Subject/Target Grade
Science and Social Studies/
Middle School (7-9)

Duration
45 minutes – Classroom setting

Materials
per class
- clear 2-L pop bottle
- spray bottle with water
- dust, talcum powder
- aromatic substances such as onion, lemon, apple, vanilla extract
- air freshener
- 3-4 tea candles or a pillar candle for demonstrations (the candles must fit under the 500-mL beaker)
- 500-mL beaker for demonstrations
- matches
- overhead projector
- 100 mL limewater (calcium hydroxide saturated, 1.0g/100 mL)
- bottle cap to hold limewater
- straw
- cobalt chloride paper
- *Danger in a Cave* (teacher resource)
- *Models of Atoms* (transparency master, cut)
- *Models of Molecules: Reactants* (transparency master)
- *Models of Molecules: Products* (transparency master)

per small group
- small tea or pillar candle
- aluminum foil or pie pan
- 500-mL beaker
- molecular models (make your own using *Models of Atoms* student resource or use purchased kits)
- envelope, if paper models are used
- scissors, if paper models are used

per student
- safety glasses
- *Burning Questions* (student activity)
- *Candles and Air Pollution* (student activity)
- *Burning Questions at Home* (home activity)
- MDEQ pamphlet *Burning Household Waste* (on MEECS Air Quality CD)

What Gets into the Air?

Lesson Overview

A burning candle is used as an introduction to air pollution. Students make observations about the candle that illustrate the chemical and physical changes during combustion. The lesson develops the basic ideas that combustion activities are a major source of air pollution and that the products of combustion include particles (soot) and gases such as carbon monoxide and carbon dioxide.

Students answer three essential questions: How does a burning candle illustrate air pollution? What are the reactants and products of burning? What can happen to the air when fuel, leaves, and trees are burned? Concepts include physical and chemical changes, reactants and products of chemical reactions, combustion, incomplete combustion, ambient air, and volatile organic compounds. A background lesson on the composition of the atmosphere and the layers of atmosphere is found on the MEECS Air Quality CD.

Objectives

Students will be able to:
1. Identify physical and chemical changes associated with combustion.
2. Identify reactants and products.
3. Explain how combustion (burning) is linked to air pollution.

Michigan Grade Level Content Expectations

Grade 6-7 Science:
- Describe the effect humans and other organisms have on the balance of the natural world. **S.RS.06.17**
- Explain how mass is conserved as it changes from state to state in a closed system. **P.CM.06.12**
- Illustrate structure of molecules using models or drawings. **P.PM.07.23**
- Describe the origins of pollution in the atmosphere, geosphere, and hydrosphere and how pollution impacts habitats, climatic change, threatens or endangers species. **E.ES.07.42**

HS Earth Science:
- Explain how carbon moves through the Earth system and how it may benefit or harm society. **E2.3D**

HS Biology:
- Examine the negative impact of human activities. **B3.4C**

HS Chemistry:
- Balance simple chemical equations applying the conservation of matter. **C5.2A**
- Distinguish between chemical and physical changes in terms of the reactants and products. **C5.2B**

Grade 6-8 Social Studies:
- Describe the environmental effects of human action on the atmosphere, biosphere, lithosphere and hydrosphere. **6 - G5.1.1, 7 - G5.1.1**

Advance Preparation

1. Background Lesson 1 on the composition and layers of the atmosphere in this unit and on the MEECS Air Quality CD should be reviewed for possible use with groups that have not been introduced to these topics.

2. Decide what type of model you will use to illustrate the reactants and products of a burning candle (kit, toothpicks and gum drops, or paper models). If the paper models are used to create molecules, prepare a set for each group of students using the *Models of Atoms* student resource. The set has one carbon atom, four oxygen atoms, and four hydrogen atoms that need to be cut out. Each notch represents a bond. The atoms fit together by linking the notches. Double bonds will be created in the oxygen and carbon dioxide molecules. Prepare transparencies of the *Models of Molecules*. Prepare a transparency of *Models of Atoms* and cut out the individual atoms.

3. Prepare a saturated solution of calcium hydroxide (limewater) several days before needed to allow it to reach saturation. Place 100 mL of distilled water in a 250-mL bottle. Add 1.0 g $Ca(OH)_2$. Seal tightly to prevent access to atmospheric CO_2. Shake the solution and let it settle. If needed, filter the solution, let it settle, and use only the clear liquid. When CO_2 gas is bubbled through colorless limewater, $Ca(OH)_2(aq)$, the limewater turns milky due to the formation of a calcium carbonate ($CaCO_3(s)$) precipitate. The chemical equation is: $CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$

Background Information

Observation of combustion is a way to introduce the subject of air pollution and review the idea that matter cannot be created or destroyed, but is merely changed in form or location. If students understand what is happening when a candle burns, they are well on their way to understanding air quality issues, which are associated with matter (gases and particles) that we often cannot see.

Over 75% of the Earth's air is found in the troposphere. Air is a mixture of gases and particles with over 99% nitrogen (N_2) and oxygen (O_2) by volume. Gases are individual atoms or molecules while particles are aggregates of atoms or molecules. Both are parts of the air pollution story. The levels of certain gases and particles beyond the background amounts contribute to air pollution

in the troposphere. Chemical processes such as combustion (burning) and physical processes such as evaporation contribute to the degradation of air quality. We are most concerned with the impact humans have on air pollution.

A burning candle illustrates basic air pollution concepts. It is easy to observe that there is less candle wax and wick after burning than before burning, but how does this happen and where does the wax go? The initial heat of the flame melts the wax (physical change). The liquid wax molecules travel up the wick and vaporize (physical change). The wax molecules react with the oxygen in the air (chemical reaction). As the wax oxidizes (burns), it produces mainly water and carbon dioxide, which dissipate in the air around the candle. This exothermic reaction yields light and heat. Candle wax (paraffin) consists of chains of connected carbon atoms surrounded by hydrogen atoms (hydrocarbons). If the wax continues to melt near the flame, it can burn completely and leave no ash or wax residue. However, incomplete combustion results in excess smoke, soot (mainly carbon), and perhaps toxic chemicals.

