Chemistry Under Glass

Overview

Students observe an interesting phenomenon and experiment to explain their observations using the gas laws.

Key Concepts

- atmospheric pressure
- claims and evidence
- combustion reaction
- experimental design
- gas laws—Charles's

National Science Education Standards

Science as Inquiry

Abilities Necessary to Do Scientific Inquiry

- *Students use logic and evidence to formulate explanations about the behavior of a candle's flame and the water in a pan during various explorations. (5–8, 9–12)*
- *Students pose testable questions about what they have observed with the candle to provide additional evidence to support their claim about the system. (5–8, 9–12)*
- *Students gain experience in identifying and controlling variables as they plan and conduct experiments to answer their testable questions. (5–8, 9–12)*

Physical Science

Properties and Changes of Properties in Matter

- *Students learn that a characteristic property of a gas is that it takes up space. (5–8)*
- *Students learn that water vapor is composed of molecules of gas that exert pressure on the inside of the flask. When water vapor condenses back to water, the number of gas molecules decrease and atmospheric pressure pushes the water into the container. (5–8)*
- *Students learn that oxygen is a required component of a combustion reaction and the flame goes out when the amount of oxygen falls below the amount needed to sustain combustion. (5–8)*

Structure and Properties of Matter

- *Students observe that water is pushed into the container and conclude that as water vapor condenses back down to a liquid, the gas pressure inside the container decreases below atmospheric pressure because the number of gas molecules has decreased. (9–12)*

Motions and Forces

- *As the glass container is lowered over the burning candle sitting in a pan of water, students observe bubbles in the water because the heated air in the container increases in volume (Charles's law) and pushes out of the container. (5–8, 9–12)*
- *Students conclude that the movement of water up the neck of the inverted container apparatus results from the lowering of pressure inside the container. Because the pressure of the atmosphere is greater than the pressure of the gases inside the container, the water is pushed up into the container. (5–8, 9–12)*

Chemical Reactions

- *Students learn that oxygen is a required component of a combustion reaction and the flame goes out when the amount of oxygen falls below the amount needed to sustain combustion. (9–12)*

Student Exploration

Explore some interesting phenomena with a burning candle.

Materials

- birthday candle
- aluminum pie pan (One without ridges works best.)
- matches
- clear, narrow-necked glass container
- water
- paper towels
- (optional) 2–5 drops food color
- (optional) small piece of clay

Procedure

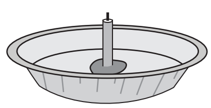


Figure 1

1. Stand a birthday candle in the middle of the pie pan using a small flattened piece of clay or by dripping hot wax into the middle of the pan and holding the candle upright in the wax until the wax hardens. (See Figure 1.) If the candle is lit, blow it out now.

2. Half-fill the pie pan with water. (To make the water more visible, add food color.) Lower the open mouth of the glass container over the unlit candle and into the water. (See Figure 2.) Let the mouth of the container rest on the bottom of the pan. *Note the water level inside and outside of the glass container.*

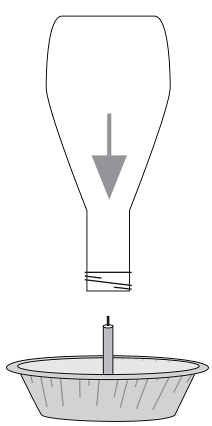


Figure 2

3. Remove the glass container. Light the candle and again lower the mouth of the container over the candle and into the water. Let the mouth of the container rest on the bottom of the pan. *Note the water level inside and outside of the container. Record your observations.*

4. Slowly lift the glass container upward. *Record your observations.* Blow into the container several times to refresh the air inside. Make sure that the candle wick and neck of the container are dry, using a paper towel if necessary.

5. Light the candle. Lower the container over the lit candle into the water, but this time *do not* rest the container on the bottom of the pan. Make sure the mouth of the bottle is kept below the water level. (See Figure 3.) *Record your observations.*

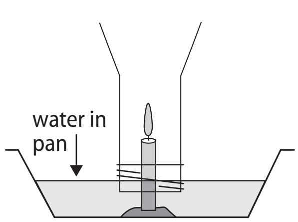


Figure 3

6. Based on your observations, develop a claim you can justify about the system you have just tested. Think of testable questions that would provide additional evidence to support this claim. Use the available materials to conduct an experiment to answer your testable question. Gather and share your evidence.

