ENERGY FOR EVERYONE
propane

The Science and Nature of Gasses

LESSON 4
UNIT: PROPANE
PROBLEM AREA: PROPANE USE IN AGRICULTURE

Propane Education & Research Council

STUDENT LEARNING OBJECTIVES

Instruction in this lesson should result in students achieving the following objectives:

1. Describe the physical and chemical properties and their relationships to the scientific laws of gases.
2. Explain the conditions under which gases assume the three states of matter.
3. Identify the effects of pressure and temperature on gases.
4. Describe the characteristics of propane gas.
5. Describe the science and products of combustion in gases.

NATIONAL SCIENCE STANDARDS ADDRESSED IN THIS LESSON

All students should develop an understanding of:

Science as Inquiry: Content Standard A
- Abilities to do scientific inquiry

Physical Science: Content Standard B
- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Interactions of energy and matter

Life Science: Content Standard C
- Matter, energy, and organization in living systems

Science and Technology: Content Standard E
- Abilities of technological design
- Understandings about science and technology

Science in Personal and Social Perspectives: Content Standard F
- Natural resources
- Environmental quality
- Science and technology in local, national, and global changes

LIST OF RESOURCES

The following resources may be useful in teaching this lesson:

- Propane.com/Agriculture
- Energy.gov
- propane101.com/aboutpropane.htm
- Propane.com

LIST OF EQUIPMENT, TOOLS, SUPPLIES, AND FACILITIES

- Two balloons
- Marker
- Helium or tape
- Matches
- Marshmallows
- Red and green gumdrops
- Toothpicks
- Copies of sample test
- Visuals from accompanying masters
- Copies of student lab sheet

TERMS

The following terms are presented in this lesson *(shown in bold italics throughout the lesson):*

1. Atomic mass
2. Avogadro's Law
3. Boyle's Law
4. Charles's Law
5. Electron configuration
6. Electron shells
7. Gay-Lussac's Law
8. Ideal gas
9. Law of the Conservation of Matter
10. Noble gases
11. Perfect gas
12. Periodic table
13. Propane gas

TELL STUDENTS…

"In this lesson we are going to discuss various properties and characteristics of gases, with an emphasis on propane. You will learn about several scientific laws and how they relate to certain gases important to the agriculture industry, as well as the conditions under which gases change from solid to liquid to gas. We will study how pressure and temperature affect the behaviors of gases and what happens when gases burn."

INTEREST APPROACH

Use an interest approach that will prepare the students for the lesson. Teachers often develop approaches for their unique class and student situations. Two possible interest approaches are included here.

Note: Interest Approach 2 could also be used as a class laboratory activity or combined with Interest Approach 1.

INTEREST APPROACH 1: GAS WEIGHT DEMONSTRATION

Materials: Two balloons, marker, either helium or tape, matches

1. Use helium to make one balloon float, or tape it to the ceiling as if it were floating. Using a marker, label the balloons as "helium" and "air." Once students arrive, ask them why one balloon floats and the other does not.

   Lead a discussion focused on the concept that some gases are lighter or heavier than others. In this situation, helium is lighter than air. Ask the students if they think propane is lighter or heavier than air.

2. Light a match, if possible, and hold it up to the balloon labeled "helium." The balloon will only pop (regardless of whether you filled it with helium or air). Discuss with the students why nothing else happened. Lead a discussion about flammable and nonflammable gases, being sure to make the point that there are many gases and each has different properties. Mention several gases with which students are familiar, and ask them to identify whether they are flammable:

   - Butane—flammable (cigarette lighters, some camp stoves, etc.)
   - Carbon dioxide—nonflammable
   - Propane—flammable

   Ask students if they think there is a relationship between a gas being classified as flammable and its capability as a fuel. (Answer: A flammable gas may be useful as a fuel.)

INTEREST APPROACH 2: PROPANE COMBUSTION WITH MARSHMALLOWS

The amounts given will result in one example of the chemical equation from propane combustion. Demonstrate this for the class, or use it as a lab in which students perform the exercise individually or in groups of two or more.

