Activity: Properties of Common Molecular Substances

FOR THE TEACHER

Summary
In this activity, students will apply their knowledge of molecular polarity, shape, and intermolecular forces to explain the differences in properties between different covalent substances.

Grade Level
High School

NGSS Alignment
This activity will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS1-1**: Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
- **HS-PS2-6**: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

- **Scientific and Engineering Practices**:
  - Developing and Using Models
  - Analyzing and Interpreting Data

AP Chemistry Curriculum Framework
This activity supports the following units, topics and learning objectives:

- **Unit 2: Molecular and Ionic Compound Structure and Properties**
  - **Topic 2.1**: Types of Chemical Bonds
    - **SAP-3.A**: Explain the relationship between the type of bonding and the properties of the elements participating in the bond.
  - **Topic 2.5**: Lewis Diagrams
    - **SAP-4.A**: Represent a molecule with a Lewis diagram.
  - **Topic 2.6**: Resonance and Formal Charge
    - **SAP-4.B**: Represent a molecule with a Lewis diagram that accounts for resonance between equivalent structures or that uses formal charge to select between nonequivalent structures.
  - **Topic 2.7**: VSEPR and Bond Hybridization
    - **SAP-4.C**: Based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities:
      - a. Explain structural properties of molecules.
      - b. Explain electron properties of molecules.

- **Unit 3: Intermolecular Forces and Properties**
  - **Topic 3.1**: Intermolecular Forces
    - **SAP-5.A**: Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when: a. The molecules are of the same chemical species. b. The molecules are of two different chemical species.
- **Topic 3.2:** Properties of Solids
  - **SAP-5.B:** Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.

- **Topic 3.10:** Solubility
  - **SPQ-3.C:** Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles.

**Objectives**

By the end of this activity, students should be able to

- Describe and understand a compound’s:
  - Name and chemical formula.
  - Intermolecular forces based on their structure and polarity.
  - Physical properties (i.e. melting/boiling point, solubility, and vapor pressure).

- Draw a Lewis Structure including all bonding and nonbonding electrons

- Determine the VSEPR shape with corresponding bond angle(s). NOTE: Do not have students identify shape name and bond angle for organic molecules.

- Analyze the dipole moments to determine overall molecular polarity.

- Contrast and compare the properties of two similar compounds based on their shape, polarity, and intermolecular forces.

**Chemistry Topics**

This activity supports students’ understanding of

- Molecules and Bonding
- Covalent Bonding
- Lewis Structures
- VSEPR Shapes
- Electronegativity
- Polarity
- Valence Electrons

**Time**

**Teacher Preparation:** 10 - 15 minutes

**Lesson:** 45 minutes (one class period)

**Materials**

- Student activity sheet
- Optional: modeling kits

**Safety**

- No specific safety precautions need to be observed for this project.

**Teacher Notes**

- This activity can be used to reinforce student understanding of the relationship between molecular structure and properties, or may serve as a summative assessment on the topic.
- A brief description of each substance has been given on the student activity sheet. You may choose to remove the description and have students conduct an online search of the common properties and uses of each.
- If you have molecular modeling kits available, and the time to use them, have the students build models of each molecule before identifying the shape, polarity, and intermolecular forces of
each. Students can also refer to the models when answering the questions asking them to compare and contrast the properties of similar molecules.

- An Answer Key document is available for teacher reference. All images of molecular models are open sourced images from Wikimedia.
FOR THE STUDENT
Lesson

Properties of Common Molecular Substances

Directions:
1. You may work individually or in a pairs to complete this activity.
2. The following table contains the name and common use of 10 common compounds.
3. For each of them fill in the empty columns: write the chemical formula, draw the Lewis Structure, draw and name the molecular shape using VSEPR theory and list all of the bond angels present in the molecule, identify all of the intermolecular forces (LD, DD, HB), and identify the molecule as polar (P) or nonpolar (NP).
4. When the table is complete, use the information to answer the follow-up questions.

<table>
<thead>
<tr>
<th>Ammonia</th>
<th>Carbon dioxide</th>
<th>Carbon tetrachloride</th>
<th>Chloroform</th>
<th>Hydrogen sulfide</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formula</td>
<td>Lewis Structure</td>
<td>Molecular Shape/Name/Bond Angels</td>
<td>IMFs</td>
<td>P/NP</td>
</tr>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

Ammonia is colorless gas that has a strong, suffocating odor. It is a common chemical compound that is used in fertilizers, and cleaners, and as a refrigerant.

Carbon dioxide is a gas at room temperature that is used during photosynthesis and is produced during hydrocarbon combustion, respiration, and fermentation.

Carbon tetrachloride is a colorless, sweet smelling liquid at room temperature. It is nonflammable and is commonly used in fire extinguishers.

Chloroform (trichloromethane) is a sweet-smelling, colorless liquid at room temperature. It is a strong anesthetic that was once referred to as the “knockout drug”.

Hydrogen sulfide is a colorless gas at room temperature. It has a foul odor similar to that of rotting eggs. It is produced in swamps, sewers, volcanos, and during digestion.
<table>
<thead>
<tr>
<th>Formula</th>
<th>Lewis Structure</th>
<th>Molecular Shape/Name/Bond Angels</th>
<th>IMFs</th>
<th>P/NP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isopropanol</strong> (2-Propanol) is a colorless, flammable liquid at room temperature. It is used in antiseptics and disinfectants, most commonly in hand sanitizers.</td>
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<tr>
<td><strong>Nitrogen trifluoride</strong>, is a colorless, odorless gas at room temperature. In addition to being used in microelectronics, it is considered to be a strong greenhouse gas.</td>
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<td><strong>Ozone</strong> is a colorless, unstable gas at room temperature. It is present in the Earth’s “ozone layer” and helps shield the earth from the sun’s ultraviolet radiation.</td>
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<td><strong>Propane</strong> is a gas a room temperature. It is commonly used in home grills because it readily vaporizes from liquid to gas as it leaves the tank, making it easy to combust.</td>
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<tr>
<td><strong>Water</strong> is a liquid at room temperature. It is thought that water is the only substance known to exist as a solid, liquid, and gas on the Earth’s surface.</td>
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</tbody>
</table>
Use the information from the table to answer the following questions about the properties of covalent substances. Be sure to include information about molecular shape, polarity, and intermolecular forces in your explanations.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which substance would you predict to have a greater vapor pressure and a lower boiling point, ozone or carbon dioxide?</td>
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<tr>
<td>Why water is a liquid at room temperature and hydrogen sulfide a gas even though they are very similar in structure?</td>
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<tr>
<td>Ammonia is 20 times more soluble than nitrogen trifluoride in water. Explain this using the information you gathered above.</td>
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<tr>
<td>Why is the boiling point of propane (-42°C) so much lower than that of isopropyl alcohol (86°C)?</td>
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<tr>
<td>Explain why chloroform has a higher solubility and lower vapor pressure than carbon tetrachloride.</td>
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</tbody>
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