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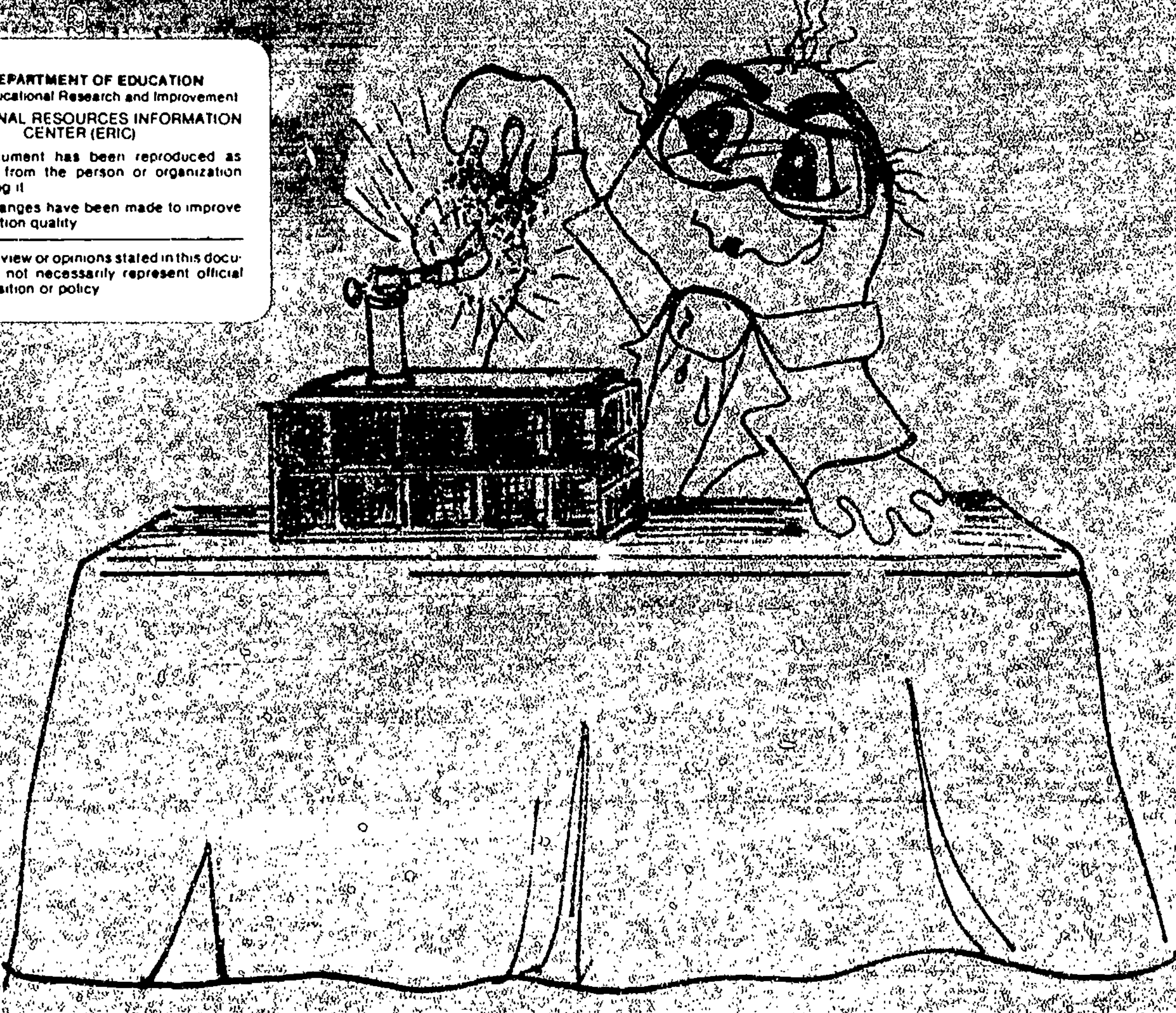
ABSTRACT

Chemical demonstrations can and do enhance an otherwise potentially dull subjects--the properties of hazardous materials. This book contains the recipes for presenting several chemical demonstrations. Demonstrations are designed to be relatively easy to perform and present minimal hazards if done properly. The book contains an introduction, safety instructions, demonstrations, and a supplier list. The demonstrations are divided into the following areas: corrosive materials (5 demos), flammable materials (8 demos), oxidizing agents (2 demos), and physical properties (3 demos). Four materials suppliers are listed. (LZ)

CHEMICAL DEMONSTRATIONS

THE CHEM DEMO BOOK



CHEM DEMO BOOK

by Thomas K. Wray

A Guide to Fun, Safe & Exciting Chemical Demonstrations

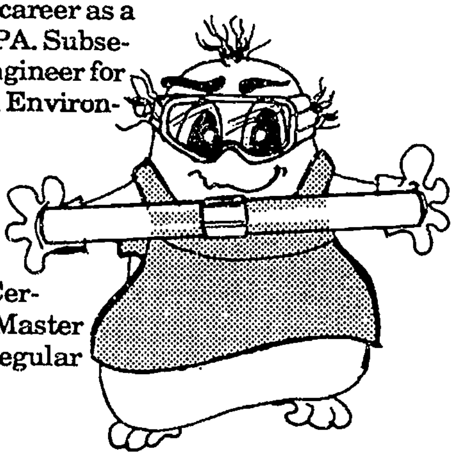
This book is dedicated to William R. Bunner and Eric J. Enholm, two of America's best instructors and lecturers. Their knowledge, wit, and insight in the art of performing chemical demonstrations is reflected in the pages of this book.

About the author...

Tom Wray is the owner and president of Waste Away Services, a hazardous waste brokerage firm also specializing in the packaging and disposal of lab packs. Mr. Wray also provides environmental training. He is a featured speaker of HazMat conferences throughout the United States.

After receiving his B.S. in Chemistry from Bowling Green State University in 1980, Tom began his environmental career as a hazardous waste compliance officer for the Ohio EPA. Subsequently, he was employed as a technical services engineer for Envirosafe Services and Associated Chemical and Environmental Services.

Tom is a member of several national organizations including the National Environmental Training Association, the American Chemical Society, and the National Fire Protection Association. He is a Certified Hazardous Materials Manager (CHMM) Master Level, and the author of "The HazMat Chemist," a regular column in the monthly periodical HazMat World.



"Haz Mat"

THE CHEM DEMO BOOK
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Introduction

This book contains the recipes for doing several chemical demonstrations. Like a cookbook, follow the recipe and the results are predictable; alter the ingredients or the procedure and pronounced changes may occur. All the demonstrations described in this book are relatively easy to perform and have been successfully replicated hundreds of times. They present minimal hazards if done properly. However, some quite hazardous substances are used in these demonstrations. We cannot eliminate the hazards associated with these substances but we can control the risks they present. To that end, *ALWAYS* wear appropriate personal protective equipment when performing these demonstrations.

Following these six simple steps will ensure the demonstrations are effective, interesting, educational, and fun:

1. **Plan, prepare, practice.** Always know exactly what you are going to do and when you are going to do it. Be certain you can correctly predict the outcome of each demonstration. Remember what one student told me: Fail to plan; plan to fail!

2. **Keep the demonstration area uncluttered.** Clutter substantively diminishes the impact of any demonstration. Keep the area where the demonstrations are being performed clear of any unnecessary equipment or materials.

3. **Make sure the demonstration is relevant.** While it is some times desirable to catch the attention of the audience by using chemical demonstrations, this should be done sparingly. Demonstrations are designed to increase the knowledge and aware ness of the audience. Use only those demonstrations which will enhance the discussion topic.

4. **Demonstrations must be lively.** There is nothing quite so boring as a lethargic, monotonous instructor performing an exciting chemical demonstration. Enthusiasm is contagious--become an exciting, spontaneous, and impassioned presenter.

5. **Let the audience observe.** Do not say: "I will now extinguish a lit splint by lowering it into a beaker of CO_2 gas." Rather, say: "Observe as I lower a lit splint in this apparently empty beaker." Allow the audience to use their powers of observation to predict the outcome of each demonstration. The principles learned may some day be invaluable.

6. **Use humor.** Don't become a class clown but where appropriate, interject a humorous anecdote. Frequently, a student will provide just the spark of humor needed to amuse the audience. An alert instructor can often use this as a springboard for future commentary. Avoid foul, vulgar, or otherwise inappropriate comments.

Especially in a workplace setting where one spends increasingly more time in training classes, chemical demonstrations can and do enhance an otherwise potentially dull subject - the properties of hazardous materials. A discussion of flammable range may be interesting to some but the demonstration of flammable range is interesting to all. Weekly, monthly, or yearly training classes can become exciting group discussions.

A Word About Safety

Practice and experiment. You may develop your own demonstrations which are far more specific and relevant to your situation than the ones described in this book. By all means, be creative. But also be careful. Experience teaches us that injuries take but a moment to occur and recovery may take weeks, months, or years. (If the damage is not permanent!)

There is always the potential for accident and injury. Always wear proper personal protective safety equipment. Expect the unexpected. Although all the chemical demonstrations in this book have been performed safely dozens of times, you should always be prepared for what OSHA calls a "foreseeable emergency". Use micro amounts of dangerous substances. Why blow up a five-pound block of sodium when a pea-sized piece works quite adequately? There is far less risk in far lesser quantities. Never endanger the audience. Where necessary, use an explosion shield; ventilate the room; or simply don't do the demonstration. Have a fire extinguisher, neutralizing media, water, etc. available. If everything is done properly, these items should be superfluous; however, a demonstrator should always err on the side of safety.

The author expressly disclaims any and all responsibility for injuries that may arise during the performance of these demonstrations. Only experienced, knowledgeable individuals should conduct these demonstrations. Demonstrators assume full responsibility for injuries or illnesses directly related to their technique. Instructors should be completely cognizant of all hazards and potential hazards for each and every demonstration they intend to perform.

CHEMICAL DEMONSTRATIONS

THE CHEM DEMO BOOK

Demo CM-1

NEUTRALIZING AN ACIDIC SOLUTION WITH SODIUM BICARBONATE

Materials Needed

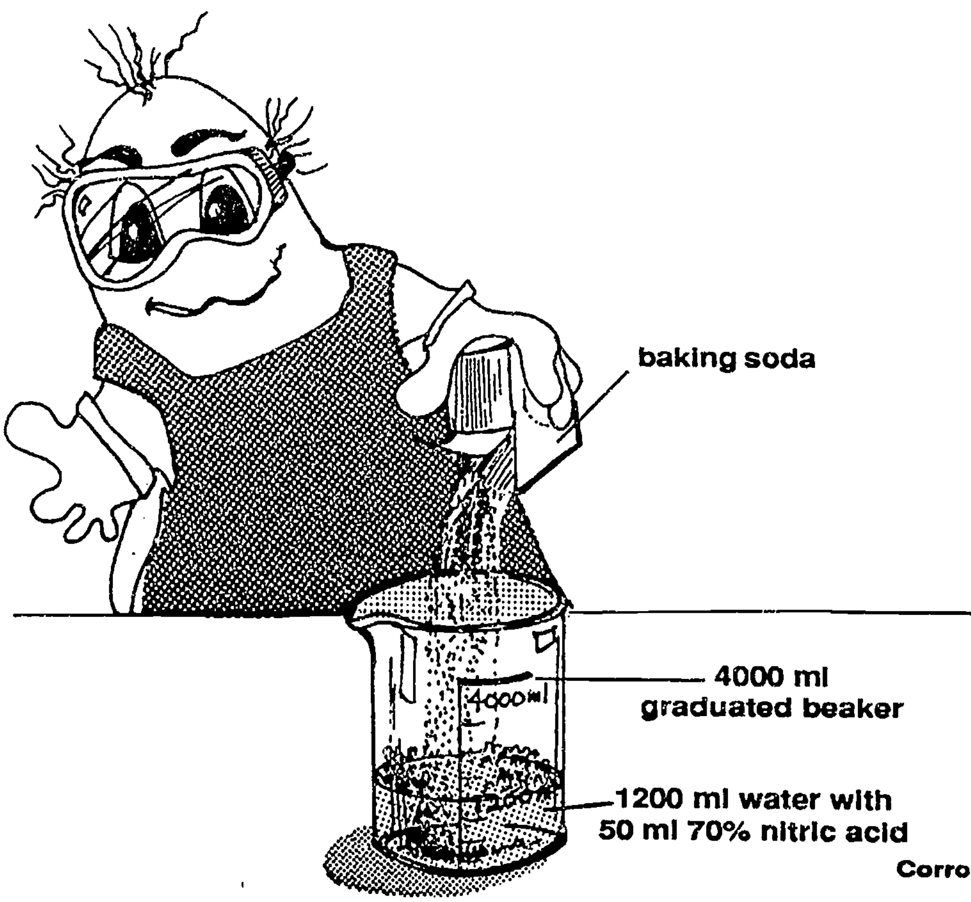
- Demonstration table
- Aluminum Foil
- 4-Liter glass beaker or comparable container
- 2000 mL tap water
- One pound box of baking soda
- 25 mL of concentrated nitric or hydrochloric acid
- pH paper or pH meter
- Glass stirring rod
- Personal protective clothing to include chemical splash goggles, acid-resistant apron, elbow-length butyl rubber gloves

Purpose To demonstrate the neutralization of an acidic solution (pH=0) with baking soda to result in a pH of 7-8.