Materials: 3 large marshmallows, 10 red gumdrops, 8 green gumdrops, 20 toothpicks (or half toothpicks) per set of models made (**VM-A**)

1. Create one propane molecule (C_3H_8) and five oxygen molecules (O_2) out of the marshmallows (carbon), gumdrops (red = oxygen; green = hydrogen), and toothpicks, or have student teams make models.

   Display and explain VM-A as a guide. Each toothpick represents a bond.

   Explain that when propane and oxygen are both present and there is a source of ignition, propane will burn. The ***Law of the Conservation of Matter*** states that matter cannot be created or destroyed. This means that the materials that make up the molecules that burn must also be present when the chemical reaction is finished.

   Solution: $C_3H_8 + 5(O_2)$

2. Take apart or have students take apart the molecules that have been created, and then make the molecules that form when propane is ignited in the presence of oxygen. The products of the combustion reaction should include three carbon dioxide molecules and four water molecules.

   Explain that these are the products formed when propane burns, under complete combustion.

   Solution: $3(CO_2) + 4(H_2O)$

Summary of Content and Teaching Strategies

OBJECTIVE 1

Describe the physical and chemical properties and their relationships to the scientific laws of gases.

ANTICIPATED PROBLEM
What are the physical and chemical properties, and how do they relate to the scientific laws of gases?

Gas is the state of matter that has no definite shape or volume; beyond that, gases vary greatly in their chemical and physical characteristics. The ***periodic table*** (an arrangement of elements by their atomic numbers) can help predict the behavior of gases. There are also many scientific laws that can be applied to gases.

A. The chemical properties of a gas describe its potential to undergo chemical change. Chemical change occurs when a reactant—a substance that reacts with another in a chemical reaction—is changed into one or more different products. Chemical properties vary from gas to gas. Propane, for instance, is a reactive gas when paired with oxygen and a source of ignition, such as fire or flames, electrical sparks, or even a very hot surface. This combination can cause combustion.

B. Physical properties are properties that can be observed or measured without altering the composition or state of the matter. Among these properties are appearance, odor, density, volume, melting point, boiling point, and mass.

C. The periodic table can assist in predicting how an element might react.

   1. The atomic symbol is the one or two letters that internationally represent the element. A few examples are H (hydrogen), Cl (chlorine), and Pb (lead).

   2. The atomic number is the number above the atomic symbol that represents the number of protons in the atom. This number determines the chemical behavior of the element.

   3. The ***atomic mass*** is the average mass of an element in atomic mass units (amu). It is found under the atomic symbol. This number can be used to predict the average number of neutrons found in the element by subtracting the atomic number from it.

   4. Electrons circle the nucleus of an atom in one or more orbits known as ***electron shells***. Each shell holds a specific number of electrons; the number of electrons in the outermost shell enables scientists to predict properties such as reactivity, stability, boiling point, and conductivity. The ***electron configuration*** gives the pattern of orbit for electrons in each element. When the outermost shell is at the maximum number of electrons, the element is generally stable and nonreactive.

   5. Elements are grouped by similarities in the periodic table to make the table easier to use. Each row is known as a period. Each element in the first period has one electron shell, and each element in the second period has two electron shells. This pattern continues as one moves downward through the table. The most electron shells found in any element is seven, which is the bottom period of the main table.

   6. Columns also share characteristics. A column from top to bottom is known as a group. Each group shares the same number of electrons in the outermost shell. With only a few exceptions, every element in the first group has one electron in its outer shell, every element in the second group has two electrons in its outer shell, and so on.

   7. The last column or group is known as the ***noble gases*** or inert gases because they have full outer electron shells. They are, therefore, stable and do not react.

      Note: If you used Interest **Approach 1**, "Gas Weight Demonstration," you may want to tie in this gas property as the reason helium did not explode when the balloon was popped with a match.

