UNIT 2

The Behavior of Particles

Unit Overview

Fundamentally, chemistry is the science of interacting particles. In this unit, students will learn about the variables that control the physical state of matter: pressure, volume, and temperature. Students will be able to distinguish among the phases of matter and explain the properties of solids, liquids, and gases based on their kinetic energy. The text and video provide real life applications of phase changes and a context for interpreting phase diagrams.

Learning Objectives and Applicable Standards

Participants will be able to:

1. Describe phase changes based on kinetic energy.
2. Relate pressure, volume, and temperature.
3. Interpret phase diagrams.

Key Concepts and People

1. **Classifying the States of Matter:** Today, scientists understand that melting, freezing, evaporating, and other changes of state do not alter the identity of a substance, just the distance between the molecules. Gases were the final phase studied because early theories of matter defined "air" as one of the four elements, rather than a mixture of many substances including oxygen, carbon dioxide, and nitrogen.
2. **Measuring Temperature:** Fahrenheit, Celsius, and Kelvin are all temperature scales named after the people who discovered them. Reliable temperature scales allowed for scientists around the world to compare their results, which provided a reproducible standard for studying phase changes.
3. **Measuring Pressure:** Pressure is defined as a force per area, and can be visualized as gas particles colliding with the walls of their container.
4. **Early Gas Chemistry:** Robert Boyle, an English chemist, discovered that pressure and volume are inversely proportional; at a constant temperature, decreasing volume corresponds with increasing pressure. Joseph Black, Joseph Priestly, and Henry Cavendish all made valuable contributions to the understanding of gases.

5. **Formulating the Gas Laws:** Robert Boyle, Jacques Charles, Joseph Louis Gay-Lussac, and Amedeo Avogadro lend their names to the gas laws that show the relationship between pressure, volume, moles, and temperature. The Ideal Gas Law is the combination of all of the work by Boyle, Charles, Gay-Lussac, and Avogadro. The Ideal Gas Law establishes that one mole of any gas at standard temperature and pressure has a volume of 22.4 L.

6. **Phase Diagrams:** The physical state of a substance depends on the pressure and temperature of the surroundings. Phase diagrams demonstrate this relationship based on the substance.

Video

This program explores the phases of matter—solids, liquids, and gases—and how particles in a given phase interact with each other. Phase diagrams explain at what temperature and pressure a given substance will be in a solid, liquid, or gas phase. Practical problems, like how to safely store enough hydrogen gas to power an automobile, are solved by understanding the different behaviors of solids, liquids, and gases. Understanding the relationships between temperature, pressure, and volume eventually led to the Ideal Gas Law, which provides the platform for examining the conditions under which matter can form a supercritical fluid. Researchers are investigating underground sequestration of supercritical carbon dioxide to mitigate the environmental impact of burning fossil fuels.

VIDEO CONTENT

Host Science Explanation
"Phase Diagram"

The host of this show, Dr. Mala Radhakrishnan, Assistant Professor of Chemistry at Wellesley College, explains what phase diagrams represent and the differences among solids, liquids, and gases.

Laboratory Demonstration
"A Model of a Gas"

In this demonstration Harvard University Lecture Demonstrator Daniel Rosenberg uses golf balls to represent gas molecules. When the temperature of a gas is raised, the molecules of the gas (in this case the golf balls) move faster, and the volume increases.

Laboratory Demonstration
"Phase Change"

At atmospheric pressure solid carbon dioxide, or dry ice, normally goes directly from a solid to a gas. According to the phase diagram of CO_2, carbon dioxide will go from a solid to a liquid with an increase in temperature and pressure. This can be seen when dry ice is placed in a tube with a rubber stopper. As the CO_2 goes from a solid to a gas, the pressure inside the tube increases. As the pressure in the tube increases, the dry ice enters a liquid phase. When the pressure is released, the liquid instantaneously goes back to a solid.

Current Chemistry Research
"Hydrogen Storage"

Hydrogen fuel cells are a promising technology that would limit the burning of fossil fuels. Like fossil fuels, hydrogen fuel cells produce energy, but instead of producing carbon dioxide as a by-product, hydrogen fuel cells produce water. The goal is to manufacture cars that run on hydrogen fuel cells, but storing hydrogen for fuel is inefficient. Cooling hydrogen to a liquid state requires a lot of energy, and hydrogen gas takes up too much space. Dr. Peter Wong, Associate Professor at Tufts University, is seeking a way to use nanofibers to increase the storage capacity of hydrogen gas tanks. Hydrogen molecules adhere to the nanofibers, thus storing more molecules in the tank.