Objective To add a sufficient quantity of baking soda to an acidic solution so the resulting products are water, an inorganic salt, and carbon dioxide.

Procedure Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Fill the 4-Liter beaker with 2000 mL of tap water. Check the pH. (Let someone from the audience announce the results.) Put on protective clothing. Slowly add the 25 mL of acid to the water. Stir. Again check the pH. It should read zero. Slowly add about 1/3 of the box of baking soda (CAUTION-a significant amount of fizzing will occur as carbon dioxide gas is liberated.) Stir. Again check the pH. It should be 7. Now add most of the baking soda remaining in the box. Ask the audience if they think the pH will be too high now (caustic). Check the pH. It should read 8.

Discussion This demonstration is designed to illustrate both the simplicity and importance of neutralization. Dilution is generally an ineffective way to handle acid spills because the pH scale is logarithmic. Each single digit increase (or decrease) is a tenfold change in the acid strength. (See BOX- pH Scale) Fortunately, neutralization is fairly easy. Neutralization is defined as: "the mutual destruction of the ions which characterize acids and bases to produce a salt and water". Assume we use hydrochloric acid (HCl). Neutralizing with baking soda ($NaHCO_3$) will produce NaCl, H_2O, and CO_2. (Carbonate salts result in the formation of carbon dioxide.) This is an effective way to control the hazard of an acid spill without significant risk or exorbitant expense. Other weak bases can also be used such as slaked lime (calcium hydroxide), magnesium hydroxide, or soda ash (sodium carbonate).



pH Scale

Increasing acid strength (pH)		Increasing base strength (pH)
0	10,000,000 x	14
1	1,000,000 x	13
2	100,000 x	12
3	10,000 x	11
4	1,000 x	10
5	100 x	9
6	10x	8
7	neutral	7

Key Words neutralization, pH, dilution, acids, bases, specific gravity

Comments Always add ACID to WATER. Heat of dilution is significant. Since acids all have higher specific gravities than water, the initial reaction will occur beneath the surface of the water minimizing the potential for injury. *Always experiment first before performing for an audience!*

Supplies:	*Suppliers:*
• Baking soda • Aluminum foil	Grocery store
• 4-Liter glass beaker • 25 mL concentrated HCl • Glass stirring rods • pH paper or pH meter	Lab supply store

Demo CM-2

DEHYDRATING A CARBOHYDRATE WITH CONCENTRATED SULFURIC ACID

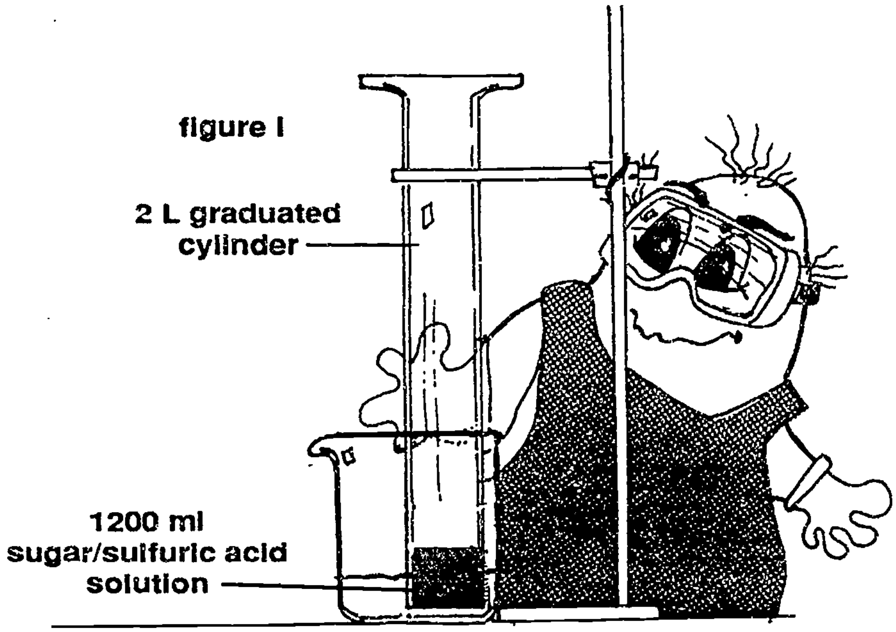
Materials Needed

- Demonstration table
- Aluminum Foil
- 4-Liter glass beaker or comparable container
- Baking soda solution (From Demo CM-1 or add 3/4 lb baking soda to 22000 mL water)
- 75 mL concentrated (96%) sulfuric acid
- 200 mL tall form beaker
- 2-Liter graduated cylinder (glass or polymethylpentene)
- Ring stand with clamp
- 2 lb box of granulated sugar
- Glass stirring rod
- Personal protective clothing to include chemical splash goggles, acid-resistant apron, elbow-length butyl rubber gloves

Purpose To demonstrate the severe dehydration effects of concentrated sulfuric acid on a simple carbohydrate (sucrose).

Objective To add concentrated sulfuric acid to table sugar in a beaker resulting in the dehydration of the sugar and the formation of an expanded column of pure carbon.

Procedure Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Fill the 4-Liter beaker with 2000 mL of baking soda solution. Don your protective clothing prior to continuing this experiment. Invert the 2-Liter graduated cylinder and clamp it to the ring stand as shown. Fill the 200 mL tall form beaker about half full of granulated



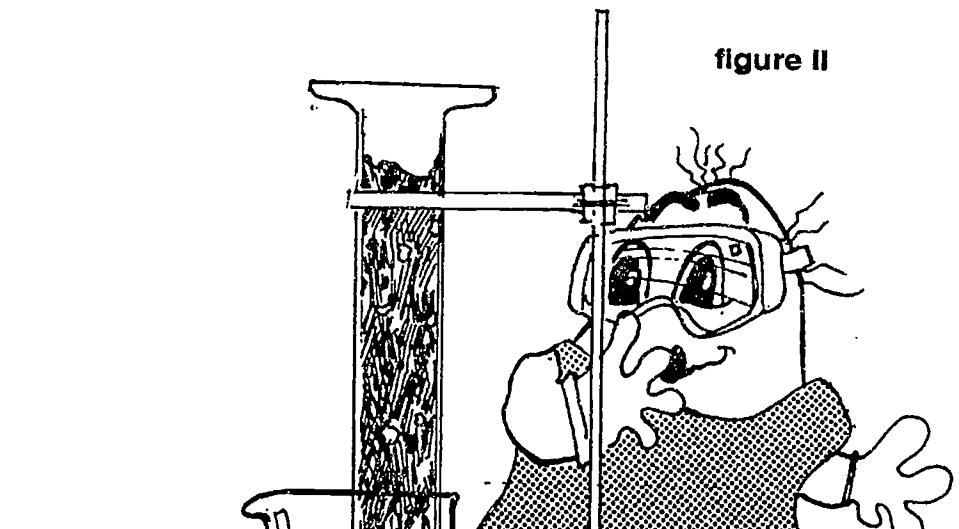
sugar. Add about 75 mL of concentrated sulfuric acid to the sugar in the beaker and stir with a glass rod. (The sugar will began to rapidly turn brown, then black.) Place the beaker upright in the baking soda solution and move the graduated cylinder over the top of the 200 mL tall form beaker so that the graduated cylinder opening is well below the surface of the bicarbonate solution. Within moments there will be a substantial amount of heat generated, the graduated cylinder will fog over as steam condenses on the interior walls, and a long black column of carbon will rise inside the cylinder.

Discussion This demonstration is designed to illustrate the severe destructive potential of a concentrated, dehydrative acid. It is quite an impressive demonstration when done correctly. Care should be taken to ensure the acid vapors released from the dehydrating sugar are neutralized in the baking soda bath. Also NEVER use powdered or ultrafine granulated sugar. The dehydration will occur much too rapidly. You should make the point to your audience that concentrated sulfuric acid can dehydrate all carbohydrate-based compounds such as paper, wood, cotton clothing, and skin. Also point out that this is the largest volume chemical produced in the U.S. (88.8 billion lbs in 1993), and probably in the developed world. It is used in a variety of processes–in making fertilizers, chemicals, dyes & pigments; in petroleum refining, in electroplating baths; in the iron & steel industry; and in the manufacture of industrial explosives. Many industries use very large volumes of sulfuric acid. Most people are at least vaguely familiar with battery acid (sulfuric acid) and some know from first-hand experience just how destructive the acid can be.

Key Words dehydration, carbohydrate, neutralize

Comments *Be certain to try this experiment first before performing for an audience!* The carbon column produced will still contain some unreacted sulfuric acid and should be neutralized with baking soda prior to handling by untrained personnel. During the dehydration reaction the audience may detect the odor of burnt sugar. This is normal. The glass beaker containing the reaction mixture can be cleaned but the residue should be neutralized with baking soda then washed down the drain.

figure II



Demo CM-2 /continued

Supplies:	*Suppliers:*
• 1 lb box Baking soda	Grocery store
• Aluminum foil	
• 2 lb box Granulated sugar	
• 4-Liter glass beaker	Lab supply store
• 2-Liter graduated cylinder	
• 75 mL concentrated sulfuric acid	
• Glass stirring rods	
• 200 mL tall form beaker	
• Ring stand w/ clamps	

Demo CM-3

THE FORMATION OF NITRIC OXIDES FROM PENNIES IN CONCENTRATED NITRIC ACID

Materials Needed

- Demonstration table
- Aluminum Foil
- 1-Liter glass beaker or comparable
- Watch glass to cover beaker
- 50 mL concentrated (70%) nitric acid
- 5-gallon bucket half-full of tap water
- One 1-lb box of baking soda
- Lid for 5-gallon bucket
- Two pennies from your audience (Pre- and Post- 1982)
- Roll of paper towels
- Personal protective clothing to include chemical splash
- goggles, acid-resistant apron, elbow-length butyl rubber gloves

Purpose To illustrate: the formation of a toxic reddish-brown gas that is heavier than air; the composition of a pre- and post-1982 penny; and the rapidity of certain chemical reactions.

Objective To add two pennies to a solution of 70% nitric acid, generating a reddish-brown gas. To stop the chemical reaction by immersing the reaction into a 5-gal container of sodium bicarbonate water, and to show the audience the pennies.

Procedure Put on protective clothing--gloves, apron, goggles! Pour approximately 25 mL of concentrated nitric acid (70%) into a 1000 mL beaker. Cover with a watch glass. Place the two pennies on top of the watch glass. Note that the pennies are pure copper–a transition metal. Lift the watch glass, drop the pennies into the beaker, and cover with the watch glass. Copper will immediately begin to dissolve in the acid producing a green solution (Copper I ion). A reddish-brown (nitrogen dioxide) gas will be liberated filling the beaker. Comment to the audience that the gas is both heavier than air and toxic. (All colored gases are poisonous!) Before the gas spills over the top of the beaker immerse it into a 5-gallon bucket one-third-full of a sodium bicarbonate solution. Pour out the solution leaving the pennies in the beaker. Immediately cover the bucket. CAREFUL- avoid inhaling nitrogen dioxide. Ventilate the room if possible and keep the bucket covered for at least 30 minutes. Pour the pennies from the beaker onto a few sheets of paper towels. Wipe off and dry the pennies. The pre-1982 penny is pure copper throughout and is now cleaner but slightly thinner. The post-1982 penny is mostly zinc with a thin electroplating of copper. This penny is now a very thin piece of zinc which may be discolored black due to the formation of zinc oxide.

Discussion This demonstration clearly illustrates the oxidizing power of nitric acid. Strong acids will dissolve metal but will not all produce dangerous oxides. Oxidizing acids, like nitric, will. Also zinc is much higher on the metal activity series than copper. (See list on following page) Thus zinc is more reactive than copper and will dissolve more rapidly in nitric acid to produce nitric oxides. The reddish-brown gas is nitrogen dioxide which is responsible for the brownish haze of urban smog in certain densely populated areas. The bucket of sodium bicarbonate water should appear blue now indicating the formation of Copper II ion. This same blue color is seen in a common algaecide–copper sulfate.