D. ***Boyle's Law*** states that the pressure of an (one that obeys the gas laws at any temperature or pressure; also called a ***perfect gas***) at constant temperature varies inversely with the volume. In other words, at a constant temperature, the volume of the gas decreases as pressure on it increases. As a formula, $P_1V_1 = P_2V_2$, where P equals pressure and V equals volume.

REAL-WORLD EXAMPLE

Boyle's Law, $(P_1 \times V_1) / T_1 = (P_2 \times V_2) / T_2$, applies to scuba diving since there is a significant change in pressure with a change in water depth. The water pressure increases with depth, and the diver is required to use far more air from the scuba tank to breathe because the volume in the tank has decreased. Mathematically, if a diver uses 1 cubic foot of air at sea level and the pressure doubles going down, the diver will then use his or her compressed air at twice the rate. By the time the diver gets very deep, he or she is using air from the tank at a very high rate.

E. ***Charles's Law*** states that at a constant pressure, the volume of a given mass of an ideal gas increases or decreases by the same factor as its temperature (in degrees Kelvin) increases or decreases. In other words, at a constant pressure, the volume of the gas increases as temperature increases. A formula displays this as $V / T = k$, where V = volume, T = temperature, and k = a constant. Another way to show this is $V_1 / T_1 = V_2 / T_1$.

REAL-WORLD EXAMPLE

An inflatable pool float may seem quite firm as it sits on a deck in the hot sun; however, minutes after it's tossed into the cold pool, the same float may seem under-inflated. Onlookers may suspect that the float has developed a slow leak, but that may not be the most likely explanation for the apparent loss of air pressure. It may be that Charles's Law is responsible. Gases expand as they are heated, and they contract as they are cooled. In other words, as the temperature of a sample of gas at constant pressure increases, the volume increases. As the temperature decreases, the volume decreases as well.

Another way to state the relationship between pressure, volume, and temperature is known as ***Gay-Lussac's Law***. While Charles did the original work to prove the law, another Frenchman, named Gay-Lussac, conducted additional experiments to verify it. Gay-Lussac observed that if volume is held constant, the pressure is equal to a constant (k) times the temperature ($P = kT$). Another way to write the equation is $P_1 / T_1 = P_2 / T_2$ or $P_1T_2 = P_2TT_1$.

REAL-WORLD EXAMPLE

At the beginning of a road trip, the pressure of an automobile tire is 2.00 atmospheres (atm) at 27°C (80.6°F). At the end of the road trip, the volume of air in the tire remains the same, but the pressure has increased to 2.20 atm. The temperature of the air in the tire has increased to 57°C (134.6°F).

F. ***Avogadro's Law*** states that equal volumes of ideal gases at the same temperature and pressure contain the same number of particles or molecules.

1. This means 2 liters of hydrogen and 2 liters of nitrogen at the same temperature and same pressure contain the same number of molecules.
2. Avogadro calculated the number of molecules present in a volume of 22.41 liters. This number, which applies to all gases, is known as Avogadro's Number and is calculated to be 6.023×10^{23}. The number is traditionally represented by N.
3. Avogadro's Number is one of the most fundamental constants of chemistry. It allows for the calculation of the mole, or the amount of pure substance in any compound. It also allows for a weight comparison between gas molecules, as it is possible to compare the weights of two gases of equal volumes.

SUGGESTED TECHNIQUES TO HELP STUDENTS MASTER THIS OBJECTIVE

1. Begin the lesson with an interest approach, state the objectives, and introduce key terms.
2. Have the students read selections from appropriate resources, such as sections copied from the content presented above (see additional resources below).
3. Lead a discussion on the basic science, nature, and laws of gas, and then on the characteristics of liquefied petroleum gases. **VM-B** is a periodic table that will be helpful for this lesson.
4. Students can also create the chemical molecules for each of the discussed gases and have a visual look at the gases. Discussion of breaking of bonds to create energy could be included here and help in understanding how energy is created.

SUGGESTED RESOURCES FOR OBJECTIVE 1

1. Interactive Periodic Table of the Elements: ChemicalElements.com
2. Nclark.net/GasLaws.html. A good website with activities, labs, and links related to the gas laws. Also, has downloadable PDF documents containing problems using each of the laws.