History of Chemistry
"Gas Laws"

Through the use of animations, this segment briefly explains the discovery of the Ideal Gas Law, which combines the work of Robert Boyle, Jacques Charles, Joseph Louis Gay-Lussac, Amedeo Avogadro, and Emile Clapeyron. The Ideal Gas Law summarizes the roles of pressure, volume, and temperature in describing the behavior of a gas.

Lab Demonstration
"Volume = Temperature"

Volume and temperature are directly proportional. For example, a helium balloon shrinks when placed in liquid nitrogen. The balloon's volume decreases due to slower moving helium atoms, which make fewer collisions with the walls of the balloon. After reaching room temperature again, the helium atoms move faster and collide more with the walls of the balloon, so the volume of the balloon increases and it rises to the ceiling.

Real World Application
"Supercritical Fluid"

C12 Energy, an independent oil and gas company, is working to store carbon dioxide as a supercritical fluid underground in order to prevent carbon dioxide from polluting the atmosphere and contributing to an increase in greenhouse gases.

Unit Text

Content Overview

Unit 2 begins with a discussion of the characteristics of the states of matter, using the Earth's water cycle as a way to illustrate phase changes. Pressure and temperature are the key variables that control states of matter. Phase diagrams are visual representations of the states of a particular substance as a function of pressure and temperature. The text includes analyses of the phase diagrams of water on both Earth and Mars, and the phase diagram of carbon dioxide. The pioneers in this field made huge gains by developing reliable measurement scales and drew important conclusions based on observable phenomena, such as hot air ballooning.

Sidebar Content

Torricelli and the Invention of the Barometer: Barometers allow scientists to quantify pressure. The gas laws are mathematical relationships among pressure, temperature, volume, and number of particles. Without a consistent and reliable measurement of pressure, the gas laws would not have been possible.

Interactives

Historical Timeline of Chemistry

This interactive illustrates how different discoveries build upon, disprove, or reinforce previous theories. This not only reinforces basic chemistry concepts, but also emphasizes the nature of science. For centuries, scientists focused on the solid and liquid phases for study. Scientists mentioned in this unit are listed on the timeline.

During the Session

Before Facilitating this Unit

An important aspect of teaching this unit is to uncover the prior knowledge of students. Phase changes are observable phenomena that are very familiar to students. Use the video, text, activities, and demonstrations to strengthen their understanding of the physical changes surrounding them. The video includes a demonstration of creating liquid carbon dioxide at room temperature, which is a great example of how environmental conditions control the state of matter. All matter can exist at the three phases, given the appropriate conditions. The video also provides real-world research applications of phase changes demonstrating that even basic science like phase changes can lead to important technological advances.

Tips and Suggestions

1. **Explain Pressure.** Gas laws are much easier to visualize if pressure is described as a direct result of collisions of particles with the walls of a container.
2. **Use as many real life examples as possible.** There are many examples of the effects of pressure, temperature, and volume on every day scenarios. Have students think about tires expanding when heated from driving, or about cake recipes having alternative

instructions based on altitude, or about basketballs that were left out in the cold overnight and no longer bounce. Many of these gas laws make inherent sense to students given the right context.

3. **More advanced students would benefit from understanding that boiling occurs when the vapor pressure equals the atmospheric pressure.** Cooking temperatures and directions are different high in the mountains compared to sea level due to differences in atmospheric pressure.

Starting the Session: Checking Prior Thinking

You might assign students a short writing assignment based on the following questions, and then spend some time discussing prior thinking. This will help elicit prior thinking and misconceptions.

1. Fill out a KWL chart about the phases of matter. A KWL chart is a great formative assessment to analyze the prior knowledge of students. The chart has three columns: K for "what you know," W for "what you want to know" and L for what you learned. The K and W sections are a pre-assessment and should be filled out at the beginning of a unit. The L section is a post-assessment for the end of a unit. Students can fill them in individually or the class can generate a list together.

2. When water boils on the stove, what is in the bubbles?

3. What are the similarities and differences among ice, water, and steam?

4. Why is having a reliable temperature scale useful?

5. What is volume?

6. What is pressure?

7. What is temperature?

Before Watching the Video

Students should be given the following questions to consider while watching:

1. What is temperature?

2. What is the relationship between pressure and volume?

3. What is the relationship between volume and temperature?

4. What is a real life example of Charles' Law?

Watch the Video

After Watching the Video

Use these additional questions as follow-up, either as a group discussion or as short writing assignments.

1. What do the terms "directly proportional" and "inversely proportional" mean? Give an example of an equation for each.
2. What does it mean to "boil"? Describe what is happening to the particles.
3. Why do gases make inefficient fuel sources?

