Big Time Ethyl Alcohol Explosion

Combustion of Alcohols

Introduction

Wow your students with a whoosh! Students will love to see the blue alcohol flame shoot out the mouth of the bottle and watch the dancing flames pulsate in the jug as more air is drawn in.

Concepts

- Exothermic reactions
- Activation energy
- Combustion

Background

Low-boiling alcohols vaporize readily, and when alcohol is placed in a 5-gallon, small-mouthed jug, it forms a volatile mixture with the air. A simple match held by the mouth of the jug provides the activation energy needed for the combustion of the alcohol/air mixture.

Only a small amount of alcohol is used and it quickly vaporizes to a heavier-than-air vapor. The alcohol vapor and air are all that remain in the bottle. Alcohol molecules in the vapor phase are farther apart than in the liquid phase and present far more surface area for reaction; therefore the combustion reaction that occurs is very fast.

Since the burning is so rapid and occurs in the confined space of a 5-gallon jug with a small neck, the sound produced is very interesting, sounding like a "whoosh." The equation for the combustion reaction of isopropyl alcohol is as follows, where 1 mole of isopropyl alcohol combines with 4.5 moles of oxygen to produce 3 moles of carbon dioxide and 4 moles of water:

$$(CH_3)_2CHOH(g) + \tfrac{9}{2}O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) \qquad \Delta H = -1{,}235 \text{ kJ/mol}$$

Materials

- Whoosh bottle, plastic jug, 5-gallon
- Ethyl alcohol, CH_3CH_2OH, 20–30 mL
- Isopropyl alcohol, $(CH_3)_2CHOH$, 20–30 mL (recommended)
- Fire blanket (highly recommended)
- Funnel, small
- Graduated cylinder, 25-mL
- Match or wood splint taped to meter stick
- Safety shield (highly recommended)

Safety Precautions

Please read all safety precautions before proceeding with this demonstration.

- Ethyl alcohol and isopropyl alcohol are flammable liquids and fire hazards. They are slightly toxic by ingestion and inhalation. Use in a well-ventilated room.
- *Always* recap the alcohol bottle and move it far from the demonstration area. *Never* leave an open bottle of alcohol in the vicinity of the demonstration.
- A safety shield is highly recommended for explosions. Even the mildest explosion creates some chance of shattering and flying objects. Protective eyewear must be worn by the demonstrator as well as by anyone viewing the demo.
- *Never* perform alcohol explosions in glass bottles. The large quantities of gases (H_2O and CO_2) produced during the rapid combustion will easily shatter a glass container. Serious accidents have occurred performing this demonstration in a glass container—do not use glass.

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- Always pour out excess unvolatilized liquid alcohol from the plastic jug before igniting. If any liquid alcohol is left, it will increase the amount of gaseous afterburning. The liquid could also ignite, which may cause the plastic jug to melt. Always keep a lid or some sort of cover handy, which can be placed over the mouth of the jug to extinguish the flame if it continues so long as to begin melting the plastic. Excess alcohol on the outside of the jug should be wiped off in order to avoid its igniting and softening the plastic jug.
- *Never*, *ever* use a pure oxygen environment as the potential for an extremely violent and deadly explosion is possible.
- Never use methyl alcohol for this demonstration. The high volatility of methyl alcohol means that it has the potential for the most violent combustion of any alcohol.
- Replace the plastic "whoosh bottle" should it show grazing, frosting, cracking, or any small flaws. Routinely replace the bottle after approximately 20 uses or so.
- Do not perform this demonstration directly underneath smoke/heat detectors or sprinkler systems.
- Make sure the ceiling is at least 4 feet above the whoosh bottle to prevent possible scorching and fire.
- *Always* wear protective eyewear when performing this demonstration. Please consult current Material Safety Data Sheets for additional safety information on isopropyl alcohol.

Preparation

Before each demonstration, inspect the plastic whoosh bottle for grazing, frosting, cracking, or any small flaws. Replace the bottle if it shows signs of fatigue.