OBJECTIVE 2

Explain the conditions under which gases assume the three states of matter.

ANTICIPATED PROBLEM

What are the conditions under which gases assume the three states of matter?

Temperature largely decides the state of matter—whether a substance is in the solid, liquid, or gaseous phase. When matter changes states, the changes are physical and not chemical ones. For example, oxygen as a gas still has the same properties as liquid oxygen; however, the individual molecules of oxygen (O_2) are closer together in a solid than in a liquid or a gas. The molecules of gas are the farthest apart.

A. Each substance has a unique temperature at which it will change from a solid to a liquid (melting point) and from a liquid to a gas (boiling point). For example, water will change from ice to a liquid at temperatures above 0°C (the melting point of water) and from a liquid to a gas at 100°C (the boiling point of water). Table salt has a melting point of 801°C.

1. The molecules of a solid begin to vibrate as heat is applied, weakening the force that holds the molecules together. As this force weakens, the molecules move farther apart to form a liquid. If the temperature continues to rise, the molecules continue to move farther apart until the boiling point is reached and a gas is formed.
2. As temperature decreases, the lack of heat causes molecules to slow their vibrations. The force holding the molecules together becomes stronger, drawing the molecules closer. If the temperature decreases to the boiling point, the substance changes from a gas to a liquid. Further decreases in temperature to the melting point result in fusion or freezing. At that point, the substance changes from a liquid to a solid.

SUGGESTED TECHNIQUES TO HELP STUDENTS MASTER THIS OBJECTIVE

1. Lead students in a discussion of the states of matter and their relationship to changing temperatures. Students should take notes.
2. Alternatively, provide student teams with sections of the reading materials and have them identify terms and key ideas in each paragraph.
3. The three states of matter are very simplistic, but be sure that students understand the states of matter and especially the state of gas before moving to the next objective.

SUGGESTED RESOURCES FOR OBJECTIVE 2

1. Participate in an experiment to help students understand that particle movement changes as a substance changes from one phase to another phase: http://sciencenetlinks.com/lessons/a-matter-of-state/
2. Endure a series of games to see how the states of matter are distinguished: legendsoflearning.com/learning-objectives/states-of-matter-and-their-structure/
3. An interactive quiz on states of matter provided by Concord Consortium: learn.concord.org/resources/3/states-of-matter

OBJECTIVE 3

Identify the effects of pressure and temperature on gases.

ANTICIPATED PROBLEM

What are the effects of pressure and temperature on gases?

As pressure increases, higher temperatures are needed to change the state of matter.

A. Water boils at exactly 100°C (212°F) at sea level, where air pressure is greater than at higher elevations. The boiling point of water is less than 100°C at higher elevations because of the reduced pressure. Lower pressure causes the molecules of water to be farther apart, requiring less heat to move them far enough apart to escape as steam. If water is placed in a vacuum chamber, where the air has been evacuated and the air pressure reduced, it will boil at room temperature.

B. Both Charles's Law and Boyle's Law help explain these relationships. See Objective 1 to review these two laws.

SUGGESTED TECHNIQUES TO HELP STUDENTS MASTER THIS OBJECTIVE

1. Review the importance of temperature to the state of matter and the relationship between pressure and temperature.
2. Pose the question to students, "If the boiling point of water at sea level is exactly 100°C, would it be higher or lower in the mountains?" Guide them to a correct response with probing questions, and make sure they understand why the boiling point is lower.
3. Review Charles's and Boyle's Laws, and make certain that students see their application in the example about the boiling point of water.

OBJECTIVE 4

Describe the characteristics of propane gas.

ANTICIPATED PROBLEM

What are the characteristics of propane gas?

Propane gas is a liquefied petroleum (LP) gas used as fuel in heating appliances, vehicles, and numerous other applications.