Instructor Notes

Tips and Instructional Strategies

- The neck of the glass container must have a greater diameter than the birthday candle. (A salad dressing bottle works well.)
- As an alternative to students blowing into the container in step 4, students can fill the container with water, then pour the water out. This refreshes the air in the container.
- You may want to have the students write and balance the chemical equation for the complete combustion of wax. They can assume that the formula of the wax is a simple, even-numbered, saturated hydrocarbon such as $C_{20}H_{42}$.
- This lesson provides a good opportunity to address a common student misconception: many students believe they exhale only CO_2, when in fact their exhaled breath is mainly N_2 and O_2. Typically, exhaled air only contains about 4% CO_2.
- Discuss experimental design as a class. Emphasize the importance of controlling variables. Establish what the variables would be for each testable question proposed, and discuss how students would control these variables. While we strongly recommend that students develop their own testable questions in step 6, you may need to seed the discussion with possible questions. Some examples follow:
    - Do different sizes and shapes of glass containers affect how long the candle will burn?
    - Does using multiple candles or different sizes of candles under the container affect the results?
    - Does having ice on top of the inverted container affect the results?
- To help students reflect on and convey their understanding of this lesson, you may want to have them create a series of captioned drawings illustrating their observations, first at the macroscopic level, and second, their visualization of what is occurring at the molecular level. If students need more structure, try a three-step storyboarding method in which students do the following:
    - create a series of drawings showing macroscopic observations,
    - create another series of drawings showing their visualizations of the molecular level, and
    - write a short paragraph describing the relationship between the macroscopic and molecular-visualization. (See Figure 4 at the end of the Explanation for an example.)

Explanation

In this exploration, a glass container is placed over a lit candle sitting in a pan of water. As the container is lowered over the candle into the water, the air in the container is heated. Heating a gas causes its volume to increase. Because the container is open at the mouth, some of the gas originally in the container is pushed out. Evidence of this escaping air can, at times, be seen as bubbles at the point where the mouth of the container is pushed beneath the water's surface, but this bubbling does not last long. The water level then begins to rise up into the neck of the container, the candle goes out, and the water rises even more. To understand what causes these observations, it is useful to consider what happens when the candle burns.

In the reaction, candle wax reacts with oxygen (O_2) to produce carbon dioxide (CO_2) gas and water vapor. The flame goes out as the amount of O_2 falls below that needed to sustain combustion. (While oxygen is consumed in the combustion of candle wax, some O_2 remains in the container even after the flame goes out, because not all of the O_2 diffused to the area around the flame.)

Some students may suggest that there is less gas in the container because O_2 is consumed. However, this is not the case. While O_2 is consumed, the products of combustion are both gaseous CO_2 and gaseous H_2O. If we assume that wax is primarily a simple, even-numbered hydrocarbon such as $C_{20}H_{42}$, then the equation for its combustion would be:

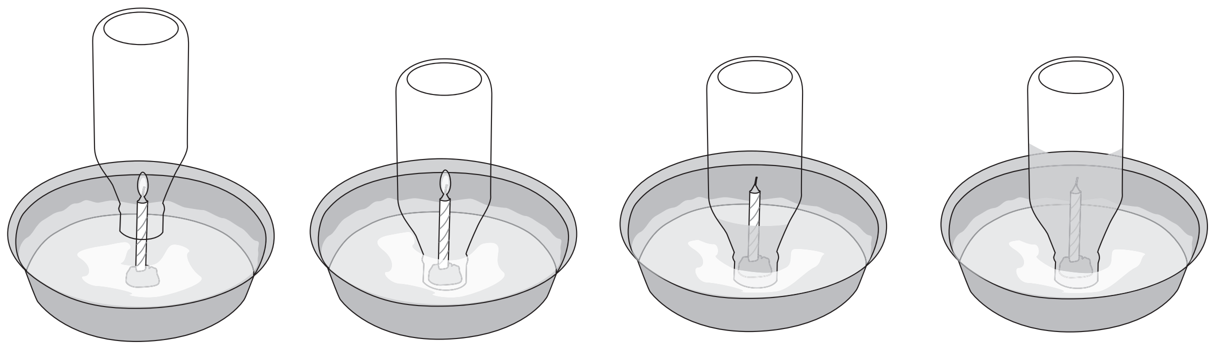
$$\underbrace{2\,C_{20}H_{42}(g) + 61\,O_2(g)}_{63\ molecules} \longrightarrow \underbrace{40\,CO_2(g) + 42\,H_2O(g)}_{82\ molecules}$$

