drying tube attached to the vent tube in the bottle. Swirl the mixture to completely wet the foil with sodium hydroxide solution. Place an ice-water bath nearby as it will become necessary to cool the reaction by immersing it in ice water (see Figure 2).
4. When the reaction subsides, remove the rubber tubing from the bottle and quickly place your finger over the vent tube. Remove the gas generating flask from the immediate area. Ignite the safety lighter, quickly remove your finger from the top of the bottle, and ignite the hydrogen escaping from the vent tube. The flame size slowly decreases and the reaction will begin to whistle. Suddenly, the flame will flicker and the hydrogen in the bottle will explode. Be certain to point out to your students that water vapor has condensed on the inside of the bottle.

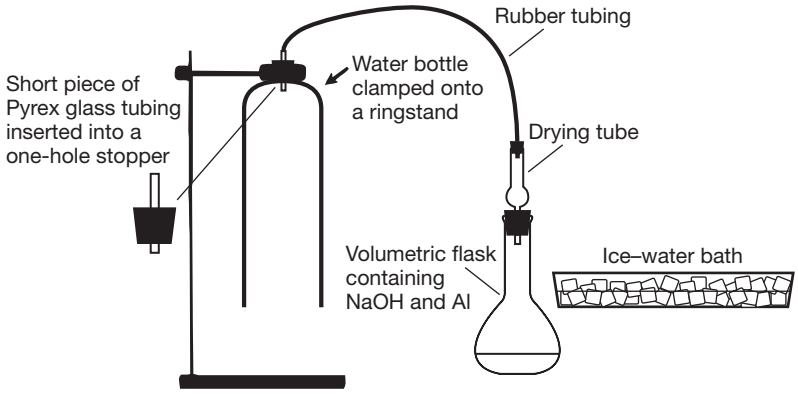

Figure 2.

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. The spent sodium hydroxide may be neutralized with 6 M hydrochloric acid and then rinsed down the drain with plenty of water according to Flinn Suggested Disposal Method #10.

Discussion

Initially, only pure, lighter-than-air hydrogen vents from the tube on top of the bottle and is burned with a luminous flame. As air replaces the hydrogen and mixes with the gas in the bottle, the ratio of oxygen to hydrogen increases, changing the stoichiometry of the flame. Since the fraction of flammable hydrogen decreases, the size of the flame decreases. Eventually, a near stoichiometric ratio is obtained, and the mixture explodes. The only product from this reaction, water, condenses on the cooler bottle surface.

Unfortunately, this spectacular demonstration is rarely performed because the usual source of hydrogen is a commercial tank, which many schools can not afford or feel the demonstration does not merit the cost. The purpose of this procedure is to describe a simple, inexpensive method of generating hydrogen gas in a manner that would allow the demonstration to be performed with the minimum effort and expense on the part of the teacher.

What is the reaction inside the flask?

Aluminum metal normally appears to be unreactive due to the formation of a stable coating of aluminum oxide. Since aluminum oxide is amphoteric, the oxide protective coating can be removed with a strong solution of sodium hydroxide producing sodium aluminate, $NaAl(OH)_4$, according to Equation 1.

$$Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \rightarrow 2NaAl(OH)_4(aq) \qquad \textit{Equation 1}$$

The fresh aluminum surface is now free to react rapidly with addition base producing hydrogen gas and more sodium aluminate (Equation 2).

$$2Al(s) + 2NaOH(aq) + 6H_2O(R) \rightarrow 2NaAl(OH)_4(aq) + 3H_2(g) \qquad \textit{Equation 2}$$

Tips

- A tall, narrow water or soda bottle works better than a squat soda bottle in this demonstration. Both the "Poland Springs" type 1.5-liter bottle and a 1-liter seltzer bottle are perfect and even a 0.5 liter water bottle gives a significant bang. Unfortunately, an ordinary two liter soda bottle is not suitable because it allows the hydrogen to mix with the air, which may cause a premature explosion.
- A 7 mm OD glass vent tube on a 1.5-L water bottle will cause the explosion to occur in 30–35 seconds while a 6 mm OD vent tube on a 1-L soda bottle requires roughly 50 seconds before the hydrogen explodes. Avoid a smaller vent tube since the reaction takes an unnecessarily long period of time, the flame is too small to be seen properly, and may blow out before the explosion occurs. It may also be helpful to tape the stopper into the bottle to prevent it from being pulled out while you are cooling the aluminum-sodium hydroxide reaction.
- While the drying tube is not absolutely necessary, the aluminum-sodium hydroxide reaction is quite exothermic producing steam as well as hydrogen. The result is that some of the steam condenses inside the bottle while it is being filled with hydrogen gas. The drying tube removes water vapor from the hydrogen so that any condensate is the result of the hydrogen-oxygen reaction adding to the educational value of this demonstration. Flinn Scientific has a description for assembling a drying tube in its catalog near its drying tube listing.
- 5.5 *M* NaOH gives the maximum rate of reaction. To prepare 5.5 *M* NaOH, dissolve 220 g of sodium hydroxide in 500 mL of water, cool, and dilute to a total volume of one liter.
- 3⁄16″ ID × 1⁄16″ wall soft latex tubing, such as Flinn Catalog No. AP2077, is ideal for this setup. If the tubing is too thin, it may develop a kink causing the pressure to push off one of the stoppers. If the tubing is too heavy, it may pull out one of the stoppers while you are cooling the reaction.
- While any flask will work in this experiment, a volumetric flask has the advantage that it has a long neck which can be used as a handle especially since the flask will become quite hot if not cooled adequately.

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 B: Physical Science, properties and changes of properties in matter, motions and forces
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions

References

Bob Lewis of WWNFF Team 4 first showed me this demonstration using a one gallon plastic milk bottle.

Brown, Theodore L., and H. Eugene LeMay, Jr., *Chemistry: The Central Science*, 4th. Ed., Prentice-Hall, Englewood Cliffs, NJ, 1988, p. 154.

Kotz, John J. and Paul Treichel Jr., *Chemistry & Chemical Reactivity*, 3rd. Ed, Saunders College Publishing Co., Orlando, FL, 1996, p. 1009.

Philip J. Durant and Beryl Durant, *Introduction to Advanced Inorganic Chemistry*, Longmans, Green, and Co., Inc., London, 1962, p. 531.

Shakhashiri, Bassam Z., *Chemical Demonstrations: A Handbook for Teachers of Chemistry*, Vol.1, The University of Wisconsin Press, Madison, WI, 1983, p. 106.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of *The Bottomless Bottle Explosion* activity, presented by John Mauch, is available in *Properties of Hydrogen*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *The Bottomless Bottle Explosion* are available from Flinn Scientific, Inc.

Catalog No.	Description
GP4040	Flask, Volumetric, Borosilicte Glass, 500 mL
S0075	Sodium Hydroxide, 500 g
A0019	Aluminum Foil, 12" wide × 25" long Roll
AP2077	Latex Tubing in 10" Sections, 3/16" ID
GP9010	Glass Tubing, Borosilicate Glass, 24", 6 mm
AP6230	Rubber Stoppers, One-Hole
GP7050	Straight Drying Tube, 100 mm
FB0680	Cotton Balls, Pkg/300
D0012	Drierite, 454 g
AP8960	Butante Safety Lighter

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