Complete combustion of hydrocarbons, such as the methane (CH_4) found in natural gas, produces water vapor and carbon dioxide. Carbon dioxide is one of the major "greenhouse gases" that contribute to global climate change. Water vapor is a "natural" greenhouse gas, and it is certainly not a pollutant. Water vapor in the atmosphere varies from 0.001% by volume at the poles to 5% in humid areas near the equator.

Gasoline and diesel fuels are mixtures of hydrocarbons, which are compounds that contain hydrogen and carbon atoms such as octane (C_8H_{18}). These fuels are burned in internal combustion engines (automobiles, trucks). If the combustion in a vehicle engine was "perfect," oxygen in the air would combine with all the hydrogen in the fuel to form water and with all the carbon in the fuel to form carbon dioxide. Nitrogen in the air would remain unaffected. In reality, the combustion process is not "perfect," and engines emit several types of pollutants. These combustion byproducts are nitrogen oxides (NO_X), partially or unburned hydrocarbons, carbon monoxide (CO), and carbon dioxide (CO_2). The physical process of evaporation of fuel releases hydrocarbons into the air. Organic (carbon-containing) compounds that readily evaporate are called volatile organic compounds (VOCs).

Incomplete combustion associated with burning gasoline and diesel fuel, burn barrels, incinerators, wood stoves, barbeque grills, wild fires, biomass burning to clear land, and coal in power plants all contribute to outdoor air pollution. Fires and open burning of leaves produce particulate matter and hydrocarbons, which contain a number of toxic, irritant, and carcinogenic (cancer-causing) compounds. Smoke from burning leaves contains carbon monoxide, a major air pollutant. Some things that go into the trash release toxic air pollutants if burned. Coal burning in power plants releases carbon monoxide, carbon dioxide, sulfur dioxide (SO_2), nitrogen oxides (NO and NO_2), particles (fly ash), and toxic metals.

It is estimated that most people spend about 90% of the time indoors. Sources of combustion pollutants found indoors include tobacco smoke, car exhaust in garages, soldering, and some hobby activities such as welding. Combustion pollutants can come from vented or unvented combustion appliances. These appliances include space heaters, gas ranges and ovens, furnaces, gas water heaters, gas clothes dryers, wood or coal-burning stoves, and fireplaces. Evaporative sources include paints, room fresheners, and out-gassing from building materials.

Sources:
Pimentel, G. (1963). *Chemistry: An Experimental Science*. San Francisco: W.H. Freeman.

U.S. Environmental Protection Agency. *Office of Air and Radiation*. Retrieved August 22, 2004, from http://www.epa.gov/air/.

Procedure

1. **Review basic atmosphere information.**

   If needed, review the layers and composition of the atmosphere with your students (see Background Lesson 1 *What Is in the Atmosphere?* in this unit). They should be familiar with the location of the troposphere and the stratosphere. Nitrogen (78%), oxygen (21%), argon (0.93%), and trace gases such as neon, helium, krypton, xenon, and hydrogen are fairly constant in air. Gases with variable percentages in the atmosphere include water vapor (about 0.25%), carbon dioxide (about 0.037%), ozone (about 0.01%), volatile organic compounds (VOCs), and many other gases and particles.

2. **Define *ambient air* as the air that surrounds us.**

   Does the composition of ambient air change? In what ways? Have students suggest things that are in air that may change [gases, particles, water vapor].

   Air pollution comes from many sources. Add potential sources of air pollution such as the following to a clear plastic 2-L bottle: dust from a vacuum cleaner, smoke from a newly extinguished match, your breath through a straw, dirt, talcum powder, and air freshener. Have students classify the substances in the demonstration as particle pollution or gases. Reinforce the idea that air quality is impacted not only by gases, but also by particles and even living things (bacteria, viruses, spores, and pollen).

   Note: Save the bottle of "polluted air" for use in Lesson 3.

   Ask students to imagine the impact on the ambient air between a quick spray of perfume and spilling the entire contents of the bottle (the dose makes the "poison"!).

   Safety Note: Keep your contaminants contained and avoid getting them into the surrounding air. Make sure that you do not have any students with severe allergies to any of the items you are using.

3. **Speculate about what burning has to do with air pollution.**

   What was life like thousands of years ago when people might have lived in caves and used fire for cooking and warmth? Ask the students to describe sights, smells, and temperature. [Soot on walls, smell of burned wood, smoke in the air, cool cave walls, hot near the fire.] *Would the air in a cave be healthy to breathe?* [Most likely not because of smoke particles, carbon dioxide, and carbon monoxide.] *What happens today in a house if a fire in the fireplace is not vented properly*? [Carbon monoxide and smoke build up in the room.] Read the article on *Danger in a Cave*. Follow up with a discussion of the use of canaries to test the air quality in mines. When the canaries were no longer singing, levels of methane and carbon monoxide could be approaching critical levels.

   What do you think the air was like in California during the fires that have destroyed many homes and the wildfires that have happened in Alaska? [Visibility is decreased, particle pollution levels are high, and carbon dioxide and carbon monoxide levels are elevated.] *How does the burning of fuel in homes, buildings, cars, trucks, power plants, and industries contribute to air pollution?* [All of these sources add to pollution.] Make the point that combustion

contributes to both outdoor and indoor air pollution and that pollution is from both gases and particles.

4. Use a burning candle to illustrate air pollution.

Organize the students into groups of two to four and give each person the *Burning Questions* student activity page and a pair of safety glasses. Provide each group with a tea or pillar candle on a piece of foil or an aluminum pan to protect the tables or desks.

> **Safety Note:** Do not use candles with a metal core wick and avoid scented candles if any of your students have allergies or respiratory problems. Students should have no extraneous combustible articles at their workstations. They should wear safety glasses. Have people with long hair tie back their hair.

What will happen when the candle is lit? Have students sketch a picture of the candle and write down their observations on the *Burning Questions* student activity page before the candle is lit. Spot-check the descriptions. [Look for qualitative and quantitative observations such as the candle is white, the wick is ½ inch above the top of the candle, etc.]