Key Words copper I ion, electroplating, oxidizing acid, nitrogen dioxide, algaecide, metal activity series

Comments *Be certain to try this experiment first before performing for an audience!*

Conduct this demonstration in a well-ventilated room, in a hood, or outdoors. Cover the bucket as quickly as possible after killing the reaction to minimize any escaping gas. A brand new shiny penny and a 30-40 year old penny make a good contrast in appearance before and after the reaction.

Supplies:	*Suppliers:*
• 1 lb box Baking soda • Paper towels	Grocery store
• 5-gallon bucket	Department store
• 1000 mL glass beaker • Watch glass • 25 mL 70% nitric acid	Lab supply store

ACTIVITY SERIES

Lithium
Potassium
Calcium
Sodium
Magnesium
Aluminum
Zinc
Chromium
Iron
Nickel
Tin
Lead
HYDROGEN
Bismuth
Copper
Mercury
Silver
Gold

Metal activity series–Listed in order of decreasing activity.

Demo CM-4

THE FORMATION OF HYDROCHLORIC ACID BY COMBINING SODIUM CHLORIDE WITH CONCENTRATED SULFURIC ACID

Materials Needed

- Demonstration table
- Aluminum Foil
- 1-Liter glass beaker or comparable
- Watch glass to cover beaker
- 10 mL concentrated (96%) sulfuric acid
- 1 oz (~25 g) common table salt
- Roll of paper towels
- Personal protective clothing to include chemical splash goggles, acid-resistant apron, elbow-length butyl rubber gloves

Purpose To illustrate: the formation of a hydrochloric acid by combining common table salt with sulfuric acid.

Objective To add 1 oz of table salt to a 600mL beaker containing 10 mL of concentrated sulfuric acid. This addition will immediately produce a small amout of HCl.

Procedure Put on protective clothing–gloves, apron, and goggles! Pour about 10mL of conc. (96%) sulfuric acid into the bottom of a 600mL beaker. Add 1 oz (~25g) table salt to the beaker. HCl will form immediately. Wet a cotton ball with household ammonia solution and hold it inside the beaker with tongs. A whitish cloud of ammonium chloride is formed.

Discussion This demonstration provides two examples of a double-displacement reaction. Sulfuric acid first combines with table salt to form hydrochloric acid (HCl) and sodium sulfate

(Eq. 1); second the HCl combines with ammonium hydroxide (NH_4OH) to form ammonium chloride and water (Eq. 2). The balanced reactions are shown.

$$H_2SO_4 + 2NaCl \longrightarrow 2HCl + Na_2SO_4 \quad \text{Eq. 1}$$

$$2HCl + 2NH_4OH \longrightarrow 2NH_4Cl + 2H_2O \quad \text{Eq. 2}$$

Key Words hydrochloric acid, ammonium hydroxide, ammonium chloride

Comments *Be certain to try this experiment first before performing for an audience!*

Conduct this demonstration in a well-ventilated room, in a hood, or outdoors. This demonstration gives the audience another contrast in visible gases. HCl, which has a highly disagreeable odor, is not readily visible; nor is ammonia which also has a pungent odor. Both gases combine to form ammonium chloride which is a highly visible cloud of infinitesmal particles of NH_4Cl.

Supplies:	*Suppliers:*
• Ammonia solution	Grocery store
• Paper towels	
• Table salt	
• Cotton balls	
• 600 mL glass beaker	Lab supply store
• Watch glass to cover beaker	
• 10 mL conc. (96%) sulfuric acid	
• Tongs	

Demo CM-5

COLLAPSING A 1-GALLON STEEL CAN CONTAINING GASEOUS ANHYDROUS AMMONIA USING ONLY 80 ML OF WATER

Materials Needed

- Demonstration table
- Teflon tape
- 1-gallon empty oblong steel can
- Small cylinder or lecture bottle of liquified anhydrous ammonia
- Two feet of clear plastic (tygon or comparable) tubing
- 100 mL beaker filled with about 80 mL tap water
- Chemical splash goggles, chemical splash apron, chemically-resistant gloves
- Non-flammable gas label

Purpose To illustrate just how water-soluble anhydrous ammonia is; and to demonstrate the power of air pressure.

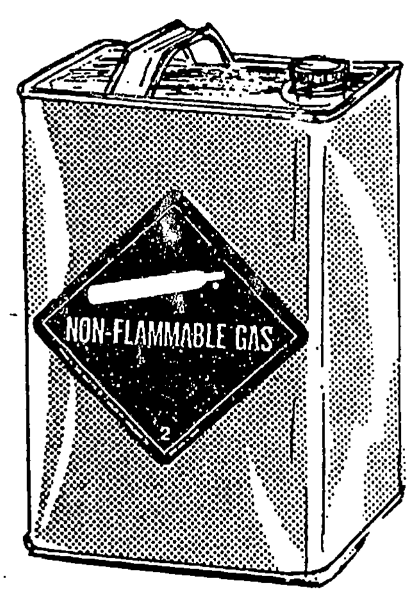
Objective To add about 80 mL of ordinary tap water to a one gallon steel can containing 100% gaseous anhydrous ammonia.

Procedure The can must be prepared in advance. Wrap the threads on the can lid with teflon tape to ensure a tight seal. Put on protective clothing–gloves, apron, goggles. Fill the can outdoors. Lay the can on the ground. With the plastic tubing securely attached to the ammonia cylinder, insert the hose into the metal can. Open the valve until a small amount of liquid ammonia enters the can. (Frost will appear on the outside of the can.) Shut the valve. Quickly screw the lid onto the can to seal in the gaseous ammonia. **CAUTION: Do not seal the can before all the liquid ammonia has vaporized.** The can is now ready for use. If properly sealed, it can be kept for several days prior to use. I usually attach a "Non-flammable gas" label to the can for later commentary. When ready to do the actual demonstration, fill the 100mL beaker with about 80mL water and set it on top of the sealed can. Note to the audience that you have a 1-gallon can and only about 2 oz of water. Set the can down on the demonstration table. Facing the audience, quickly remove the cap, pour in the water and re-seal the can. Swirl the can a few times. The metal container will collapse, as the ammonia gas dissolves, due to higher outside air pressure.

Discussion This demonstration clearly illustrates the solubility of an anhydrous gas as well as the significance of air pressure differences. One part water will absorb about 700 parts gaseous anhydrous ammonia. Since the human body is 65-70% water, gaseous anhydrous ammonia can be readily absorbed forming a corrosive solution of ammonium hydroxide:

$$NH_3 + H_2O \longrightarrow NH_4OH$$

Anhydrous ammonia is quite toxic. The immediately dangerous to life or health (IDLH) level is only 500 ppm. Fortunately the odor threshold is much lower–about 0.05 ppm. Anhydrous ammonia can also burn if present in the air between 16-25% or at a lower concentration if the oxygen level exceeds 20.9%. Anhydrous ammonia is one of the few gases that is lighter than air (0.6) and will therefore dissipate fairly rapidly.



Key Words anhydrous, immediately dangerous to life or health

(IDLH), solubility, odor threshold

Comments *Be certain to try this experiment first before performing for an audience!*

This demonstration can easily be conducted indoors although the people seated in the front row may detect a slight ammonia odor. Filling the can with ammonia gas is the tricky part of this demo. Always wear protective clothing and DO NOT have contact with liquified anhydrous ammonia as severe burns may occur. (Unfortunately, I learned this fact through a painful personal experience.)

Supplies:	*Suppliers:*
• 1-gallon metal oblong can	Consolidated Plastics
• 100 mL glass beaker • Two feet plastic (Tygon) tubing	Lab supply store/ Edmund Scientific
• Liquified anhydrous ammonia • Teflon tape	Welding supply
• Non-flammable gas labels	J.J. Keller/Labelmaster

Demo FM-1

BURNING AN ORGANIC SOLID

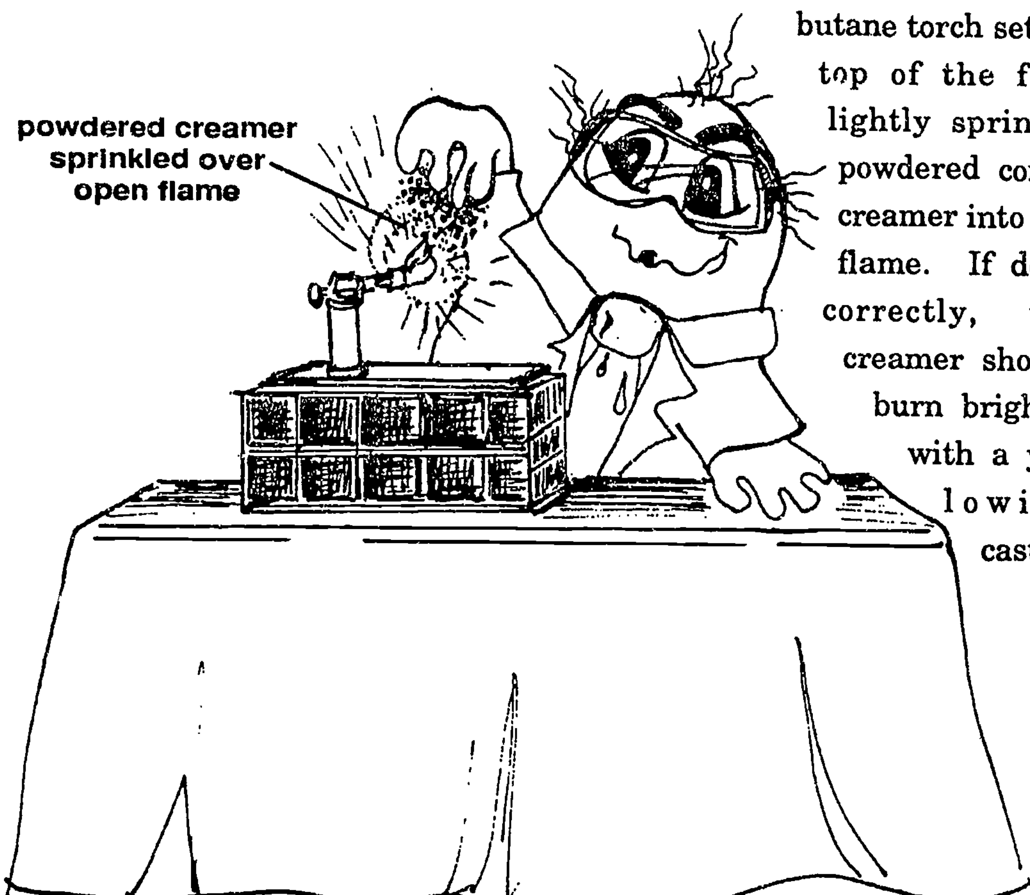
Materials Needed

- Demonstration table
- Aluminum Foil
- Propane or butane torch
- Powdered non-dairy creamer

Purpose To illustrate that all organic materials will burn.

Objective To burn a common organic solid (coffee creamer) in a hot flame.

Procedure Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Using either a portable propane or butane torch set on top of the foil, lightly sprinkle powdered coffee creamer into the flame. If done correctly, the creamer should burn brightly with a yellowish cast.



Discussion This simple demonstration is designed to illustrate a primary potential hazard of all **organic** materials–flammability. Substances which contain a high percentage of carbon and hydrogen will burn. The addition of oxygen and nitrogen atoms generally increases the rate of **combustion**. Foods, natural and **synthetic** clothing, pharmaceutical drugs, **vitamins**, carpets, and upholstery are all examples of common organic substances. However, surface area is an important consideration. The more finely divided the substance, the more readily it will burn. The larger the particle size the more difficult it is to ignite. Generally dust fires will occur when the particulates are less than 100 microns. However, materials combust only after they reach their **fire point**. The fire point is the temperature of the substance which allows sustained combustion without the application of outside energy. Fire points apply only to liquids and solids. Substances **vaporize** prior to combustion although these **vapors** (or **gases**) are rarely visible. As finely-divided particulate [organic] material has more surface area exposed to the flame, it readily vaporizes (and ignites). Larger particulate organic matter must have heat applied for a longer period to reach the fire point of the substance.