Group Learning Activities

Marshmallow Madness

Objective

Observe Boyle's Law using a small marshmallow and needle-less syringe. In this activity a small marshmallow is inserted into a closed syringe. The marshmallow expands when the volume increases due to a decrease in pressure. The marshmallow shrinks when the volume decreases due to an increase in pressure. The main point of this activity is for students to see the inverse proportionality between pressure and volume.

List of Materials

- Needle-less syringe
- Mini-marshmallows

Procedure

1. Remove the plunger from the syringe and place a mini-marshmallow inside the chamber.
2. Replace the plunger.
3. Plug the tip of the syringe with your finger and move the plunger up and down.
4. Observe the change in the volume of the marshmallow as the pressure changes.

Discussion

The following questions can help students reflect on this exercise. If possible, have students record their responses to the questions in a journal and spend some time discussing as a class.

1. What happens to the marshmallow when the volume decreases? Why?
2. What happens to the marshmallow when the volume increases? Why?
3. What is the relationship between pressure and volume?

Hazards
There is no increased risk of harm to do this activity.

Disposal
There are no special disposal considerations.

Bead Manipulatives for the Phases of Matter

Objective
By modeling solid, liquid, and gas phases with small plastic beads in Petri dishes, students can compare and contrast the freedom of movement and the packing of particles in different phases. The dish for "gas" will only contain a few beads, whereas the dish for "solid" will be completely full. The dish for "liquid" should contain just enough beads to cover the bottom.

List of Materials
- Three Petri dishes for each group of students
- Small plastic beads

Set Up
1. Give each group of students three Petri dishes and beads.
2. Explain that the beads represent particles. Each Petri dish is for one state of matter.

Procedure
1. In a Petri dish, arrange beads to create a model of how particles are arranged in a gas phase.
2. Repeat so that you have one Petri dish that represents a gas phase, one that represents a solid phase, and one that represents a liquid phase.

Discussion
The following questions can guide a discussion and help students reflect on this exercise.
1. How do the Petri dishes that represent solid, liquid, and gas differ from one another?
2. Which phase allows for the greatest freedom of movement?
3. Which phase allows for the least freedom of movement?
4. What do scientists mean by the word "model"?

Hazards
There is no increased risk of harm to do this activity.

Disposal
There are no special disposal considerations.

In-Class Chemical Demonstrations

The Weight of Air

Objective
This demonstration helps students realize that gases have mass, and that a small amount of gas can occupy a large volume.

List of Materials
- Deflated basketball
- Bike pump
- Balance

Procedure
1. Show the students the deflated basketball and mass it.
2. Ask the students how much the mass will change once it is inflated. The guesses will probably have a wide range.
3. Inflate the basketball and mass it again.

Discussion
Students are always surprised by how little mass air has even with a rather large volume. Another important point to bring up here is what is going on inside the basketball to keep it inflated: The molecules of air are exerting force on the walls of the basketball. Here are some questions that can help guide a discussion.

1. Why do you think the air has such a small mass?
2. What is happening inside the basketball to keep it inflated?

Hazards
There is no increased risk of harm to do this activity.

Disposal
There are no special disposal considerations.

Crushing Soda Cans

Objective

This demonstration shows the relationship between temperature and pressure. A soda can is filled with about a half inch of water and allowed to boil. As the water boils, it turns to steam, pushing air out of the can and filling the can with water vapor. Once the water has boiled, the can is inverted and submerged into a beaker of water. As the can is submerged, the water vapor in the can cools and condenses back to liquid water. This decreases the volume of the water inside the can. As a result, the pressure inside the can decreases, so the air outside of the can has enough pressure to crush the can.

List of Materials

- Two empty soda cans (in order to repeat the demonstration)
- Hot plate
- Tongs
- Large beaker
- Water

Procedure

1. Fill the large beaker with cold water from the tap.
2. Fill the soda can with about half an inch of water.
3. Heat the can until the water has boiled.
4. Using the tongs quickly place the can upside down into the large beaker.
5. Repeat the previous step with the second can.

Discussion

The cans crumple very quickly and loudly upon being placed in the beaker of water. This shows that a quick decrease in temperature of water vapor causes a quick decrease in volume, and thus a decrease in pressure inside the can. Students will want to see it twice, so have two cans on hand. These questions can help guide a discussion.

1. What happens to the air inside the can when the water in the can boils?
2. What happens to the gas inside the can when the can is placed upside down in the cool water?
3. Why do the cans crumple?
4. What would happen if instead of using a soda can, we used a thicker, sturdier soup can?

Hazards

There is no increased risk of harm to do this activity.