Light each group's candle. For the next 5 to 10 minutes, have each student make a sketch of the lighted candle and record his or her observations. Place a 500-mL beaker over the candle to extinguish it and have the students make a final set of sketches and observations of what happens inside the beaker as the candle goes out.

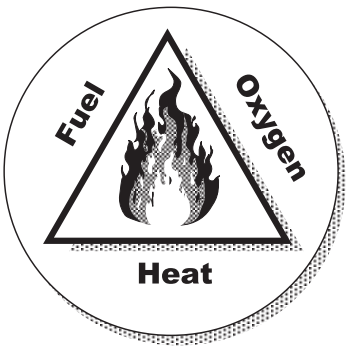
Groups share their observations with the class. Point out that there are descriptive (qualitative) as well as measurement (quantitative) observations. This is a good opportunity to review chemical and physical changes and the release of energy and light by the burning of the wax. *Did the students notice anything that might contribute to air pollution from the burning candle?* [Smoke, soot.]

5. Use models to understand what happens in burning and what this has to do with air pollution.

Using your choice of models of molecules, guide students through the following series of activities. They will manipulate atoms to form molecules and will create reactants and products. If paper models are used, give each group (or person) an envelope with one carbon atom, four hydrogen atoms, and four oxygen atoms, which are the chemical elements involved in the burning of a candle. Alternatively, give students the *Models of Atoms* sheet to cut out the atoms. Tell them that each notch in the paper models represents one chemical bond.

> **Note:** If you have an overhead projector, students can follow along with your demonstration. Using the template for the atoms, create a transparency and cut out the atoms.

What is needed for burning? [Fuel, heat, oxygen.] Students may be familiar with the fire triangle, which includes fuel, heat, and oxygen. Introduce the terms "**reactant**" (a substance at the start of a reaction) and "**product**" (a substance present as a result of the reaction).

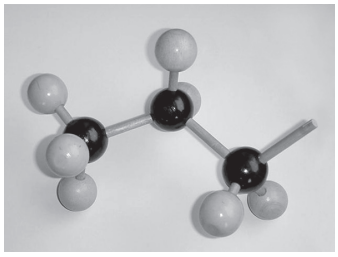


What does oxygen have to do with burning? Show the model of oxygen (O_2) and have students make oxygen molecules by putting two oxygen atoms together. About 21% of the atmosphere is oxygen. Either place a beaker over a burning candle and note that the candle goes out, or remind the students that they had observed this earlier.

Why did the candle go out? There are actually at least two reasons: (1) lack of sufficient oxygen and (2) the carbon dioxide produced extinguishes the flame. However, establish that oxygen is a reactant needed for burning.

What is the composition of candle wax (the fuel/reactant)? Show a model of a candle wax (paraffin) molecule using toothpicks and gumdrops, paper atoms, or traditional wooden ball and stick models (see figure below). The wax (paraffin) is a long chain of carbon atoms with hydrogen atoms attached.

Part of a Wax Molecule



Another type of fuel is methane (CH_4), a component of natural gas. Have students construct a methane molecule using one carbon and four hydrogen atoms.

What will happen when methane burns (reacts with oxygen)? Take apart the reactants (oxygen and methane) and use only these atoms to make products. The rules for making products are: (1) carbon and hydrogen can combine only with oxygen, (2) the products need to be a different composition from the reactants, (3) all atoms must be used, and (4) no atoms can be added.

What is one of the products of burning that contains carbon? [Using the models, students should determine that a product of combustion is carbon dioxide (CO_2).]

To confirm this, do the following demonstration: use a straw to exhale into a small container of limewater (saturated solution of calcium hydroxide). Cloudiness in the limewater indicates the presence of carbon dioxide. Place a small container (bottle cap) of fresh limewater next to a burning candle and put a beaker over the candle and the limewater. Have students make observations. Carbon dioxide generated by combustion is a major greenhouse gas and increased levels contribute to global climate change.

What is a product of burning that contains hydrogen? [Water (H_2O) is the other product. Two water molecules will be formed from burning of one methane molecule.]

To demonstrate that a liquid is produced in the reaction, burn a candle and extinguish it by placing a beaker over it. Carefully sprinkle some talcum powder into the beaker. It should stick to the walls if there is enough water produced. The control for this demonstration is to follow the procedure above but put an unlit candle under the beaker.

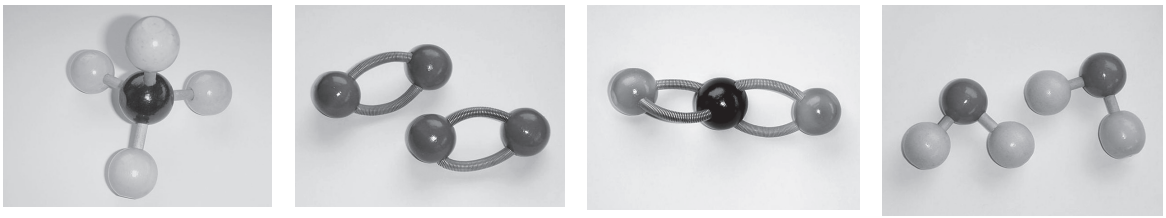
Note: If you have access to cobalt chloride paper, the presence of water can be confirmed. Be careful with its use. Put a drop of water on cobalt chloride paper and note the color change (blue to pink). Rub a piece of cobalt chloride paper on the inside of the beaker that was used to extinguish the candle. A color change indicates water (blue to pink).

6. Tying it all together.

Identify the reactants and the products of the burning wax. To simplify things, use methane to represent a small piece of paraffin (see figure below). In its simplest form, burning is like respiration in terms of the overall chemical reaction. Carbon compounds combine with oxygen to form water (in vapor form) and carbon dioxide. However, combustion is relatively fast whereas respiration is slow and controlled. Make sure students note that heat and light are given off in this exothermic reaction and that there is conservation of mass.

Complete Combustion Reaction

CH_4	+	$2O_2$	→	CO_2	+	$2H_2O$
Methane	+	2 Oxygen	→	Carbon Dioxide	+	2 Water



For advanced classes, work with students to develop the chemical shorthand (balanced equation) for the burning candle. The equation for burning of a typical wax molecule is:

$$2\ C_{28}H_{58}\ (s) + 85\ O_2\ (g) \rightarrow 56\ CO_2\ (g) + 58\ H_2O\ (g)$$

(The composition of candle wax varies and the burning candle reactions are actually much more complex.)