A. Propane gas must be stored in a container under moderate pressure, or it will evaporate at room temperature.

B. Propane has many distinctive characteristics.

   1. In its vapor or gaseous state, it is heavier than air and has a specific gravity of 1.5. In the event of a leak, it will disperse into a space, but higher concentrations may be found in the lowest areas.
   2. In its liquid state, it is lighter than water and has a specific gravity of 0.504.
   3. Propane gas is naturally odorless. Ethyl mercaptan, an odorant, is added for leak detection and safety.
   4. Propane gas is colorless.
   5. Propane gas is tasteless.
   6. Propane gas is nontoxic but can displace oxygen and cause suffocation in high concentrations.
   7. The boiling point of propane at atmospheric pressure is –44°F.

SUGGESTED TECHNIQUE TO HELP STUDENTS MASTER THIS OBJECTIVE

1. Have students create a table listing the characteristics of propane gas.

OBJECTIVE 5

Describe the science and products of combustion in gases.

ANTICIPATED PROBLEM

What is the science of gas combustion, and what products are produced?

For combustion to occur, three things must be present: fuel, oxygen, and a source of ignition. In addition, they must be proportionally correct. Only water and carbon dioxide are produced when propane is burned in complete combustion.

A. Hydrocarbon fuels contain molecules of hydrogen and carbon atoms. Some common examples are natural gas (methane – CH_4), ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}).

B. Oxygen is present in the air we breathe. This air consists of 20 percent oxygen and 79 percent nitrogen, with the other 1 percent composed of various other gases.

C. If hydrocarbon fuel vapors are in the air (which contains oxygen), the only item missing for combustion is a source of ignition to heat the fuel vapors to the ignition temperature. The ignition temperatures of common hydrocarbon fuels are methane, 1,076°F; ethane, 859°F; propane, 940°F; and butane, 900°F. These ignition temperatures are all higher than that of gasoline, which will ignite at 430° to 500°F.

D. The only products of the complete combustion of pure hydrocarbon fuels are water and carbon dioxide.

   Example: Combustion of propane
   $C_3H_8 + 5(O_2) = 3(CO_2) + 4(H_2O)$

   Example: Combustion of butane
   $2(C_4H_{10}) + 13(O_2) = 8(CO_2) + 10(H_2O)$

E. Natural gas and propane are particularly clean-burning fuels. They leave no lead, varnish, or carbon deposits. This means that they produce fewer air pollutants than most other fuels and leave no deposits that might cause premature wearing of pistons, rings, valves, or spark plugs. For this reason, propane is a particularly useful fuel for farm equipment.

SUGGESTED TECHNIQUES TO HELP STUDENTS MASTER THIS OBJECTIVE

1. Review the components of combustion by asking students to identify the necessary elements.
2. Review the chemical combustion of both propane and butane. Make certain that students know the products of the reactions and why these gases are considered clean-burning fuels.

SUGGESTED RESOURCES FOR OBJECTIVE 5

3. Web site listing facts about LP gas: E-LPG.com/LP_Gas.asp
4. Resource explaining hydrocarbon combustion: energyeducation.ca/encyclopedia/Hydrocarbon_combustion

REVIEW/SUMMARY

Use the student learning objectives to summarize the lesson. Have students explain the content associated with each objective. Student responses can be used in determining which objectives need to be reviewed or taught from a different angle. The anticipated problems can be used as review questions.

APPLICATION

Use the included visual masters to apply the information presented in the lesson.

EVALUATION

Evaluation should focus on student achievement of the objectives for the lesson. Various techniques can be used, such as student performance on the application activities. A sample written test is provided.

ANSWERS TO SAMPLE TEST

Use the included lab sheets to apply the information presented in the lesson.