Key Words Organic, combustion, synthetic, vitamins, fire point, vaporize, vapors, gases

Comments Many other substances can be substituted for non-dairy creamer – *Sweet & Low*, ground aspirin, flour, etc. *Always experiment first before performing for an audience!*

Supplies:	*Suppliers:*
• Non-dairy creamer • Aluminum foil	Grocery store
• Propane torch	Hardware store
• Butane torch	Welding supply/Edmund Scientific

Demo FM-2

A SIMPLE DUST EXPLOSION

Materials Needed

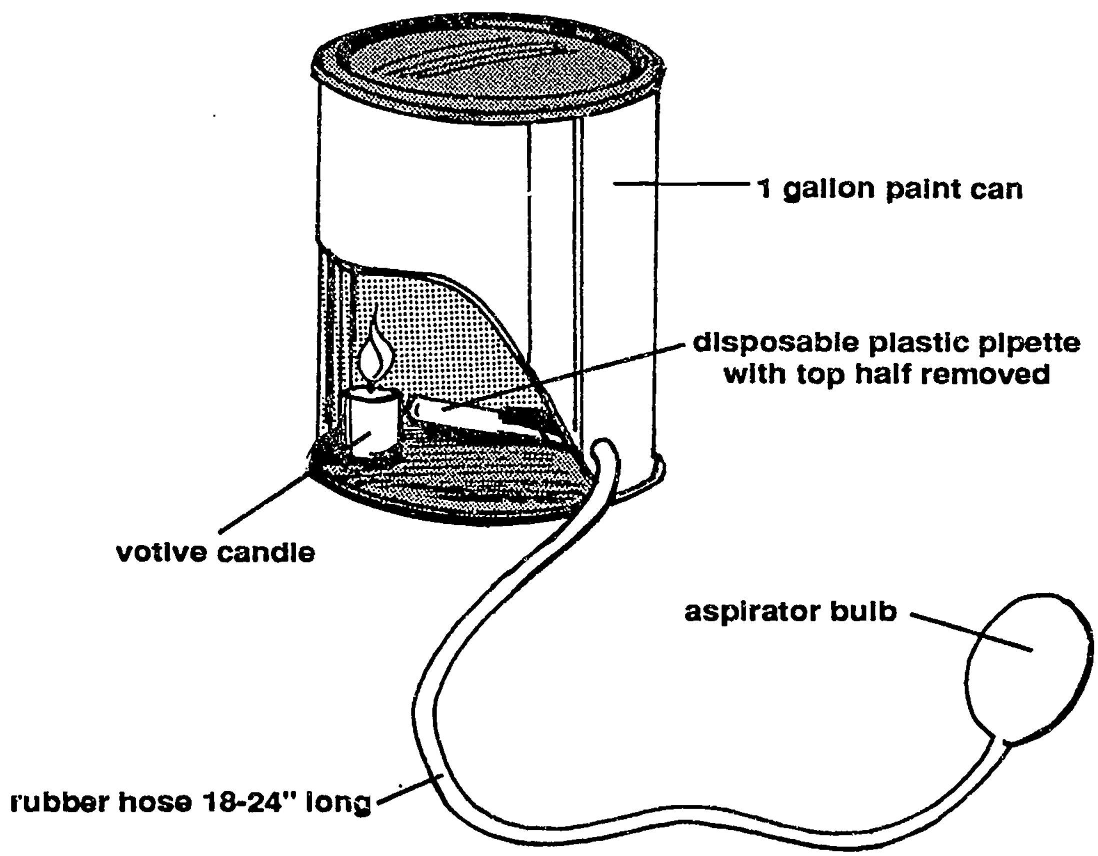
- Demonstration table
- Aluminum Foil
- Plastic disposable eyedropper
- One packet powdered non-dairy creamer
- Collapsible crate or similar
- New 1-gallon paint can w/lid (unused)
- 18–24" 1/4" O.D. rubber hose
- Aspirator bulb (optional)
- Votive candle
- Fireplace ignitor

Purpose To replicate a simple dust explosion.

Objective To aspirate a common organic solid (coffee creamer) into a candle flame inside of a sealed 1-gallon paint can.

Procedure Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Using a razor knife, carefully cut the top off of a disposable plastic eyedropper. Drill or puncture a 1/4" hole in the side of a 1-gallon can near the bottom. Set the can on top of a collapsible crate. Push the small end of the eyedropper through the hole from inside the can. Attach the rubber hose and aspirator. Empty the contents of one packet of non-dairy creamer into the eyedropper. Place the votive candle inside the can opposite the eyedropper filled with creamer. Light the candle inside the can using the fireplace ignitor. Quickly force the cover onto the can. Then squeeze the aspirator bulb (or blow through the hose). The lid will blow off the can with a loud bang accompanied by a yellow flash of flame.

Discussion Organic dusts and inorganic metallic dusts can burn if the available heat energy exceeds the ignition temperature of a substance. The more finely divided the substance, the more readily it will burn. The larger the particle size the more difficult it is to ignite. Generally dust fires will occur when the particulates are less than 100 microns. If these dusts are confined, an explosion can occur. Dust explosions have claimed many lives in the U.S. Plant areas should be kept free of dust accumulation from organic substances or inorganic metallic substances.



Key Words dust explosion, inorganic metallic dust, ignition temperature, particulates

Comments Many other substances can be substituted for non-dairy creamer – *Sweet & Low*, ground aspirin, flour, etc. *Always experiment first before performing for an audience!*

Supplies:	*Suppliers:*
• Non-dairy creamer • Aluminum foil	Grocery store
• Collapsible crate	Department store
• 1-gallon paint can	Hardware store Paint supply store
• Rubber hose • Aspirator bulb • Plastic disposable eyedropper	Hobby store or Lab supply store

Demo FM-3

ACTIVATION ENERGY / CATALYST

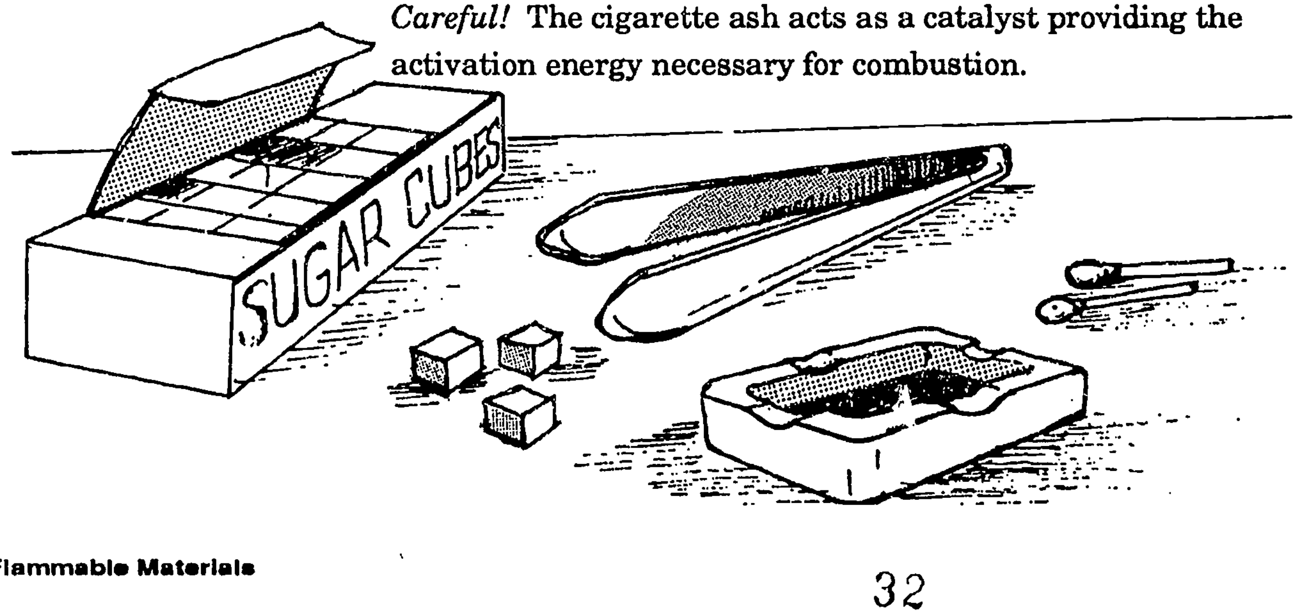
Materials Needed

- Demonstration table
- Aluminum Foil
- Clear ashtray
- Sugar cubes
- Crucible tongs
- Cigarette (ash)
- Matches

Purpose To illustrate how a catalyst works.

Objective To burn a common sugar cube using a catalyst (cigarette ash).

Procedure Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Using tongs, attempt to ignite a sugar cube with a match. Try this several times. After convincing your audience that the sugar will not ignite, burn a cigarette to produce a small amount of ash. Dip a corner of the sugar cube in the ash. Now try igniting the sugar cube. *Careful!* The cigarette ash acts as a catalyst providing the activation energy necessary for combustion.



Discussion This simple demonstration is designed to illustrate a primary potential hazard of all **organic** materials–flammability. Substances which contain a high percentage of carbon and hydrogen will burn. The addition of oxygen and nitrogen atoms generally increases the rate of **combustion.** As finely-divided particulate [organic] material has more surface area exposed to the flame, it readily vaporizes (and ignites). Larger particulate organic matter must have sufficient heat applied for a longer period to reach the fire point of the substance or use a catalyst to lower the activation energy necessary for a chemical reaction.

Key Words activation energy, catalyst, combustion

Comments Catalysts are commonly employed in industrial production processes–oil refining, plastic manufacturing, etc. Automotive catalytic converters use a combination of three catalysts to effectuate optimal combustion.

Supplies:	*Suppliers:*
• Clear ashtray	Grocery store
• Sugar cubes	
• Cigarettes	
• Matches	
• Aluminum foil	
• Crucible tongs	Lab supply or hobby store

Demo FM-4
FLAME PROPAGATION TUBE

Materials Needed

- Demonstration table
- Aluminum Foil
- Welding gloves
- Eye protection
- Propane or butane torch
- Lighter fluid (I prefer Ronsonol)
- Butane refill (optional)
- Two 18" long pieces of heavy wall glass drainpipe
- Clamp (to connect drainpipe)
- Weight (a 35mm film case filled with sand will work)

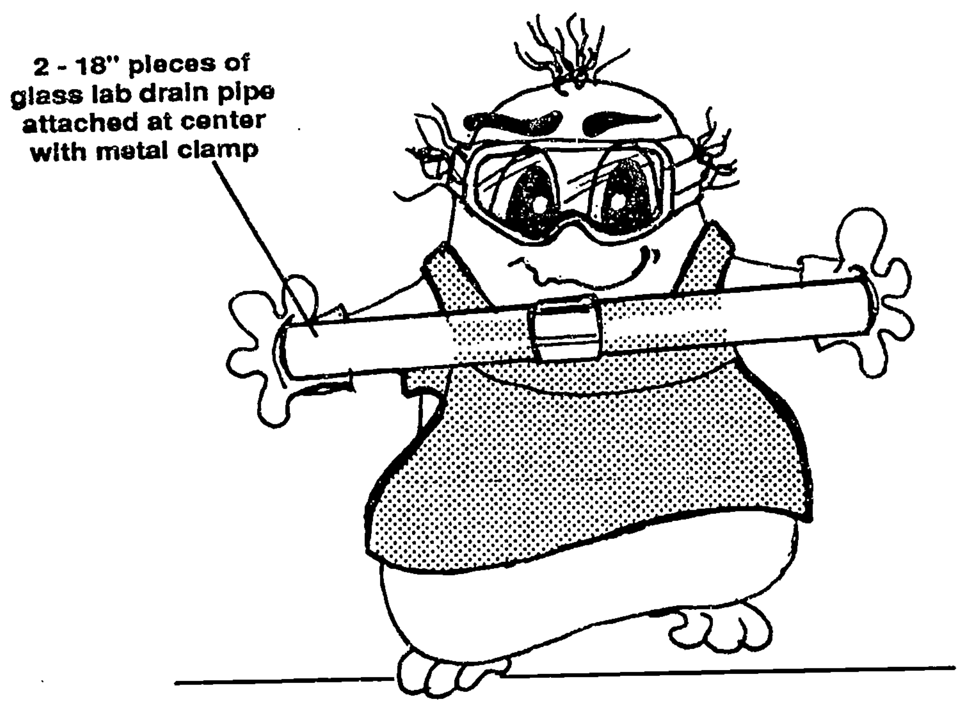
Purpose To illustrate flammable range visually.

Objective To ignite lighter fluid vapors in a glass tube at various concentrations.