In this balanced equation, the reactants consist of a total of 63 gas molecules (see the "Observing Candles" lesson for a discussion of why the reacting wax is a gas) that produce 82 gas molecules of products during the combustion reaction. If the increase in the number of gas molecules were the only thing that happened, there would be more gas in the container as a result of combustion, and the pressure inside the container would increase. However, we don't see this. The water moves up into the container and is not pushed out of it. Why? There are three factors that contribute to the lowering of the pressure inside the container. The first factor is that once the temperature decreases when the candle goes out, the water vapor condenses into liquid water, so a reduction occurs in the number of molecules in the gaseous state. This reduction in the number of molecules of gas in the container reduces the pressure inside the container to less than atmospheric pressure, allowing water to be pushed into the container.

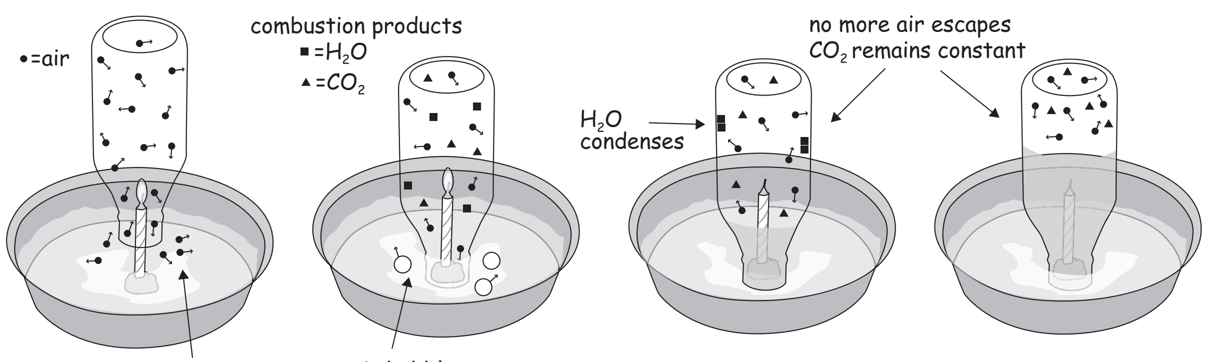
The second factor contributing to the lowering of pressure inside the container is that some of the air escapes from the container because of the volume increase due to heating (Charles's law). Fewer gas molecules inside the bottle results in less pressure. (Remember the bubbling that occurs as the container is first lowered over the lit candle.) The third, least significant factor is that the pressure inside the container decreases as the gases cool after the flame goes out.

Because the atmospheric pressure outside the container is greater than the gas pressure inside the container, water is pushed into the container. The water movement ceases when the atmospheric pressure equals the sum of the gas pressure inside and the pressure exerted by the column of water inside the container. Figure 4 is a sample storyboard that could be used to explain the phenomenon.

MACROSCOPIC



PARTICLE LEVEL



WRITING

Molecules in the air are heated as the bottle is lowered over the candle. Heat causes these gaseous molecules to move faster, spread out more, and escape out of the bottle. Once the mouth of the bottle is under water, the warmed gas molecules in the bottle can escape as air bubbles. As the candle burns, $H_2O(g)$ and $CO_2(g)$ form as products of combustion. Once the candle goes out, the air cools; this allows the water vapor that was produced to condense, further reducing the number of gas molecules in the bottle and thus reducing the pressure. The air pressure outside is now greater than the pressure inside, so the liquid water in the pan is pushed up further into the bottle. The movement of water into the bottle stops when pressure inside the bottle plus the pressure exerted by the column of water in the bottle equals atmosperic pressure outside.

Figure 4: Sample storyboard

Answers to Student Questions

Step 2

The water levels inside and outside the container are about the same.

Step 3

Gas bubbles out of the container as the container is lowered into the water. The water rises into the container after the candle goes out.

Step 4

Water flows out of the bottle once the rim of the bottle is raised above the water level in the pan. (Occasionally, the pan will be held in place as the bottle is raised.)

Step 5

Bubbles appear at the mouth of the container as it is first immersed, and bubbling continues as the candle burns. Water rises more quickly in the container. The candle goes out and the water continues to rise.

References

Birk, J.P.; Lawson, A.E. The Persistence of the Candle-and-Cylinder Misconception. *J. Chem. Educ.* **1996,** *76* (7), 914–916.

Sarquis, M.; Hogue, L. Evicting Air. *Classroom Science A to Z;* Terrific Science Press: Middletown, OH, 2000; pp 59–69.