Procedure

1. Add about 20–30 mL of isopropyl alcohol to the 5-gallon plastic jug. Do not add more than 30 mL of alcohol. Recap the bottle of alcohol tightly and move it far from the demonstration area.
2. Lay the jug sideways on a flat surface allowing the alcohol to flow from base to mouth. Slowly swirl the jug for about 30 seconds, trying to spread alcohol liquid completely over the entire interior surface. This allows the liquid alcohol to volatilize and makes the vapor concentration uniform throughout the bottle. If a lot of liquid alcohol is still visible, swirl the bottle for another 30 seconds.
3. Pour out any excess liquid alcohol and shake out the bottle.
4. Stand the jug on the floor, placing it in the front of the room and behind a safety shield. *Note:* If desired, the demonstration can be performed on a fireproof demonstration table provided that the ceilings are at least 10 feet high.
5. Dim the lights in the room.
6. Light a match or wood splint that is taped to a meter stick or other long stick.
7. Stand back and, at arm's length, bring the burning match or wood splint over or slightly down into the mouth of the bottle. *Note:* Be sure you are on the safe side of the safety shield as well.
8. Observe the explosive "whoosh" that results.
9. After the reaction has subsided and all the flames are out, wait for a minute or two until the bottle has cooled slightly. Pour out the water droplets from the bottle into a 25-mL graduated cylinder using a small funnel. As much as 12–14 mL of water may result, showing that water is one of the products of the combustion of alcohol.

Repeating the Demonstration

The demonstration *cannot* be repeated immediately for a few reasons—for one, the demonstration *will not work* due to the buildup of CO_2 in the bottle. There is not enough oxygen in the bottle to allow combustion to occur. More importantly, it can be extremely dangerous to add alcohol to the jug if the jug is still hot. A flash back can occur causing a fire.

Therefore, in order to successfully repeat the demonstration for the same class or another class, follow the steps below:

1. Allow the bottle to cool to room temperature.

2. Pour out the water that forms as a result of the combustion.
3. Fill the bottle with about 1″ of cold tap water and swirl the tap water around in the bottle. Pour the tap water into the sink, and repeat the washing with more cold tap water. Pour all the water out into the sink.
4. Dry out the bottle as much as possible by either allowing it to sit upside down or (to speed up the drying) by drying it with a long string of paper towels pushed into the mouth. A few water droplets on the inside of the bottle do not seem to hinder the combustion.
5. In order to reduce the amount of water in the bottle and speed up the drying, try a double rinse of the bottle with a small amount of isopropyl alcohol.
6. Follow the procedure steps 1–9 above.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Excess alcohol may be disposed of by allowing it to evaporate in a fume hood according to Flinn Suggested Disposal Method #18a. Before storing the jug, allow it to remain open to the air to allow any remaining vapors to be released.

Observable Effects

The first effect that may be observed is the usual “whoosh,” which involves a moderately violent thrust of flames and blue gas out of the mouth of the bottle. Some afterburning or dancing flames of burning vapor in the body of the bottle may also result.

The second effect is a slower burn of gas down the inside surface of the bottle, producing a ring, plate, or cone of fire, which may be accompanied by an upward thrust or ball of yellow flames in the center of the jug. The sound accompanying these slower burns is actually more of a “whomp.” This effect can also be observed by using 70% isopropyl alcohol, illustrating reduced vapor pressure due to dilution.

Tips

- Various sound and flame effects may be produced depending on the alcohol used and its dilution with water. Try using ethyl alcohol or n-propyl alcohol. Compare the results to isopropyl alcohol. Ethyl alcohol proceeds somewhat faster and more violently due to its higher volatility. Propyl alcohol burns slower producing more heat, which may damage the bottle. *Do not try this demonstration with methyl alcohol.* The high volatility of methyl alcohol means that one must be particularly cautious when using methyl alcohol as it has the potential for the most violent combustion and possible rupture of the bottle.
- Depending on how much alcohol vapor is in the bottle, you may have to place the flame slightly inside the lip of the whoosh bottle before it ignites.
- The demonstration works best if the alcohol vapor is prepared immediately before the demonstration. If the bottle with the vapor sits for a while, the vapor tends to settle and is harder to light.
- Reagent isopropyl alcohol (99%) or 70% isopropyl alcohol can be used for the demonstration. The 70% alcohol produces a slightly slower burn due to the water vapor.
- Use a graduated cylinder to measure the volume of water produced by the reaction. Have your students perform calculations to determine the volume of water expected from the starting amount of isopropyl alcohol.