Procedure Turn down the room lights for this demo. Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Set either a portable propane or butane torch on top of the foil and turn it on. Put on your gloves and eye protection. (A lab coat or leather apron is also advisable) Place just a few drops of lighter fluid in the tube, insert the weight, pick up the tube and covering both ends with your hands, rock the tube back and forth for a few moments while explaining that you must first convert the liquid to vapor before it will burn. Then, keeping one hand clamped tightly over the end of the tube, remove your other hand and tilt the open end into the flame (the weight will fall out). Nothing happens because the vapor-air concentration was below the

LEL. Repeat the procedure adding more lighter fluid this time (two quick squirts). If done properly, a rather slow burning blue flame will travel through the tube indicative of a combustion very close to the LEL. Aerate the tube by swinging it back and forth then repeat the procedure a third time increasing the fuel content by adding four quick squirts. The combustion will now be much more vigorous and noisy. This will illustrate a combustion at about the ideal (stoichiometric ratio) concentration for complete conversion of hydrocarbon fuel to carbon dioxide and water.

Discussion This demonstration is designed to illustrate a visual difference between flammable vapor-air mixtures. It also illustrates the need to vaporize materials before ignition. Remember substances will combust only after they reach their **fire point**. The fire point is the temperature of the substance which allows sustained combustion without the application of outside energy. Note that a fire always travels from the point of ignition into the fuel. After using all of the available oxygen in a given area, a fire will create a vacuum



(backdraft) which allows combustion of the remaining fuel. Hence the noise heard in the third attempt. Combustion efficiency is denoted somewhat by color. Blue flames are indicative of lean burning mixtures while yellow and orange flames suggest a higher fuel concentration (incomplete combustion).

Hazards Lighter fluid is flammable. Always use a container with a small opening to minimize the possibility of a spill.

Key Words stoichiometric, LEL, hydrocarbon, fire point, backdraft

Comments *This demonstration should be practiced several times before performing for an audience.* Make sure you always add the correct amount of fuel. You can add one addition to this demonstration to illustrate a UEL level. Hold the tube upright with your right hand clamped underneath. Have an assistant spray liquid butane into the tube for a few seconds. Immediately cover the open end with your left hand. Now remove your hand and tilt one end into the flame. *Careful!* The flame will burn outside the tube now because there is no air available. The vapor concentration is too rich; hence above the UEL.

Supplies:	Suppliers:
• Lighter fluid • Aluminum foil • Butane refill (optional)	Grocery store
• Propane torch	Hardware store
• Butane torch	Welding supply/Edmund Scientific
• Laboratory glass drainpipe	Plumbing supply
• Eye protection • Leather welding gloves	Welding supply

Demo FM-5
CONFINED SPACE / OXYGEN DEFICIENCY

Materials Needed

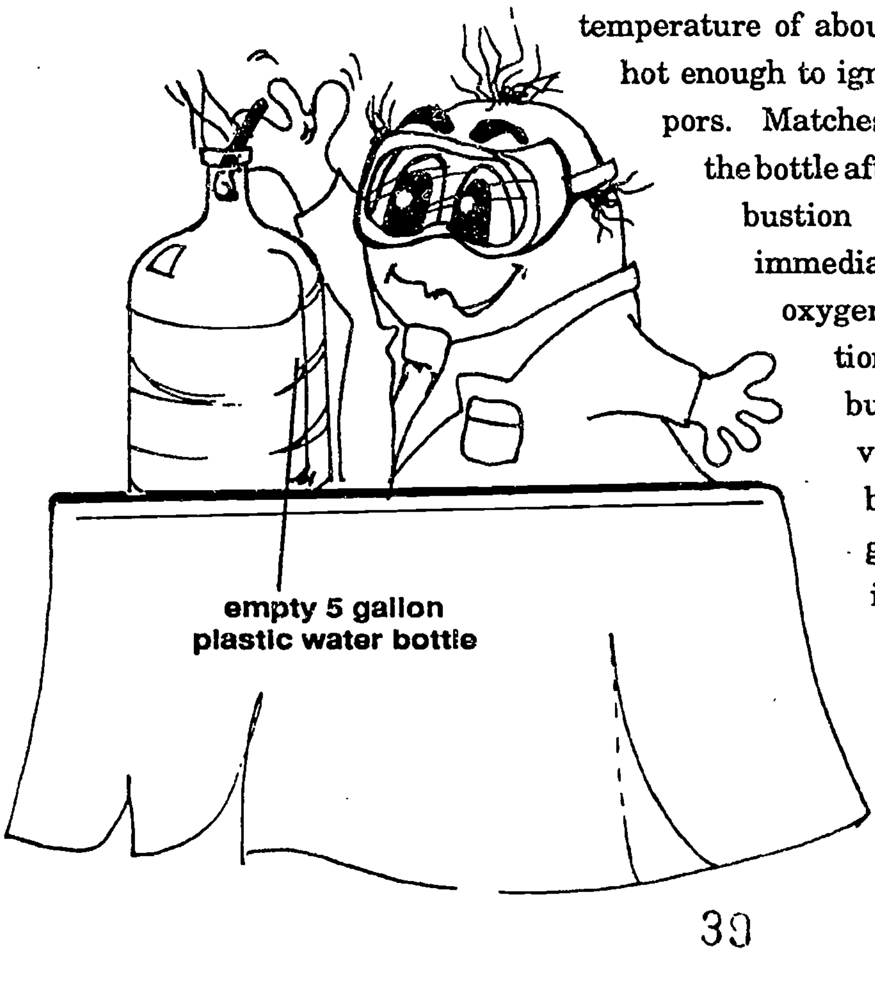
- Demonstration table
- Aluminum Foil
- Welding gloves
- Eye protection
- Lighter fluid (I prefer Ronsonol)
- 5-gallon plastic water bottle

Purpose To illustrate ignition temperature and oxygen deficiency

Objective To ignite lighter fluid vapors in a 5-gallon plastic water bottle.

Procedure Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Place a 5-gallon water bottle on top of the aluminum foil. Put on your eye protection. (A lab coat or leather apron is also advisable). Explain that this bottle represents a confined space, (That is–a space not designed for human occupancy with a limited means of egress) and in your confined space are little people. Squirt just enough lighter fluid into the bottle to wet the bottom of the container. Ask the audience if there is now fuel in the tube (YES), ask if there is sufficient oxygen in the tube. Answers will vary but explain there is until the fuel has had time to vaporize. (You can use an oxygen detector to measure the space if you wish.) Ask a member of the audience to donate a cigarette. (I usually let them light it and take a couple puffs before sacrificing it.) Turn down the room lights. Ask the audience to decide for themselves what they think will happen, then behind a protection shield, insert the cigarette into the bottle. Holding the neck of the bottle, shake it vigorously thereby producing significant sparks but no ignition. Ask why it didn't ignite. (See discussion on following page) Then remove a match from a booklet, strike it and quickly insert it into the bottle (Careful!). There will be a loud whoosh as the vapor ignites and rushes out the top of the bottle. Now light several more matches and drop them into the bottle. They immediately extinguish.

Discussion This demonstration is designed to vividly illustrate the importance of ignition temperature and how combustion in a confined space produces an oxygen-deficient environment. The instructor should explain during the demonstration that ignition fails to occur using the cigarette for two reasons: 1) the ignition temperature of the lit cigarette is about 200°C, too low to ignite the lighter fluid (naptha) with an ignition temperature of 287°C; 2) the ash on the cigarette behaves much like a flashback arrestor preventing combustion of the fuel. The lit match which has an ignition temperature of about 800°C is hot enough to ignite the vapors. Matches placed in the bottle after the combustion extinguish immediately due to oxygen depravation. The fuel burns rather vigorously but extinguishes rapidly since only 20 percent of the space



is oxygen. This part of the demonstration illustrates the folly of not following prescribed standard operating expenses and utilizing appropriate personal protective equipment prior to entry. OSHA's Confined Space Entry standard (29 CFR 1910.146) was implemented to specify employer requirements regarding entry into confined spaces. For flammable materials, the standard stipulates the space must first be ventilated to 50% of 10 percent of the LEL. Thus, if the LEL is 1.3%, 10 percent of that is 0.13%, 50% of that figure is 0.065% which is the maximum allowable concentration of flammable vapors in the space prior to entry. NOTE: On rare occasions the matches placed into the bottle subsequent to the ignition will re-ignite the vapors. This happens only if sufficient air has re-entered the space after the combustion.

Hazards Lighter fluid is flammable. Always use a container with a small opening to minimize the possibility of a spill. Be careful lighting the bottle the first time–two instructors have had bottles blow apart. (One occurred because oxygen was introduced, the other because an older bottle was used.) A high ceiling (at least 10') is preferable although this demo can be done in a room with a lower ceiling but avoid sprinkler heads and smoke alarms. Also exercise caution if in a room with a hanging ceiling–it is very easy to re-arrange ceiling tiles.

Key Words organic, combustion, synthetic, vitamins, fire point, vaporize, vapors, gases

Comments *This demonstration should be practiced several times before performing for an audience.* This demonstration was first used very effectively by an OSHA instructor at the OSHA Training Institute in Des Plaines, IL and has been successfully replicated thousands of times since by other instructors.

The importance of standard operating procedures should be stressed as well as the necessity for tank ventilation and testing. Students should understand how different fuels may affect the combustion; a few milliliters of a 70% isopropyl alcohol solution will behave somewhat differently than lighter fluid. This demonstration provides one of the most vivid, eye-catching, and spectacular displays of the hazards associated with flammable liquids in a confined space.

Supplies:	*Suppliers:*
• Lighter fluid • Aluminum foil • Matches	Grocery store
• 5-gallon water bottle	Bottled water supply co.
• Eye protection • Leather welding gloves	Welding supply

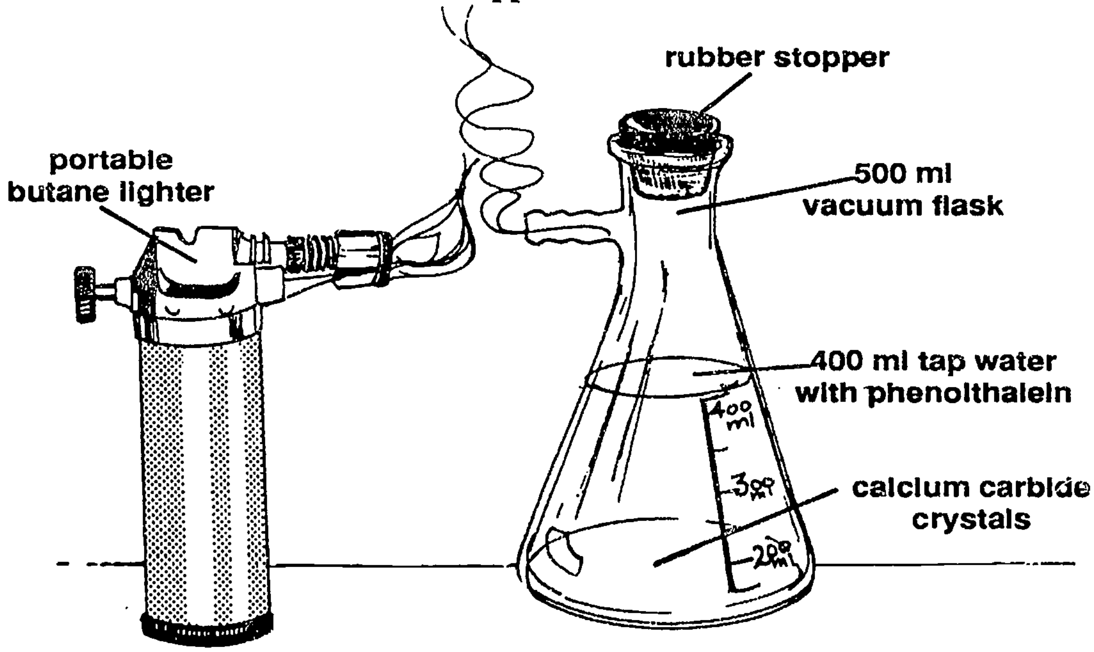
Demo FM-6
LOWER EXPLOSIVE LIMIT

Materials Needed

- Demonstration table
- Aluminum Foil
- 500mL vacuum flask
- no. 7 rubber stopper
- Propane or butane torch
- Phenolthalein solution
- A few crystals of Calcium carbide
- Protection shield

Purpose To illustrate lower explosive limit and the products of a water reactive solid.

Objective Threefold: 1) To produce 2.5% acetylene gas (the LEL) in the air space of the 500 mL flask by placing calcium carbide crystals in water; 2) To observe a chemical change is taking place by noting the change in the color of the solution; 3) To blow the rubber stopper out of the flask.



Procedure *Practice this demo a few times prior to performing for an audience*. Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Elevate the flask by placing it on an inverted crate (or similar object) covered with aluminum foil. Add about 400 mL of water to the flask and add a few drops of phenolthalein. (NOTE: If the solution turns pink right away, you water is too alkaline and will have to be acidified first.) Ignite the propane or butane torch. Now add a few crystals of calcium carbide (2-3 if peppercorn-sized; 7-10 if smaller) to the flask and quickly stopper the flask. *(Be Careful! The greater the force used to insert the stopper--the greater the force blowing it out of the flask.)* Immediately place the lit torch to the nipple on the flask. The solution will begin changing color upon addition of the calcium carbide. After a few seconds the acetylene should ignite cleanly blowing the rubber stopper out of the flask.