What would be the products from burning a candle or methane (CH_4) if there wasn't enough oxygen? [There can be incomplete combustion where not everything is burned.] Using the models, demonstrate making products out of one carbon, four hydrogen, and only three oxygen atoms. The results are carbon monoxide (CO) and two water molecules (H_2O). As an air pollutant, carbon monoxide binds to hemoglobin in the blood and inhibits uptake of oxygen.

Hold a beaker above a burning candle to collect soot on the bottom of the beaker. Soot (black carbon and other compounds) consists of particles that can be harmful to the respiratory system. Smoke contains partially burned carbon compounds.

Toxic chemicals can be produced by burning candles. These air toxics can be organic compounds or metals. Candles with lead in their wicks can emit unacceptable levels of lead. The student reading on *Candles and Air Pollution* would be appropriate at this point.

What can candles tell us about other types of air pollution? [A burning candle mirrors what is happening in combustion of coal in power plants, gasoline in car engines, trash in burn barrels, wood in wood stoves, charcoal in barbeque grills, and fuel in combustion appliances. Incinerators, biomass burning, and wild fires contribute combustion pollutants to the atmosphere. Complete combustion does not always occur when things burn.] Point out that burning contributes to air pollution but there are other sources such as dust, volcanic eruptions, various industrial processes, and vaporization of certain compounds.

In class or for homework, have students complete the *Burning Questions* student activity page. They will complete the reactants and products equation, and write a paragraph about what they have learned about air pollution by observing the burning candle. Look for evidence of identification of reactants (wax and oxygen) and products (water and carbon dioxide), gases and particles, and what burning has to do with air pollution.

7. **Homework.**

   For homework assign students to read the Michigan Department of Environmental Quality (MDEQ) pamphlet on *Burning Household Waste* found on the MEECS Air Quality CD. Then ask the students to list all of the combustion appliances, fireplaces, burn barrels, vehicles, gas-powered lawn mowers, etc., and the potential air pollution that they might cause on the *Burning Questions at Home* student activity page. At the bottom of the page, students put the number of carbon monoxide and smoke detectors where they live. Compile these statistics and have students calculate the total number of combustion sources per class and the average number of these items. The results of this assignment could be used in the final lesson, which addresses global climate change.

Assessment Options

1. After students have observed the burning candle and discussed the products and reactions, they are ready to extend their knowledge to what happens in forest fires to impair air quality. Have students list each reactant [trees with lots of organic molecules made of carbon-hydrogen-oxygen and O_2] and each product [heat, smoke, CO_2, and H_2O vapor] of the forest fire.
2. The rubric below (adapted from MI CLiMB) can be used for evaluating the candle observations in *Burning Questions*.

Scoring of Classroom Assessment for SCI IV.2.MS.2

Criteria	Apprentice	Basic	Meets	Exceeds
Accuracy of identification-reactants	Identifies none of the reactants	Identifies one of the reactants	Identifies two reactants	Identifies two reactants and includes the wick
Accuracy of identification-products	Identifies none of the products	Identifies one of the products	Identifies two of the products	Identifies two products plus heat, light, soot
Air pollution example	Provides no examples	Provides one example	Provides two examples	Provides three examples
Observations	Makes one observation	Makes two observations	Makes four observations	Makes six observations

Adaptations/Extensions/ Enhancements

1. Challenge students to determine how many municipal incinerators are in Michigan, where they are located, and what air quality rules apply to them. Michigan environmental groups are especially concerned about the impacts of incinerators in cities such as Detroit.

2. Have the class do a trash audit for a week in the classroom. Determine the impacts of what would happen if all the trash was burned. How could this trash be managed without burning it (i.e., composting, recycling)?

3. Students could do research on local ordinances regulating open burning. If there is none in your community, draft an ordinance using models from other communities. See model burning ordinances at http://www.epa.gov/burnwise/pdfs/mi_model_ordinance.pdf.

4. Students could do a survey of barbecue grill, fireplace, or burn barrel use in their community and then educate people in the correct use of these devices by creating a brochure.

5. As an art project, ask students to develop posters on topics such as what may be in trash that is harmful to burn, indoor air pollution from combustion, and leaf burning.

6. Read passages from the Michael Faraday series of lectures on "The Chemical History of a Candle," at http://www.fordham.edu/halsall/mod/1860Faraday-candle.html.

   Faraday was an English chemist who gave these lectures in the 1860s. Try to repeat some of Faraday's demonstrations. The lectures are as follows:

   - Lecture I: A Candle: The Flame - Its Sources - Structure Mobility - Brightness
   - Lecture II: Brightness of the Flame - Air Necessary for Combustion - Production of Water
   - Lecture III: Products: Water From the Combustion - Nature of Water - A Compound - Hydrogen
   - Lecture IV: Hydrogen in the Candle - Burns into Water - The Other Part of Water - Oxygen
   - Lecture V: Oxygen Present in Air - Nature of the Atmosphere - Carbonic Acid
   - Lecture VI: Carbon or Charcoal - Coal Gas - Respiration and Its Analogy to a Candle

7. Lessons on Faraday's candle observations by a Minneapolis Junior High teacher are found at http://www1.umn.edu/ships/religion/faraday.htm. There is an extension using the Bunsen burner.

8. With students, explore fire as a forest management tool. Fire is a source of smoke, which contributes to air pollution. However, fire also plays an important role in many forest ecosystems. See the wildfire education site at http://www.wildlandfire.com/docs/wildfire_edu.htm.

Additional Resources

Air Defenders: The Quest for Clean Air
Air Defenders is a community educational resource on open burning, air quality, and respiratory health developed by the Wisconsin Environmental Health Association in partnership with the Wisconsin Department of Natural Resources. It includes hands-on classroom lessons for students, posters, videos, and online music. Wisconsin Environmental Health Association. (2004). *Air Defenders*. Retrieved June 1, 2011, from http://www.airdefenders.org/.