PART ONE: MATCHING

1. c
2. d
3. b
4. a
5. e

PART TWO: TRUE / FALSE

1. F
2. T
3. T
4. F
5. T

PART THREE: COMPLETION

1. shape, volume
2. temperature
3. temperature
4. heavier
5. fuel, oxygen, a source of ignition

NAME: ______________________________

The Science and Nature of Gases

PART ONE: MATCHING

INSTRUCTIONS: Match the term with the correct definition.

a. ideal gas
b. Charles's Law
c. Avogadro's Law
d. Boyle's Law
e. propane gas

_______ 1. The law that states that equal volumes of ideal gases at the same temperature and pressure contain the same number of particles or molecules

_______ 2. The law that states that the pressure of an ideal gas at constant temperature varies inversely with the volume

_______ 3. The law that states that at a constant pressure, the volume of an ideal gas increases or decreases as its temperature increases or decreases

_______ 4. A gas that obeys exactly Boyle's Law and Charles's Law (also Gay-Lussac's Law) at any temperature or pressure

_______ 5. A fuel used in heating appliances, vehicles, and numerous other applications

PART TWO: TRUE / FALSE

INSTRUCTIONS: Write T for true or F for false.

_______ 1. Propane gas naturally has a very strong scent that is unique and easy to recognize.

_______ 2. Gas is the state of matter that has no definite shape or volume.

_______ 3. Two liters of hydrogen and 2 liters of nitrogen at the same temperature and same pressure contain the same number of atoms.

_______ 4. Because propane gas is nontoxic, people can safely breathe it in large amounts.

_______ 5. The only products of the combustion of propane are water and carbon dioxide.

PART THREE: COMPLETION

INSTRUCTIONS: Provide the word or words to complete the following statements.

1. Gas is a state of matter that has no definite ______________________________ or ______________________________.

2. ______________________ largely decides the state of matter something is in.

3. The higher the pressure, the higher the ___________________ needed to change the state of the material.

4. Propane gas is ___________________ than air.

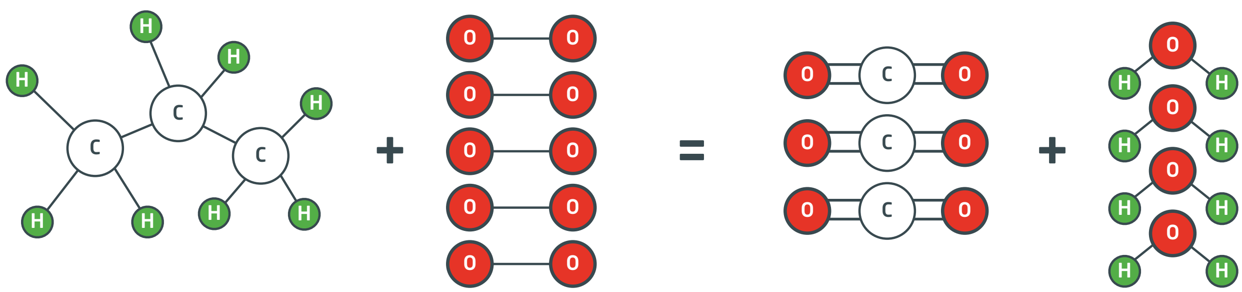
5. For combustion to occur, three things must be present: __________________________________ , __________________________________ , and ________________________________.

Propane Reaction

PROPANE:

$$C_3H_8 + 5(O_2) = 3(CO_2) + 4(H_2O)$$

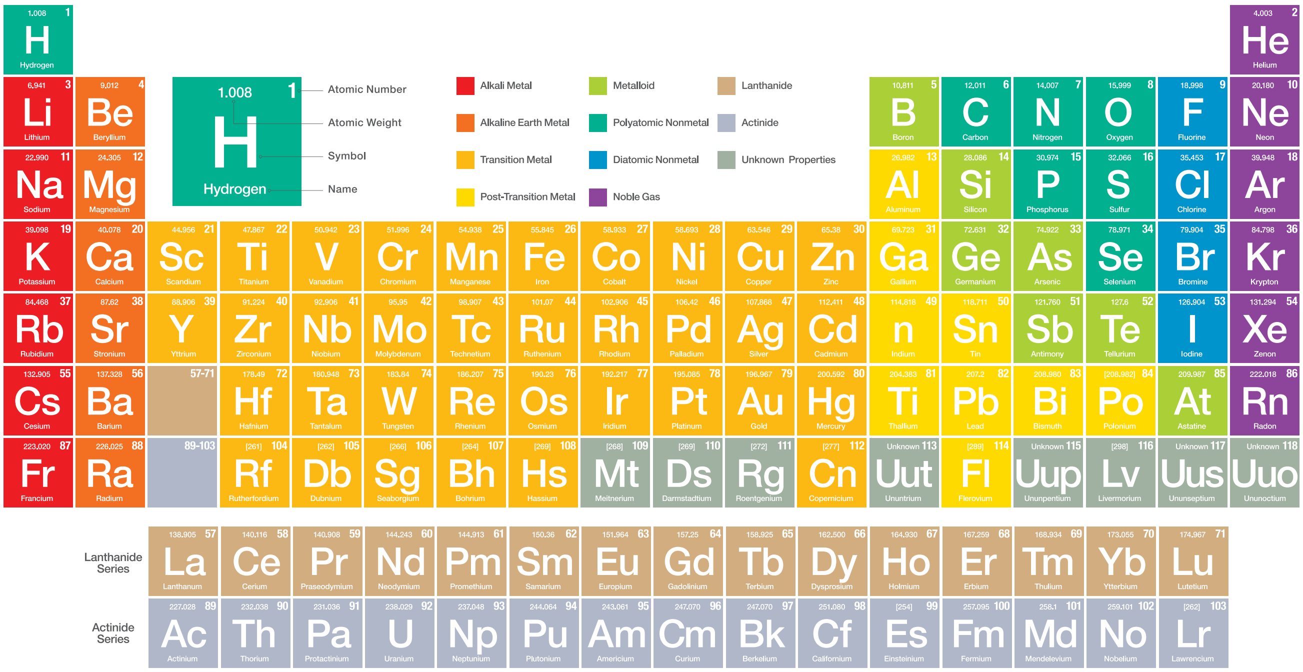
The chemical breakdown molecularly of propane igniting in the presence of oxygen and burning to produce carbon dioxide and water.



SUPPLY LIST

C	O	H	—
carbon (C)	oxygen (O)	hydrogen (H)	bonds
3 marshmallows	*10 red gumdrops*	*8 green gumdrops*	*20 toothpicks*

Periodic Table of Elements



Heavier Than Air

PURPOSE

The purpose of this activity is to demonstrate that some gases are heavier than air, causing them to sink to the ground or other solid surface when released.

OBJECTIVE

Demonstrate that propane gas is heavier than air by using carbon dioxide to represent propane for safety reasons.

MATERIALS

- Large bowl
- Baking soda
- Vinegar
- Bottle of bubble liquid with a wand
- VM-C
- VM-D
- VM-E

PROCEDURE

1. Pour a layer of baking soda over the bottom of the bowl.
2. Pour vinegar over the baking soda. View VM-C.
3. Wait for the reaction of the baking soda and vinegar to stop. There will now be an invisible layer of CO2 above the liquid solution in the bowl. View VM-D.
4. Blow bubbles over the bowl so that they fall into it.
5. Observe that the bubbles are suspended in midair over the solution. View VM-E.
6. Explain why this phenomenon exists. How can the bubbles be suspended without any visible support?
7. Explain how the weights of the gases relate to their behavior.
8. Explain how the floating bubbles relate to propane.
9. Explain why propane was not used to demonstrate this.

Review LS-A and the procedure with the class. Use VM-C, VM-D, and VM-E to help the students understand the procedure.

Enhance this activity by having students calculate atomic mass of CO_2 and C_3H_8 so they can see that they are the same atomic mass. Then calculate the atomic mass of air (20% O_2 and 79% N_2), and make a prediction of what should happen before conducting the experiment.

Students could perform some calculations using Charles's and Boyle's Laws.