Discussion This simple demonstration is designed to clearly illustrate that flammable substances will not ignite if the fuel:air mixture is below the LEL. The color change observed in the solution affords an opportunity to discuss how water-reactive solids act--the water molecule is broken into ions (H^+, OH^-) which combine chemically with the constituent elements of the water-reactive solid, in this case calcium and carbon as shown: $CaC_2 + 2H_2O \longrightarrow Ca(OH)_2 + C_2H_2$ Phenolthalein is an indicator which only changes color when the pH of the solution is between 8-10. Therefore the solution is shown to be alkaline but not caustic since calcium hydroxide is a weak base. The acetylene gas produced has to build up to the LEL (2.5%) in the air space before it will combust.

Hazards Calcium carbide is highly water reactive, **DO NOT** allow moisture to enter a storage container or an explosion could occur. Phenolthalein is an organic solid which is sparingly soluble in water, and is therefore mixed in a solution of ethanol which is flammable. Solid calcium hydroxide will settle to the bottom of the flask and can be flushed down the drain with water.

Key Words calcium carbide, phenolthalein, alkaline, acetylene, indicator

Comments Calcium carbide is readily available from a lab supply or Army-Navy surplus store. Phenolthalein solution can be purchased from either a lab supply or hobby store. If none is readily available, a solution can be made by mixing a bit of an Ex-Lax tablet with a small amount of grain alcohol. (Phenolthalein is the active ingredient in Ex-Lax!)

Supplies:	*Suppliers:*
• Aluminum foil	Grocery store
• Calcium carbide • 500 mL vacuum flask • Rubber stopper • Phenolthalein solution	Lab supply or hobby store
• Propane or butane torch	Hardware store

Demo FM-7
UPPER EXPLOSIVE LIMIT

Materials Needed

- Demonstration table
- Aluminum Foil
- 1-qt steel paint can (new)
- Hydrogen gas label (optional)
- Protection shield
- Eye protection
- Collapsible crate
- Fireplace ignitor
- Lecture bottle or sm. cylinder of hydrogen

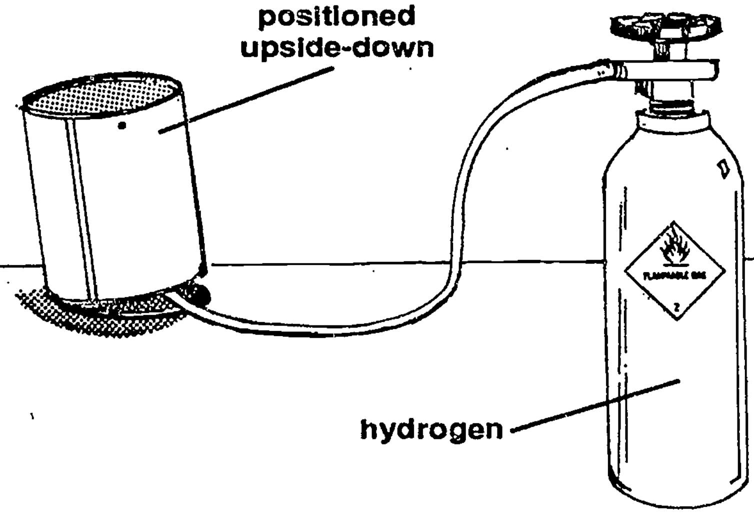
Purpose To illustrate upper explosive limit.

Objective To fill a 1-qt paint can full of hydrogen gas, ignite it, and allow the hydrogen to burn until the fuel:air mixture reaches the UEL.

Procedure *(Practice this demo a few times prior to performing before an audience.*) Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Drill a 1/16" hole in the center of the can lid and tape with masking tape (fold one edge so the tape can be easily removed), then drill a 1/8" hole in the side of the can right above the bottom seam, cover this with masking tape the same way. Using either a lecture bottle or small cylinder of hydrogen gas, remove the can lid and place it face down on a hard surface, invert the can above the lid (make sure the masking tape is in place), insert a fill hose from the cylinder, open the valve for 5-10 seconds, then immediately remove the hose, forcibly place the can onto the lid and turn off the cylinder. Elevate the 1-qt can by placing it on an inverted crate (or similar object) covered with aluminum foil behind an explosion shield. Remove the tape and ignite the hydrogen at the top of the can with a fireplace ignitor or similar device. (The flame will likely not be visible.)

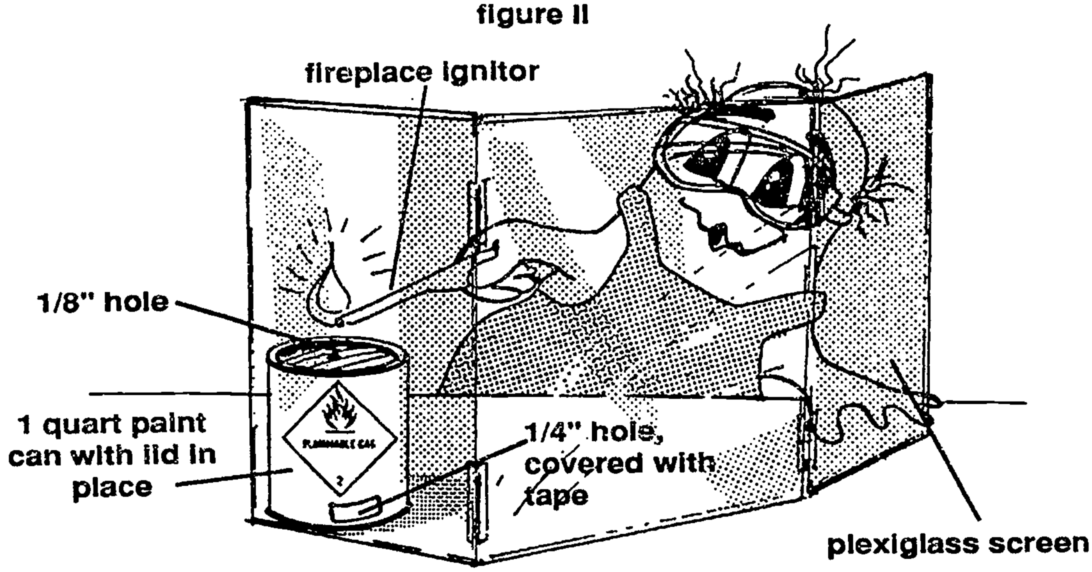
Discussion This simple demonstration is designed to clearly illustrate that flammable substances will not ignite if the fuel:air mixture is above the UEL. Initially the concentration of

figure I



hydrogen gas inside the can is 100 percent. As the hydrogen burns in air at the can opening and air enters the can from the lower opening, the fuel–air mixture is gradually reduced from 100 percent to 75 percent which is the UEL for hydrogen. At this point the lid will blow off the can with a loud bang. You should probably warn the audience that a loud noise will ensue. You may also want to place the can inside the collapsible crate set on its end as it may ricochet off the ceiling. A low-pitched whine will also be audible as the fuel–air mixture approaches the UEL. This occurs due to resonance resulting from the different sized openings in the can.

figure II



Hazards Hydrogen gas is highly flammable. Explosive range in air is 4%–75%. The cylinder should be handled with care and the valve cap should remain in place except when the cylinder is in use. If the mixture in the can is between 4% – 75% when ignited the lid will blow off the can immediately.

Key Words upper explosive limit, resonance, fuel-air mixture

Comments This demonstration is visually and audibly effective for discussing upper explosive limit. If done properly, it is also very safe. Another variation of this demonstration uses a 2-liter soda bottle. Cut off the bottom of a used 2-liter bottle and wash it to remove any residue. Remove the squeeze bulb from an eyedropper and insert into the hole in the small end of a #3 rubber stopper. Push the stopper into the neck of the bottle. Support the bottle upright by clamping the neck to a ring stand. Fill the bottle with hydrogen gas from a cylinder and immediately ignite the gas escaping from the eyedropper. Turn down the room lights. After burning for a time the mixture reaches the UEL and the gas ignites with a brilliant flash. (The bottle will be melted somewhat—ready for recycling.)

Demo FM-7 /continued

Supplies	*Suppliers*
• Aluminum foil • 2-liter soda bottle • Eyedropper	Grocery store/drug store
• Ring stand/clamp • Rubber stopper	Lab supply or hobby store
• Hydrogen cylinder	Welding supply or specialty gas supplier (e.g. AGA)

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Demo FM-8
OXYGEN DEFICIENCY / EGG IN THE BOTTLE

Materials Needed

- Demonstration table
- Aluminum Foil
- 1000 mL Erlenmeyer flask
- Bottle of 70-90% isopropyl alcohol
- Tongs
- Small piece of paper towel (wetted)
- Lighter
- Large Grade A hard boiled egg (peeled)

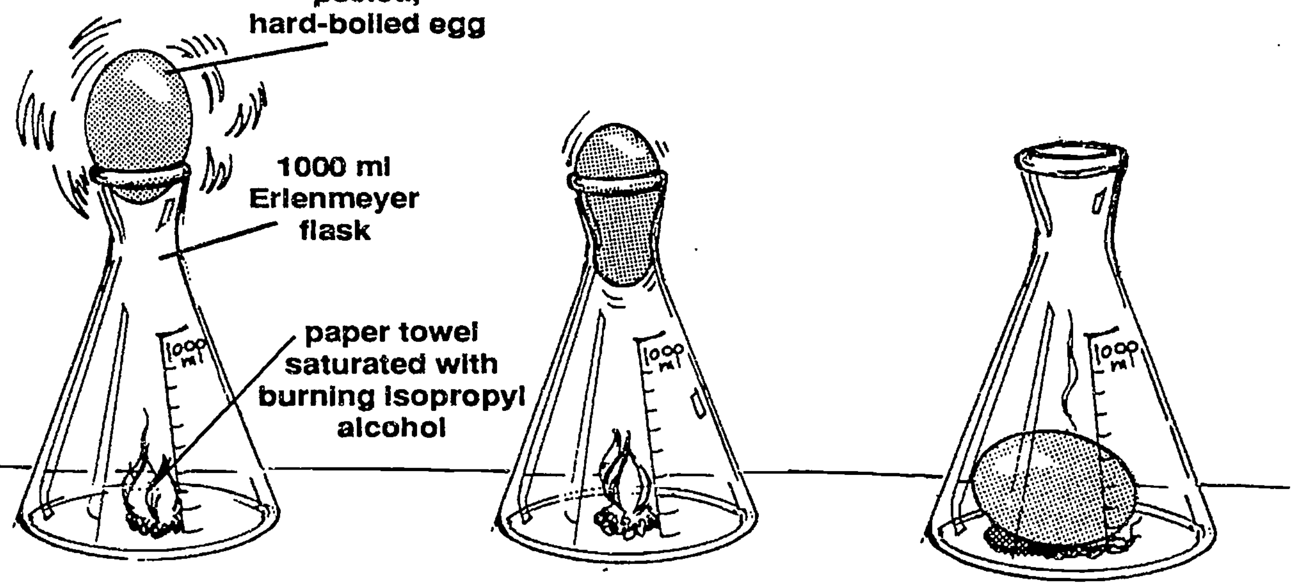


figure I figure II figure III

Purpose To illustrate that a fire in a confined area will reduce the oxygen level.

Objective To burn a small piece of paper towel saturated with isopropyl alcohol in a 1000 mL flask causing an egg to be forced into the flask by higher outside air pressure.

Procedure Clear at least a three foot by three foot (3' x 3') area on top of a demonstration table. Cover the primary demonstration area with aluminum foil. Elevate the flask by setting it on top of a collapsible crate. Place the hard boiled egg in the neck of the flask. (Ideally the egg should be just slightly larger than the opening.) Try to force the egg into the flask by pushing down and quickly releasing pressure. The egg will push its way out of the neck due to air pressure inside the flask. Take a small piece of wetted paper towel formed into a ball and saturate it with isopropyl alcohol. Holding this with the tongs, light the paper towel, lift the egg out of the neck, quickly drop in the burning paper towel and place the egg back in the neck of the flask. As the burning paper towel uses up the oxygen inside the flask, the egg is forced inside the beaker. To remove the egg, tilt the flask toward your mouth until the egg slides up into the neck of the flask. Keeping the flask tilted toward you, blow forcibly into the flask. The egg will pop out.