An Introduction to Indoor Air Quality
This website is an introduction to the many facets of indoor air pollution including combustion appliances. United States Environmental Protection Agency. (2011). *An Introduction to Indoor Air Quality*. Retrieved June 1, 2011, from http://www.epa.gov/iaq/ia-intro.html.

Burn Wise
Burn Wise is a partnership program of the U.S. Environmental Protection Agency that emphasizes the importance of burning the right wood, the right way, in the right wood-burning appliance to protect your home, health, and the air we breathe. Within this site you will find information for consumers to make informed decisions. United States Environmental Protection Agency. (2011). *Burn Wise*. Retrieved June 1, 2011, from http://www.epa.gov/burnwise/.

Delaware Air Quality Curriculum
Delaware's air quality curriculum for grades 6-12 is available online. It is organized around questions such as: Why Study Air Pollution? What Impact Does Open Burning Have on Air Quality? What Impact Does Transportation Have on Air Quality? What is Acid Rain? The activities complement the Michigan unit. Delaware Department of Natural Resources. *Air Quality Education Program*. Retrieved June 1, 2011, from http://www.dnrec.state.de.us/DNREC2000/Divisions/AWM/aqm/education/educationprogram.htm.

Leaf Burning: Effects and Alternatives
This is a helpful booklet that explores the health effects of leaf burning, alternatives to burning, and ordinances. American Lung Association of Iowa. *Leaf Burning*. Retrieved June 1, 2011, from http://www.iowadnr.gov/air/citizen/burn/files/effect_alt.pdf.

Methane
Methane is a greenhouse gas that is 20 times more effective than carbon dioxide in trapping heat in the atmosphere. The U.S. EPA provides information about the methane problem at this web site. U.S. Environmental Protection Agency. (2011). *Methane*. Retrieved June 1, 2011, from http://www.epa.gov/methane.

Open Burning
As a portal website, "open burning" has links to a variety of publications and laws relating to open burning in Michigan. Michigan Department of Environmental Quality. (2011). *Open Burning*. Retrieved June 1, 2011, from http://www.michigan.gov/deq/0,1607,7-135-3310_4148_55793---,00.html.

Smoke and Air Quality
This online resource describes the health effects of smoke and smoke management. There are tips on how to protect yourself from the health effects of smoke from agricultural and forest fires.
U.S. Environmental Protection Agency. (2011). *Smoke and Air Quality*. Retrieved June 1, 2011, from http://yosemite.epa.gov/R10/AIRPAGE.NSF/Smoke/Smoke.

What You Should Know About Combustion Appliances and Indoor Air Pollution
This is an online booklet prepared by the Consumer Product Safety Commission (CPSC), the U.S. Environmental Protection Agency, and the American Lung Association. The booklet answers some common questions about the indoor air pollution associated with combustion appliances.
U.S. Consumer Product Safety Commission. *What You Should Know About Combustion Appliances and Indoor Air Pollution*. CPSC Document #452. Retrieved June 1, 2011, from http://mmdhome.com/PDF/MMd-combustion_appliances.pdf.

Wildfire Smoke: A Guide for Public Health Officials
Smoke events can catch us off guard. This guide is intended to provide local health officials with information they need when smoke is present so they can adequately communicate risk to the public.
California Air Resources Board. (2008). *Wildfire Smoke: A Guide for Public Health Officials*. Retrieved June 1, 2011, from http://www.arb.ca.gov/smp/progdev/pubeduc/wfgv8.pdf.

Wood Burning and Air Quality in Michigan
Wood burning has been a part of Michigan's heritage. Homeowners choosing to use fireplaces and woodstoves need to understand that healthy indoor and outdoor air quality requires good wood burning habits. This site has guidelines for responsible wood burning to minimize health problems and help keep the environment clean. Also, look for information on open burning. Michigan Department of Environmental Quality. (2011). *Wood Burning and Air Quality*. Retrieved June 1, 2011, from http://www.michigan.gov/deq/0,1607,7-135-3310-85746--,00.html.

Danger in a Cave

How can a cave serve as an introduction to air pollution problems? Consider this modern-day example.

Wednesday, April 28, 2004
St. Paul, Minnesota

It was televised on the national news that day - what was just another adventure for five high school students became deadly. Three teenagers died while exploring a cave along the banks of the Mississippi River near St. Paul, Minnesota. One boy was able to get out of the cave to call for help, but it was too late for three of his friends. His fourth friend survived after being rescued.

The cave was in a large network of caves with so many entrances that it would be hard to close all entrances to the caves. There were signs warning people to stay out of the caves since two other teens died there in 1992.

Unlike natural caves in parts of the United States, many of these man-made "caves" were left by sandstone miners in the 1800s. At one time, the caves were used to grow mushrooms, make and store cheese, and store bricks. There was even a nightclub in one of these caves in the 1930s.

What went wrong with the cave exploration? Something in the cave was lethal. As for natural sources, bad air in caves can result from build-up of gases from decomposing vegetation and bat guano. Could the problem be methane? Carbon dioxide? Ammonia? Officials speculated that the culprit was carbon monoxide.

How did the pollution happen? St. Paul officials believe that fires in the caves started by previous visitors could have produced the carbon monoxide. Poor ventilation probably contributed to incomplete combustion and the production of carbon monoxide instead of carbon dioxide.

Closing all of the entrances to the caves is not feasible. Warning signs do not seem to work. What can be done to prevent another tragedy?