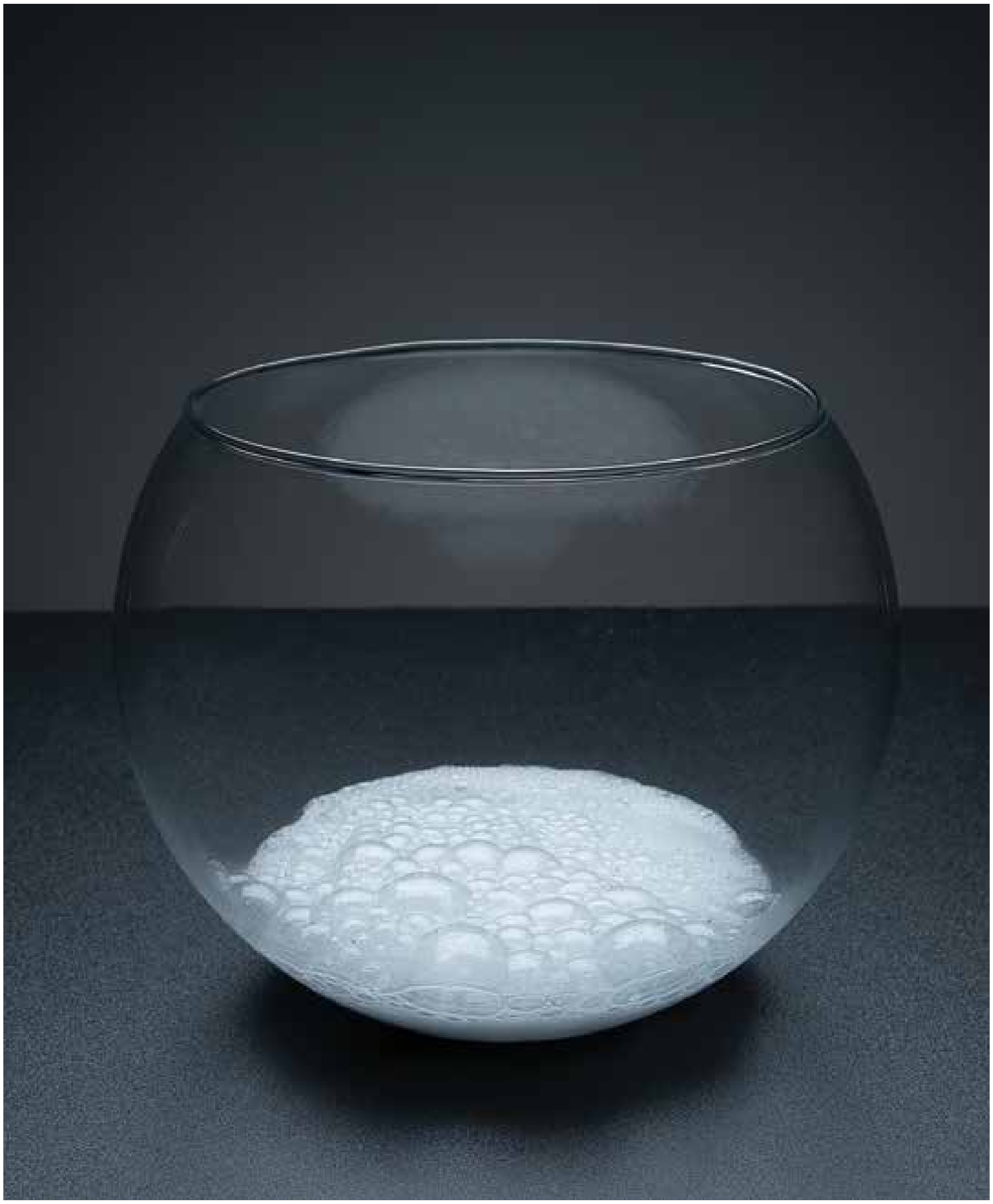
PRIMARY RESULT: The bubbles sit on top of the carbon dioxide instead of sinking to the bottom of the bowl because the carbon dioxide is heavier than the air in the bubbles.

Adding Vinegar to Baking Soda

Vinegar being added to, and reacting with, baking soda to create carbon dioxide.

Reaction Ending

The vinegar and baking soda reaction slowing down as carbon dioxide is formed.



Suspended Bubbles

The bubbles suspended above carbon dioxide that has formed in the bowl.