Discussion This simple demonstration is designed to illustrate a primary potential hazard of combustion in a confined space. The oxygen level can quickly be reduced below 19.5 percent (the OSHA limit for oxygen deficiency) and rapidly below 16 percent (the physiological limit for survival with no apparent adverse effects.) This demonstration is a nice visual illustration of 0_2 deficiency. It is best to use one of the alcohols for this demonstration since they produce almost no by-products other than CO_2 and H_2O. The egg may dance around in a rather amusing fashion before being forced into the flask due to the heat energy from burning.

Key Words isopropyl alcohol, oxygen deficiency

Comments Make sure the egg is hard-boiled. Avoid spilling the alcohol. If you show this demo to your children, make sure they don't drink the alcohol. There is a little bit of a trick to blowing the egg out of the flask. If it does get stuck in the neck, simply heat the flask slightly and it will be forced out by the expanding gas. Another topic for discussion!

Supplies:	*Suppliers:*
• Hard-boiled egg • Aluminum foil • Paper towel	House
• 1000 mL Erlenmeyer flask	Lab supply store or Hobby Center
• Tongs • Lighter	Grocery store or Lab supply

Demo OX-1

COMPARING COMBUSTION EFFICIENCY USING THREE 16 oz COKE BOTTLES

Materials Needed

- Demonstration table
- Three (3) 16 oz glass COKE bottles
- Three (3) No. 2 rubber stoppers
- Small cylinder or lecture bottle of hydrogen gas (purity or grade unimportant)
- Small bottle of oxygen gas (I use Sports oxygen) with 18-24" rubber tubing
- Two feet of clear plastic (tygon or comparable) tubing (1/2" O.D.)
- Propane or butane torch
- Explosion shield
- Protective lenses ("glasses" or goggles)
- Small bucket of water or pneumatic trough

Purpose To illustrate the impact of an oxygen-rich environment on combustion efficiency.

Objective To expose three (3) 16 oz Coke bottles filled with different gases to an ignition source to compare combustion.

Procedure Wrap one of the Coke bottles with clear tape (for identification and the unlikely event of breakage), mark another by attaching a piece of masking tape to the bottom of the bottle, the third needs no marking. Put a No. 2 rubber stopper in the unmarked bottle. We'll call this "New Coke". Now with one end of the tygon tubing fit inside the valve on the hydrogen cylinder and the other end in the Coke bottle marked with masking tape (We'll call this "Classic Coke"), invert the bottle, open the cylinder valve and fill the bottle with hydrogen gas (this will only take a few seconds at high pressure). Seal the bottle with a No.2 stopper before uprighting. Next, fill the third bottle with water and invert this bottle into a bucket. Insert the hose on the oxygen cylinder into the third Coke bottle (We'll call this "Original Coke"), open the cylinder valve and displace water until the bottle is approximately 1/3 - 1/2 full of oxygen. Turn off the valve, remove the hose. Just barely crack open the valve on the hydrogen so the gas flows very slowly from the cylinder. Insert the hose into the still-inverted Coke bottle. Displace the remaining water until bubbles just begin to emanate from the opening of the bottle. Keeping the bottle up-ended under the water, seal it with a No.2 stopper. The bottles are now ready. See the Discussion section for how to perform the actual demonstration.

Discussion This demonstration is very noisy. Be sure to warn the audience there will be a big bang. Set the propane or butane torch on a collapsible crate behind an explosion shield. Ignite the torch. Explain you're going to test the three types of Coke–New Coke, Classic Coke, and Original Coke. (See Comments) Take the "New Coke", invert the bottle, quickly remove the stopper and place the opening just outside the flame on the torch. Nothing will happen. Say "That's just what you should expect from "New Coke" - nothing. Next take the "Classic Coke" and follow the same procedure, a slight popping sound will be heard. Casually mention that this IS a "pop" bottle. Finally, repeat the procedure with the "Original Coke". There will be a loud boom.

Comments *Be certain to try this experiment first before performing for an audience!* Make sure you use the right bottle at the right time. The "New Coke" makes no sound as it contains only ambient air. The "Classic Coke" makes a slight popping sound because the hydrogen gas released from the bottle combines with air to create a flammable atmosphere. The gas mixture inside the bottle will not burn because it's above the upper explosive limit of hydrogen (75%). The "Original Coke" ignites with a loud bang because of the presence of oxygen in the bottle. (2/3rds hydrogen and 1/3rd oxygen–a highly combustible mixture)

Supplies	*Suppliers*
• Three (3) 16 oz glass Coke bottles	Flea market? (any where you can find them)
• Small hydrogen gas cylinder	Welding supply store
• Propane or butane torch	
• Sports Oxygen cylinder	

Demo OX-2

THE ACCELERATED, ENHANCED COMBUSTION OF GRANULATED SUGAR USING POTASSIUM CHLORATE

Materials Needed

- Demonstration table
- Approximately 1 TBSP granulated sugar
- Approximately 1 TBSP potassium chlorate ($KClO_4$)
- Aluminum foil
- 2-3 mL conc. (96%) sulfuric acid
- Disposable pipette (eyedropper)
- Medium-sized (1-qt or 1-gal) fishbowl
- Chemical splash goggles
- Acid-resistant apron
- Acid-resistant gloves

Purpose To illustrate the impact of a solid oxidizing agent on the combustion of granulated sugar ($C_{12}H_{22}O_{11}$)

Objective To put a small quantity of granulated sugar and potassium chlorate in a 2" diameter "pie tin" formed from aluminum foil and to initiate combustion with a few milliliters of sulfuric acid.

Procedure Form a 2" diameter "pie-tin" out of a few thicknesses of aluminum foil. There should be at least a 1/2" lip on the tin. Place about 1 tablespoon of granulated sugar and 1 tablespoon of potassium chlorate in the tin. Agitate the tin so the two substances mix together. Set the tin on top of an inverted collapsible crate covered with two sheets of aluminum foil. Turn down the room lights to enhance visibility. After donning protective clothing, fill a disposable syringe with about 3 mL 96% sulfuric acid. Quickly empty the contents of the syringe into the pie tin with the sugar-$KClO_4$ mixture and immediately cover with the fishbowl. The sulfuric acid rapidly dehydrates the sugar producing sufficient heat energy to ignite the mixture. The potassium chlorate decomposes enriching the atmosphere with oxygen and a very hot fire, with considerable smoke, burns for about 30 seconds. The temperature of this combustion exceeds 1250°F (the melting point of aluminum) as a portion of the pie tin is destroyed.

Discussion This demonstration is rather striking. That a fire so hot and so violent can be produced by burning common table sugar is quite impressive. The sulfuric acid merely acts as a catalyst to initiate the reaction. It does not burn but is partly destroyed in the fire as can be noted by the sulfur residue inside the inverted fishbowl. The primary combustion reaction is:

$$C_{12}H_{22}O_{11} + 6KClO_4 + H_2SO_4 + 2Al \longrightarrow 12CO_2 + 12H_2O + Al_2O_3 + 6KCl + S$$

There are undoubtedly other reactions occuring but these are the most likely by-products of this oxidizer-enhanced fire.

Comments *Be certain to try this a few times experiment before performing for an audience! It is best to perform this demonstration outdoors or in a well-ventilated area as it does create some smoke.* However, if done properly, the fishbowl will contain the smoke as the aluminum foil is pulled into the opening from the vacuum created by burning the mixture. Take the fishbowl and the now-burnt mixture outdoors to ventilate. Set the "pie tin" on a clean piece of aluminum foil and pass it around the room so the audience can see the destruction of the sugar and the aluminum. Rinse out the fishbowl several times saving the rinsate. Check the pH and adjust with sodium bicarbonate before flushing down the sink.

The flame color in this demonstration will appear reddish-orange due to the presence of potassium. The color can be altered by adding different salts to the mixture. (Nitrate salts work best but any save chloride salts, which tend to produce chlorine, are acceptable.) This is the flame ionization principle [atomic absorption] which analytical chemists use to identify metallic constituents. Well-known colors are:

Sodium (Na)	yellow	Copper (Cu)	blue
Lithium (Li)	red	Barium (Ba)	green

Experiment. There are multiple possibilities.

Supplies:	*Suppliers:*
• Granulated sugar (DO NOT use extra fine or powdered) • Aluminum foil	Grocery store
• Medium-sized (1-qt or 1-gal) fishbowl	Pet/Hobby store
• Potassium chlorate ($KClO_4$) • Conc. (96%) sulfuric acid • Disposable pipette (eyedropper)	Lab supply store
• Chemical splash goggles • Acid-resistant apron • Acid-resistant gloves (butyl rubber)	Safety supply

Demo PP-1

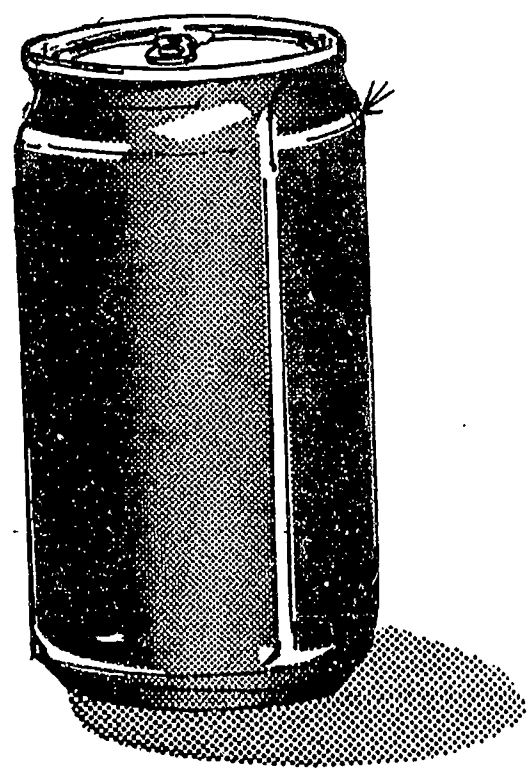
VAPOR PRESSURE DEMO / "CRUSHING" A 12-OUNCE SODA CAN

Materials Needed

- Demonstration table
- A 1000 mL beaker about 3/4 full of cold tap water
- One 12-ounce soda can (I prefer "Orange Crush") containing about 10-15 mL tap water
- Portable propane or butane torch
- Tongs (for handling the can while heating)
- Eye protection

Purpose To illustrate the increase in vapor pressure with temperature and to demonstrate air pressure.

Objective To heat 10-15 mL water in a 12 oz. aluminum can until steam is visible, then to quickly invert the can into a 1000 mL beaker of cold tap water



Procedure This demonstration is easy to perform and is visually and audibly impressive. This demo works best if the water in the soda can is pre-heated by setting it on a hot plate or by simply adding 10-15 mL of hot water from a coffee (tea) service. Put on protective eyewear and, using the tongs, heat the can above the hot flame of a portable propane or butane torch. Steam will begin to rise out of the can opening after 1-2 minutes (if the water is already hot). Wait another 30-60 seconds after steam first becomes visible before inverting the can into the cold water. This will ensure an adequate pressure differential.

Discussion This demonstration illustrates the concept of increasing vapor pressure with increasing temperature. It also shows the disastrous consequences of air pressure differences. A small degree of humor can be interjected with the use of a "Crush" soda can as the can collapses (is crushed) immediately after immersion in the cold water bath. The collapse occurs as the water vapor (steam) is recondensed (liquified). At temperatures at or just below the boiling point of water, the vapor pressure of steam is near one atmosphere (760 mm at sea level). When the can is inverted in the cold water bath, the only opening is sealed and the water vapor (steam) immediately condenses. The steam water molecules which had been previously exerting force against the side of the can are now in a more dense physical state. This causes a reduction in the internal pressure of the can and the resulting higher [air] pressure outside the can causes it to collapse.

Key Words vapor pressure, boiling point, condense

Comments An attentive individual can observe several manifestations of this phenomenon: A waste sampled at temperatures higher than ambient and placed into a non-rigid wall container (e.g. polyethylene) will partially collapse as the sample equilibrates to outside air temperature; Similarly, a gasoline can set out in the hot sun then brought inside a cool garage may collapse or implode; Steam cleaning tankers then not allowing them to equalize to the outside air temperature prior to sealing the openings, can cause partial or complete collapse of the equipment; Off-loading the contents of any container using a vacuum pump mandates the container first be vented to atmosphere or the pressure reduction can allow the tank to implode.

A similar demonstration can be done using a 1-gallon oblong steel can. Place about 200 mL tap water in the bottom of the can. Heat to boiling on a hot plate, stove, or with a portable propane torch. After heating the can, USING LEATHER GLOVES, quickly screw the cap onto the container. Run the can under cold water in the sink or immerse in an ice bath. The can should collapse audibly.