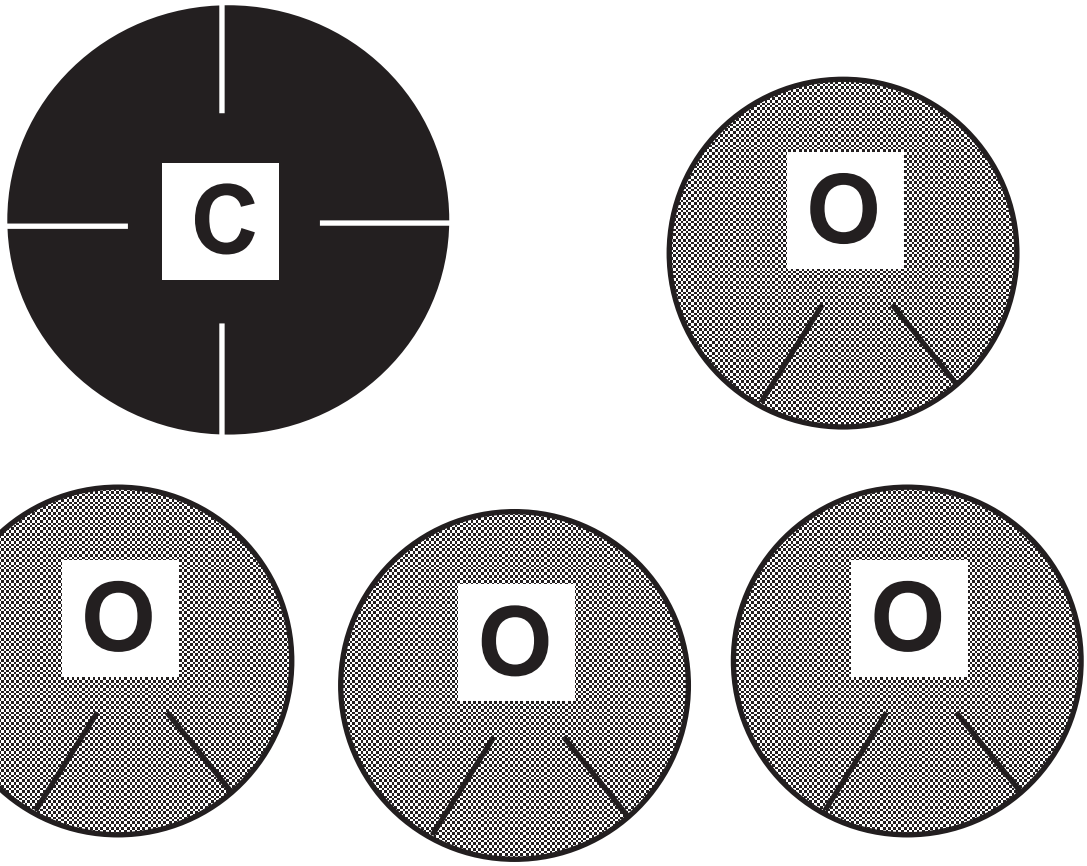
Update as of February 2005
The city of St. Paul is working on a plan to address the problem using barricades. A cave where there is a bat sanctuary will not be sealed due to concerns of naturalists. A protective gate is already in place at the bat cave.

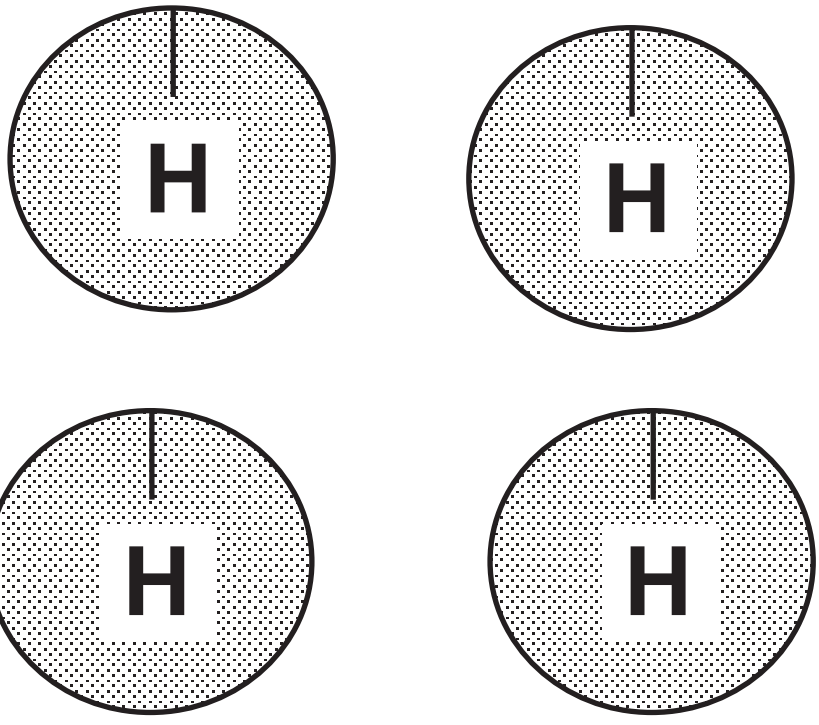
Thought Questions

We no longer live in caves, but are our homes and buildings at risk for air pollution? Although not enclosed like a cave, what are the similarities between what is happening in the Earth's atmosphere and what happened in the cave story?

Source*:* Cable News Network. (2004, April 28). *Three Teens Die of Carbon Monoxide Poisoning in Minnesota Cave.* Retrieved August 22, 2004, from http://www.cnn.com/2004/US/Midwest/04/28/cave.deaths/.