For example, if 20 mL of isopropyl alcohol (density = 0.78 g/mL) are used:

20 mL × 0.78 g/mL = 15.6 g × 1 mole/60 g = 0.26 mol isopropyl alcohol

From the balanced equation,

0.26 mol isopropyl alcohol × 4 mol H_2O/1 mol isopropyl alcohol = 1.04 mol H_2O

So,

1.04 mol H_2O × 18 g/mol = 18.7 g = 18.7 mL of H_2O expected

Discuss possible reasons why the actual volume of water may have been slightly less, such as evaporation or the droplets of water remaining on the inside of the bottle.

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 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, interactions of energy and matter

Answers to Worksheet Questions

1. Describe what happened in this demonstration.

A small amount of isopropyl alcohol was used to coat the inside of a large plastic jug. A light wood splint was held over the jug with a meter stick. The isopropyl alchol ignited, causing an explosive "whoosh" sound accompanied by flames jumping out of the mouth of the jug. Some flames could be seen afterward in the bottle. Also, flames inside the jug thrust upward and around, making a "whomp" sound.

2. Write a balanced chemical equation for the combustion of isopropyl alcohol.

$(CH_3)_2CHOH(g) + 9/2O_2(g) \rightarrow 3CO_2(g) + 4H_2O\ (g)$

3. Calculate the volume of water you would expect to be produced by this reaction if 20 mL of isopropyl alcohol with a density of 0.78 g/mL were used.

20 mL × 0.78 g/mL = 15.6 g × 1 mole/60 g = 0.26 mol isopropyl alcohol

From the balanced equation, we know that 1 mol isopropyl alcohol = 4 mol water.

Therefore, 0.26 mol isopropyl alcohol × 4 mol H_2O*/1 mol isopropyl alcohol = 1.04 mol* H_2O

1.04 mol H_2O *× 18 g/mol = 18.7 mL of* H_2O *expected.*

4. Why does this reaction occur faster when the alcohol is in the vapor phase rather than the liquid phase?

Alcohol molecules that are in the vapor phase combust faster than molecules in the liquid phase because they are spread further apart in the container. They therefore have a much greater surface area for the reaction, and this increased surface area allows for more molecules to react immediately with oxygen in the air.

Acknowledgments

Flinn Scientific would like to thank John Fortman, Dept. of Chemistry, Wright State University, Dayton, OH for all of his research in providing safety notes and variations on this excellent demonstration. John has written an excellent article on this demonstration; see reference listed below. Lee Marek, Naperville North H. S., Naperville, IL and Bill Deese have also popularized this demonstration.

Reference

Fortman, J. J.; Rush, A. C.; Stamper, J. E. *J. Chem. Ed.* **1999**, *76*, 1092–1093.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Big Time Ethyl Alcohol Explosion* activity, presented by Lee Marek, is available in *Combustion of Alcohols* and in *Stoichiometry in Combustion Reations*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Big Time Ethyl Alcohol Explosion* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Whoosh Bottle—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP5943	Whoosh Bottle—Chemical Demonstration Kit
SE225	Safety shield, 309 × 169
I0019	Isopropyl alcohol, 500 mL
E0009	Ethyl alcohol, 500 mL

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

Big Time Ethyl Alcohol Explosion Worksheet

Discussion Questions

1. Describe what happened in this demonstration.

2. Write a balanced chemical equation for the combustion of isopropyl alcohol.

3. Calculate the volume of water you would expect to be produced by this reaction using the equation above. Remember, 20 mL of isopropyl alcohol with a density of 0.78 g/mL were used.

4. Why does this reaction occur faster when the alcohol is in the vapor phase rather than the liquid phase?