Supplies:	*Suppliers:*
• 1-gallon metal oblong can	Consolidated Plastics
• 12 ounce soda can ("Crush")	Grocery store or carry-out
• Tongs • 1000 mL beaker	Lab supply

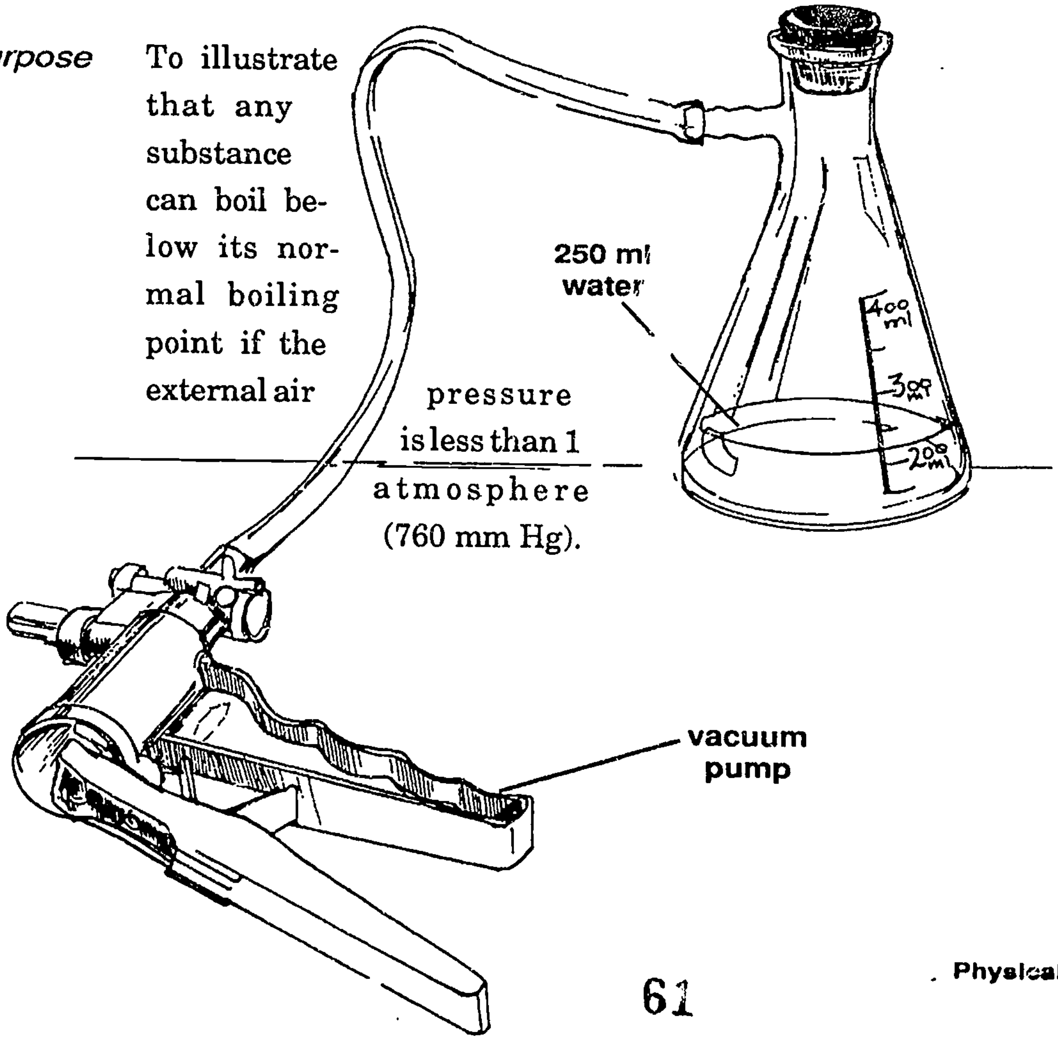
Demo PP-2

BOILING WATER AT 140°F USING A HAND-HELD VACUUM PUMP

Materials Needed

- Demonstration table
- 500 mL vacuum flask w/ no. 7 rubber stopper
- 100 mL tap water heated to 140-150°F
- Hot plate/heating element
- Food coloring (I prefer green)
- Leather welding gloves
- Hand-held vacuum pump
  (Available from Edmund Scientific or Wal-Mart / automotive section)
- Digital thermometer

Purpose To illustrate that any substance can boil below its normal boiling point if the external air pressure is less than 1 atmosphere (760 mm Hg).



Objective To use a hand-held vacuum pump to evacuate air from a sealed 500 mL vacuum flask containing 100 mL colored water until the water begins to rapidly boil.

Procedure This demonstration is relatively easy to perform and is visually striking. It transcends the boundary between accepted fact and visual proof. After heating the water to between 140-150°F, the vacuum pump should be attached to the vacuum flask as shown in diagram on page 51. After placing the rubber stopper into the flask, put a leather glove on the hand which will hold the flask. Slowly and deliberately actuate the pump until the water in the flask begins to boil vigorously. Then increase the pressure inside the flask by opening the seal on the pump. The water stops boiling immediately.

Discussion As the vacuum pump is being operated to remove air from the flask, explain that the boiling point of a liquid is simply the temperature where the vapor pressure equals the outside atmospheric pressure. Water, for example, has a vapor pressure of only 17.5 mm (Hg) at 68°F. When the temperature is increased to 212°F (at sea level), the vapor pressure rises to 760 mm (Hg)–the equivalent of 1 atmosphere. Once the vapor pressure of a liquid equals the outside air pressure, the substance boils. In fact under adiabatic (constant pressure) conditions, the boiling temperature of a substance can never be exceeded regardless of the amount of heat applied. The liquid will evaporate more rapidly as external heat is applied but the temperature of the liquid itself will never exceed its boiling point unless the outside air pressure is varied. There are three ways to accomplish this: 1) Reduce air pressure. A vacuum can be applied or one can simply go up, i.e. increase altitude. As the atmospheric pressure decreases with increased altitude, the boiling point decreases. 2) Increase air pressure. Sealing a container and increasing the internal pressure above ambient conditions (e.g. 1 atmosphere) will raise the boiling point of a substance. Superheated steam (water vapor above 212°F) is produced in this manner by pressurizing steam pipes. 3) Adulterate the liquid. That is add a substance which dissolves to produce an azeotropic (constant boiling) mixture. One example is adding salt to water. The resulting mixture will now boil at a higher temperature. This knowledge is especially useful at higher elevations (5000 ft +) where boiling just water will not allow sufficient heat energy to cook certain foods such as hard-boiled eggs.

Key Words adiabatic, azeotropic

Comments Riding on an airplane as I write this offers an excellent observation of the phenomenon of reduced air pressure at altitude. My package of Pepperidge Farms Distinctive CHESSMAN Butter Cookies (Yum!) is rather puffy. Packaged in Pennsylvania at close to sea level, the air in these packages, now on an airplane pressurized to about 8000 feet, has expanded. This is a common manifestation of Boyles' Law which states simply that a decrease in pressure will result in a corresponding increase in volume and vice-versa.

Another good way to demonstrate boiling point is to use a "hand boiler". These are devices with two hand-blown glass globes, the top one smaller than the bottom one, connected via a piece of looped glass tubing. These are usually filled with fairly low boiling liquid such as ethanol (BP 78.3°F). Holding the lower globe in a closed palm quickly raises the temperature of the enclosed liquid and it boils from the lower glass globe through the looped tubing into the smaller top globe. Removing the heat causes the liquid to return to the lower globe.

Demo PP-2 /continued

Supplies:	*Suppliers:*
• Hand-held vacuum pump • Hand boiler	Edmund Scientific
• 500 mL vacuum flask • Two feet plastic (Tygon) tubing • Heating plate	Lab supply store
• Digital Thermometer	W.W. Grainger

Demo PP-3

ILLUSTRATING VAPOR DENSITY USING DRY ICE

Materials Needed

- Demonstration table
- Two (2) 1000 mL beakers
- Two (2) wooden splints
- 800 mL hot water w/food coloring
- 2000 mL graduated cylinder (glass, polymethylpentene, or other)
- 5 lbs of dry ice
- Votive candle
- Two (2) 18" pieces of glass laboratory drainpipe w/ connec tor (see Demo FM-3)
- Fireplace ignitor
- Pair of leather gloves
- Eye protection

Purpose To illustrate vapor density visibly and to show that some undetectable gases are hazardous. To demonstrate the odorless, colorless, tasteless properties characteristic of most gases.

Objective To produce visible CO_2 gas by placing pieces of dry ice into hot water and to place a small amount of dry ice in a 1000 mL beaker.

Procedure This demonstration is easy to perform and is visually effective. First heat about 800 mL water in a 1000 mL beaker on a hot plate to about 170°F +. Then, wearing leather gloves, pour the hot water into the 2-Liter graduated cylinder. Place a few walnut-sized pieces of dry ice into the cylinder. CAUTION: DRY ICE IS EXTREMELY COLD [-109°F].

HANDLE ONLY WITH LEATHER GLOVES. AVOID DIRECT SKIN CONTACT AS SERIOUS BURN INJURIES CAN RESULT. A substantive volume of white vapor is produced. [Explain to the audience that this is condensation of water vapor by the cold CO_2 gas. Note that as the visible vapor moves away from the source it is no longer visible.] Light the votive candle and "pour" the carbon dioxide gas through the glass tube toward the votive candle. As the gas reaches the candle, it goes out due to oxygen deficiency. This is an excellent visual demonstration of vapor density. However, as most gases are odorless, coloreless and tasteless, it is best followed by another demonstration: Light a wooden splint then take a 1000 mL beaker, fill it with air by sweeping it through the air a few times. Insert the burning splint into the beaker. It will burn since the beaker is full of air. Next take another beaker in which you have previously placed a small amount of crushed dry ice. As this completely evaporates, the gas displaces the air in the beaker. Light another wooden splint and slowly insert this into the beaker. If done correctly, the splint will go out as it is lowered into the beaker.

Discussion This demonstration illustrates several things. 1) Heavier than air gases will collect in low spots; 2) Cold gas or vapor can condense moisture resulting in a visible cloud; 3) Most gases are odorless, colorless, and tasteless; and 4) Oxygen deficiency can kill. With very few exceptions (helium, hydrogen, methane, ethane, and ammonia), most gases, and virtually all vapors, are heavier than air. Unfortunately many gases are also undetectable to the human senses. Note how quickly the splint extinguishes in the carbon dioxide gas. This concentration of CO_2 would cause rapid asphyxiation and death. Flammable liquids, such as gasoline, can produce very high levels of vapors which may travel a considerable distance to an ignition source and flashback. The vapors of ALL flammable liquids are heavier than air!

Key Words flashback, sublimation, asphyxiation

Comments Solid carbon dioxide is known as "dry ice" because it goes directly from the solid state to the vapor state-a property called sublimation. (Carbon dioxide, like all gases, can be liquified under the right conditions of temperature and pressure. If dry ice is unavailable, the invisible CO_2 demo can still be performed by mixing sodium bicarbonate with a small amount of any acid (or vinegar). Care should be taken to ensure the gas does not escape before it can be used.

My brother-in-law, Jon Corum, a secondary education teacher and biologist, explained to me that mosquitos are attracted to the 4% or so carbon dioxide in exhaled breath. Some dry ice companies suggest using dry ice as a means of controlling mosquitos. I have yet to evaluate this practice although it seems reasonable enough–asphyxiate and/or freeze the pesky predators!

Supplies:	*Suppliers:*
• Votive candle • Fireplace ignitor	Grocery/Drug/or Department Store
• Two (2) 1000 mL beakers • Two (2) wooden splints • 2000 mL graduated cylinder (glass, polymethylpentene, or other)	Lab Supply/Edmund Scientific
• 5 lbs of dry ice	Check Yellow Pages
• Pair of leather gloves • Eye protection	Welding Supply Store

SUPPLIER LIST

Supplier	*Items*
Leland Ltd., Inc. *P.O. Box 382* *Bedminster, NJ 07921* *908/234-1750*	*Sports Oxygen (small oxygen bottle)*
J.J. Keller & Associates, Inc. *3003 W. Breezewood Lane* *P.O. Box 368* *Neenah, WI 54957-0368* *800/558-5011*	*Labels*
Edmund Scientific Company *101 E. Gloucester Pike* *Barrington, NJ 08007-1380 U.S.A.* *609/573-6250 or 609/547-3488*	*Science Supplies*
W.W.Grainger, Inc. *1300 Third Street, Ampoint* *Perrysburg, OH 43551* *419/666-3320*	*Mechanical/Safety Equipment*