Disposal
There are no special disposal considerations.

Hard-boiled Egg Trick

Objective

This demonstration shows the relationship between pressure and temperature.

List of Materials

- A hard-boiled egg without the shell
- Erlenmeyer flask
- Matches

Procedure

1. Light a match and place it in an Erlenmeyer flask.
2. Immediately place a peeled hard-boiled egg into the neck of the flask.

Discussion
The egg is sucked into the flask due to a change in pressure. The match initially heats up the air in the flask, causing an increase in pressure. Once the match goes out, there is a drop in pressure, causing the egg to fall into the flask. These questions can help guide students thinking about this demonstration:

1. What happens to the air inside the flask when the match is lit?
2. Once the match goes out, what happens to the air inside the flask?
3. Why does the egg fall into the flask?
4. Why does the match go out?

Challenge Question

1. How can you get the egg back out of the flask without destroying the egg?

Hazards
There is no increased risk of harm to do this activity.

Disposal
There are no special disposal considerations.

Going Deeper (In-Class Discussion or Reflection)

Instructors should allow up to 30 minutes for discussion at the end of the unit, or students can use the time to reflect on one or more of these questions in journals.

1. Revisit the KWL chart you created before the unit and fill in the "L" section- what you have learned. Did you learn everything you wanted to? Is there anything that you thought you knew but found out was incorrect?
2. Does warm soda or cold soda become flat more quickly? Why?
3. Imagine that you left a basketball outside in the winter. Would you be able to shoot some hoops the next day? Why or why not?
4. Why is it so important for airplanes to have pressurized cabins and oxygen masks?
5. Water boils at lower temperatures at higher elevations. Explain.

Before the Next Unit

Learners should read the Unit 2 text if they haven't already done so. They may wish to read one or more of the reading assignments from the list below, or, if you choose to have them use the course materials outside of class, they can watch the Unit 3 video and/or read the Unit 3 text as an assignment before the next session.

References and Additional Resources

Dhar, Deepak. "States of Matter." *Resonance*, 15.6 (2010): 514-525. Web. 1 July 2013.

NOVA. "Absolute Zero," NOVA. Accessed February 3, 2013. http://www.pbs.org/wgbh/nova/zero/

Phet Interactive Simulations. "States of Matter," University of Colorado at Boulder. Accessed February 3, 2013. http://phet.colorado.edu/en/simulation/states-of-matter

Lappert, Michael F. and John N. Murrell, "John Dalton, the Man and his Legacy: the Bicentenary of his Atomic Theory," *Dalton Transactions*, 2003, pp. 3811-3820. Accessed October 27, 2014. http://matematicas.udea.edu.co/~carlopez/daton_theory.pdf

For Professional Development

In addition to watching the videos, reading the text, and going through the activities listed in the course guide, participants taking this course for professional development should read the following papers and answer the corresponding reflection questions. Participants should then complete the accompanying professional development assignments.

Further Reading & Reflection Questions

Barker, Vanessa. "Beyond Appearances: Students' Misconceptions about Basic Chemical Ideas." A report prepared for the Royal Society of Chemistry. Accessed July 8, 2013. http://modeling.asu.edu/modeling/KindVanessaBarkerchem.pdf : 3-19.

1. How do you think children's views about matter may affect their ability to understand the states of matter as they move into high school chemistry?

2. In your teaching experience, have you encountered students who held any of these "naïve" views? Are there any that are more common than others? How have you addressed those views in the past?

3. How could you incorporate this author's "suggestions for progress" in how to teach the particulate nature of matter and phase changes? Do you foresee any difficulties in implementing any of her suggestions?

Milne, Catherine and Tracey Otieno. Understanding Engagement: Science Demonstrations and Emotional Energy. *Science Education* 2007. Accessed July, 13, 2013. DOI: 10.1002/sce https://steinhardt.nyu.edu/scmsAdmin/uploads/000/402/Milne%20%26%20Otieno.pdf

1. Do you think a student's perception of what chemistry is or who chemists are affects how engaged they are in learning chemistry content? If so, how? If not, why not?
2. Does this paper change the way you think about engagement and how to assess student engagement?
3. What do you think makes a science demonstration successful?
4. Does this study change the way you think about science demonstrations or influence how you will conduct science demonstrations in the future?

Professional Development Assignments

1. After reading the papers above and reflecting on the questions presented develop a lesson plan designed to teach material presented in this unit.

2. Using a group activity or classroom demonstration presented in this course guide, show how you would implement it into your classroom. Where would it fit into your curriculum or standards? Would you change the demonstration or activity in any way? How would you assess student learning?