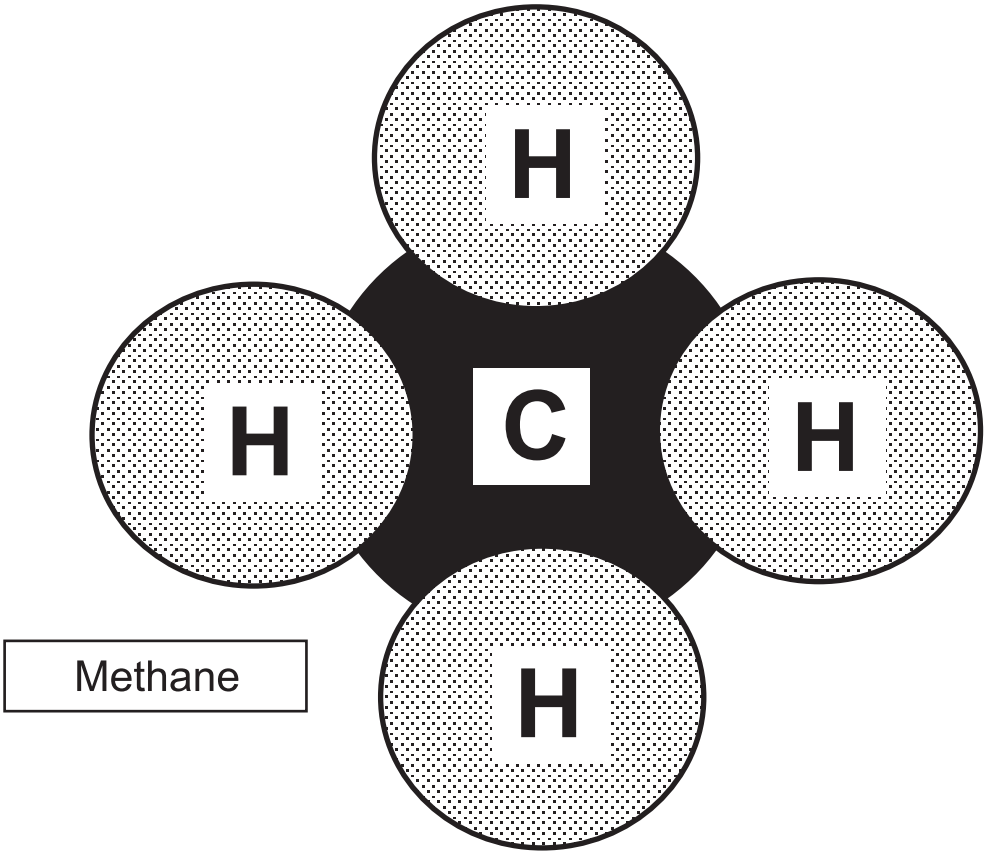
Models of Atoms



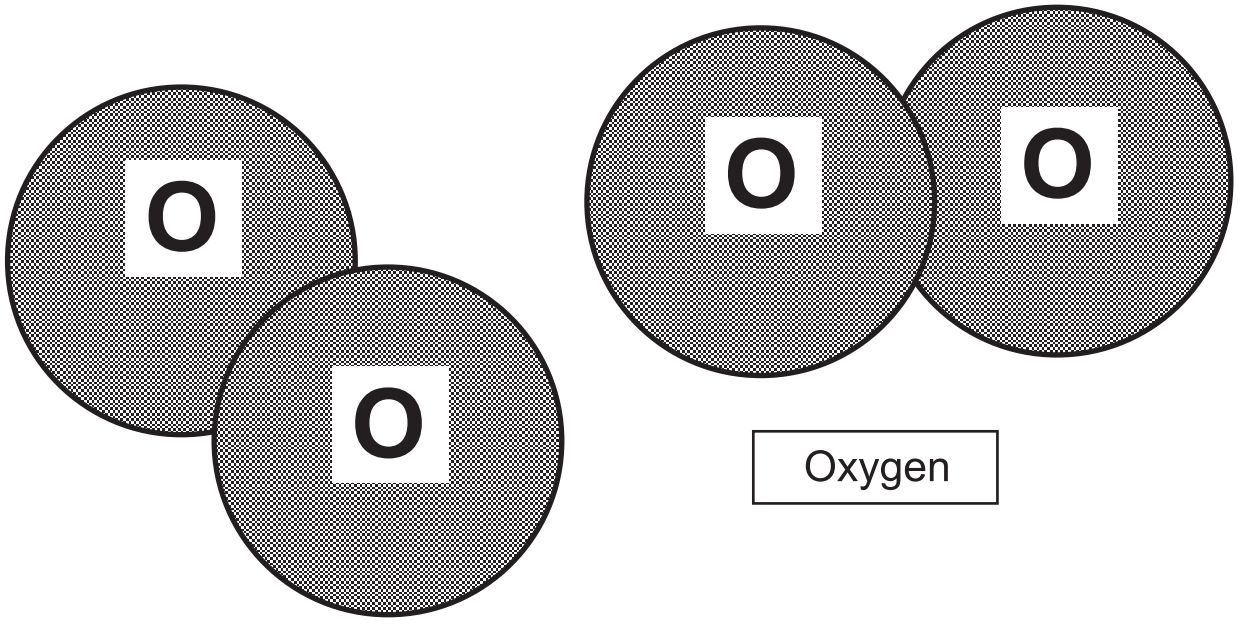


Cut out each of the atoms, including the notches (bonds).

Models of Molecules: Reactants

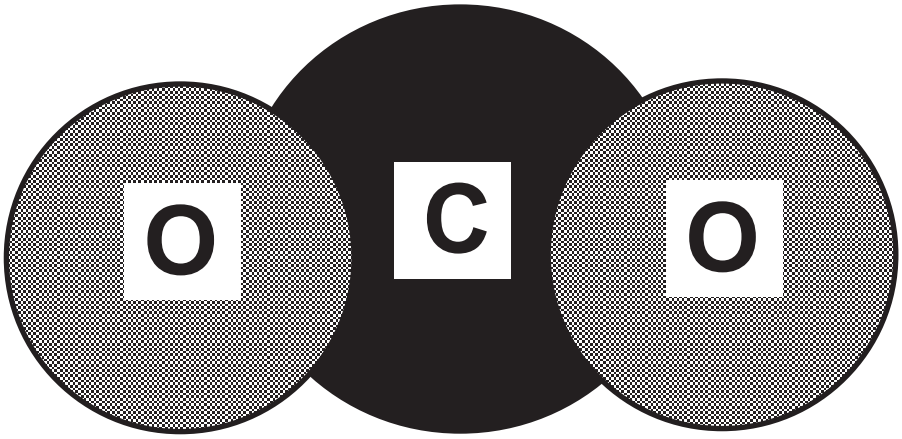


Methane

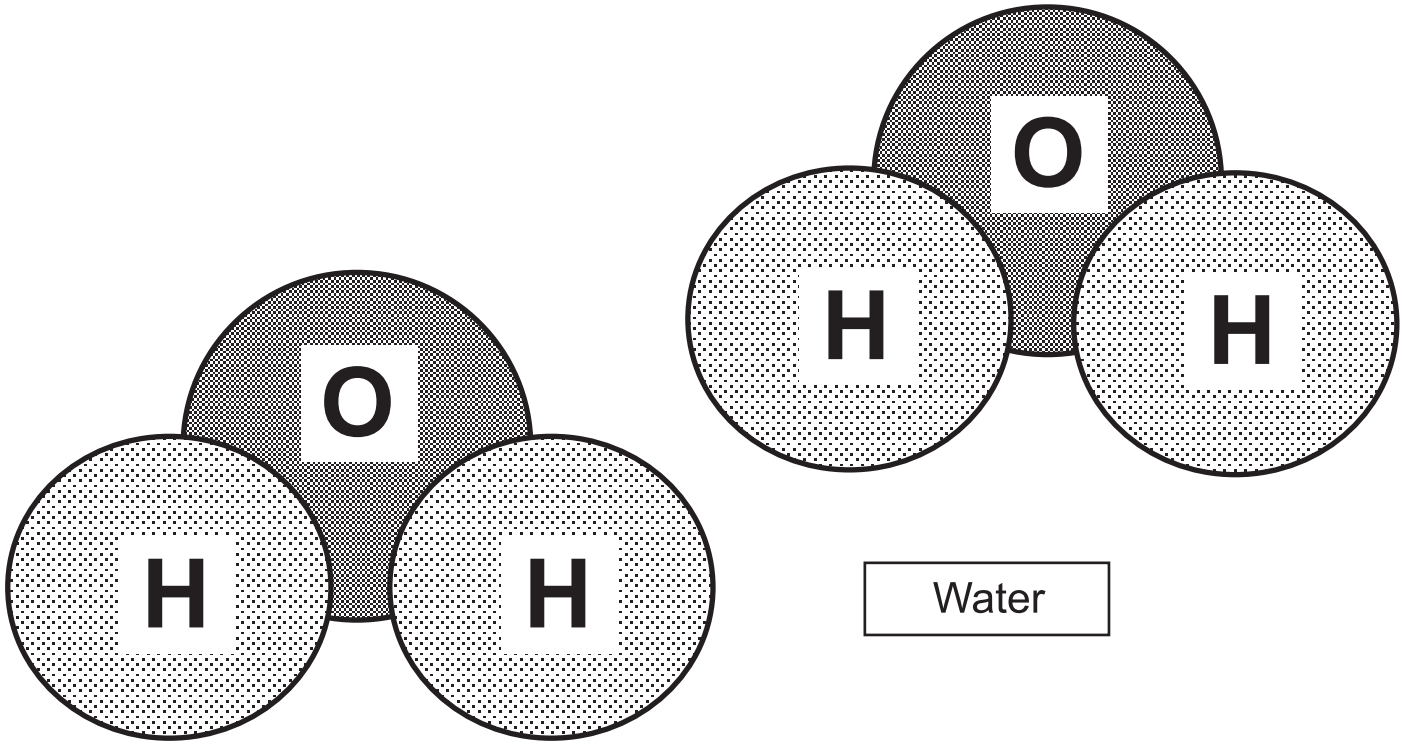


Oxygen

Models of Molecules: Products



Carbon Dioxide



Water

Name_____

Burning Questions

Directions: Put on your safety glasses and follow the directions that your teacher gives you. Make a list of observations about a candle before it is lit, after your teacher lights it, and after it is extinguished. Draw a picture of the candle in the first column. Record your information in the observation column. Use as many senses as you can except taste for your observations.

Picture	Observations
Before Candle is Lit	
Lighted Candle	
Extinguished Candle	

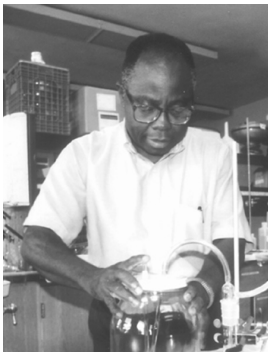
How did the air quality change after the candle burned?

_____ + _____ = _____ + _____

Reactants Products

On the back of your paper, write a paragraph explaining what observing a burning candle tells you about air pollution.

Name_____



Dr. Jerome Nriagu
Photo by Bob Kalmback

Candles and Air Pollution

A University of Michigan School of Public Health study of candles that were purchased from stores in southeast Michigan shows that some candles on the market today are made with wicks that have either lead or lead cores that emit potentially dangerous levels of lead into the air.

The study is by Jerome Nriagu, professor of environmental health sciences, who examined lead emissions from 15 brands of candles made in the United States, Mexico, and China. He also examined the concentration levels of lead that lingered in the air in an enclosed space, such as a 12 x 12 x 10-foot room, after a one-hour burn and then after a five-hour burn.

Nriagu's study showed that lead emission rates for the candles ranged between 0.5 and 327 micrograms per hour. After burning candles from all 15 brands for one hour, the lead levels lingering in the air of an enclosed space were estimated to range from 0.04 to 13.1 micrograms per cubic meter. The U.S. Environmental Protection Agency recommendation for lead levels in the air is 1.5 micrograms per cubic meter for ambient air.

Candles produced in China and the United States released the highest levels of lead into the air. In general, Nriagu found that metal cores in candles from China were made of either pure lead or lead alloy while those made in the United States or Mexico consisted of zinc or lead-containing alloys. Regular exposure to lead in this manner in confined spaces could pose health risks to people with weak immune systems, especially children and the elderly, Nriagu said.

Source: Reyes, A. (1999, October 18). "Some Candles Emit Potentially Dangerous Levels of Lead." *The University Record*, 55(7), Article 8. Retrieved August 22, 2004, from http://www.umich.edu/~urecord/9900/Oct18_99/8.htm.
Reprinted with permission from The University Record at the University of Michigan.

---

1. What was Dr. Nriagu's hypothesis for his experiment?

2. How did Dr. Nriagu perform his experiments?

3. Were all the candles equally harmful? How do you know?

4. How much above the recommended lead level was the most polluting candle?

Name_____

Burning Questions at Home

Directions: Look around where you live and list each combustion or fuel-burning source (gas appliances, fireplace, cars, burn barrel, lawn mower, barbecue grills, etc.) that you see and what air pollution might happen with its use. At the bottom of the page, record the number of smoke and carbon monoxide detectors.

Combustion Source	Air Pollution

Number of Smoke Detectors_____

Number of Carbon Monoxide Detectors_____