Unit 3 – Bonding

Big Idea: The structure of an atom determines the types of bonds formed and interactions between molecules. The type of bonds and intermolecular attractions present in a substance influence the chemical and physical properties of the substance.

Lesson 1  Physical Properties of Compounds Inquiry Lab

Lesson 2  Bonding POGIL – types of bonds

Lesson 3  Bond Polarity and Electronegativity

Lesson 4  Lewis dot structures

Lesson 5  Molecule Shapes
  • Molecule Shapes PhET simulation
  • Molecules Shapes Lab activity with model kits

Lesson 6  Molecule Polarity PhET Simulation

Lesson 7  Intermolecular Attractions POGIL activity

Lesson 8  Physical Properties of Compounds Lab – Part 2
  Sugar and Salt Solutions PhET simulation

Lesson 9  Metallic Bonding
## Unit 3 – Bonding

**Big Idea:** The structure of an atom determines the types of bonds formed and interactions between molecules. The type of bonds and intermolecular attractions present in a substance influence the chemical and physical properties of the substance.

**Essential Questions:**

1. Why are metals used to make electrical wires? Why is plastic used to coat the electrical wires?
2. What happens when salt or sugar dissolve in water?
3. Why can you melt sugar but not salt?
4. Why can’t you mix oil and water?
5. Why is oxygen a gas at room temperature but water is a liquid?

**Colorado Academic Standard:**  
SC09-GR.HS-5.1-GLE4 Atoms bond in different ways to form molecules and compounds that have definite properties

**Evidence Outcomes:**

- a) Develop, communicate, and justify an evidence-based scientific explanation supporting the current models of chemical bonding.
- b) Gather, analyze, and interpret data on chemical and physical properties of different compounds such as density, melting point, boiling point, pH, and conductivity.
- c) Use characteristic physical and chemical properties to develop predictions and supporting claims about compounds’ classification as ionic, polar or covalent.
- d) Describe the role electrons play in atomic bonding.
- e) Predict the type of bonding that will occur among elements based on their position in the periodic table.

**NGSS:**  
**Structure and Properties of Matter**

**Performance Expectation:** PS-HS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

**Clarification Statement:** Emphasis is on understanding the strengths of forces between particles, and not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.

**Assessment Boundary:** Assessment does not include Raoult’s law calculations of vapor pressure.

**Disciplinary Core Ideas:**

**PS1.A: Structure and Properties of Matter**
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

**PS2.B: Types of Interactions**
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

**Science and Engineering Practices:**

**Planning and Carrying Out Investigations**
- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, measurement error, variability in the population, and randomization).
cost, risk, time), and refine the design accordingly.

**Crosscutting Concepts:**

**Patterns**
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

**Performance Expectation:** PS-HS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*

**Clarification Statement:** Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.

**Assessment Boundary:** Assessment is limited to provided molecular structures of specific designed materials.

**Disciplinary Core Ideas:**

**PS2.B: Types of Interactions**
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

**Science and Engineering Practices:**

**Obtaining, Evaluating, and Communicating Information**
- Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

**Crosscutting Concepts:**

**Structure and Function**
- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-PS2-6)

**Motion and Stability: Forces and Interactions**

**Performance Expectation:** HS-PS2-4 Use mathematical representations of Newton’s Law of Gravitation and Coulomb’s Law to describe and predict the gravitational and electrostatic forces between objects.

**Disciplinary Core Ideas:**

**PS2.B Types of Interactions**
- Newton’s law of universal gravitation and Coulomb’s law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.

**Science and Engineering Practices:**

**Using Mathematics and Computational Thinking**
- Use mathematical representations of phenomena to describe explanations.
**Crosscutting Concepts:**

*Patterns*
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

<table>
<thead>
<tr>
<th>Lesson Number</th>
<th>In Class Activity</th>
<th>Learning Objectives Students will be able to:</th>
<th>Homework</th>
</tr>
</thead>
</table>
| 1             | **Question of the day:** Do all compounds have the same physical properties? | - Experimentally determine physical properties of a compound such as melting point, solubility, and the conductivity of the aqueous solution.  
- Categorize compounds based on their physical properties, citing evidence to justify your categorization.  
- Compare and contrast the dissolving of salt and sugar. | Discussion section of laboratory report for Physical Properties of Compounds Inquiry lab.  
Writing/Modeling assignment: Rough draft – What is the difference between sugar and salt? |
| 2             | **Question of the day:** How do atoms stick together to form molecules? | - Describe ionic and covalent bonding, specifically referring to the role of valence electrons in bond formation.  
- Compare and contrast polar covalent and nonpolar covalent bonding. | Writing/Modeling assignment: Rough draft – What happens when sugar and salt dissolve in water? |
| 3             | **Question of the day:** What determines the type of bond that forms between two atoms? | - Determine the polarity of a bond between two atoms.  
- Use common conventions to signify the direction of polarity in a bond.  
- Explain what causes a bond to be ionic, polar covalent, or nonpolar covalent using the terms electronegativity and effective nuclear charge. | Bond Polarity Practice Sheet |
| 4             | **Question of the day:** How can we model sharing of electrons in covalent bonding? | - Determine the number of valence electrons that should be shown in a Lewis dot structure of covalent compound.  
- Draw the Lewis structure of a simple covalent molecule that contains a central atom. | Lewis Structures Practice Sheet |
| Lesson Number | In Class Activity | Learning Objectives
Students will be able to: | Homework |
|---------------|------------------|-----------------------------|-----------|
| 5             | **Question of the day:** How can we tell the shape of covalent molecules?  
**Activities:**  
- Molecule Shape PhET Simulation  
- Molecule Shape Lab using model kits |  
- Describe the factors that influence molecule shape using evidence from the simulation.  
- Explain why some molecules have different electron and molecule geometries.  
- Describe on molecule shape of the effect of lone electron pairs around the central atom.  
- Predict the molecule geometry, electron geometry, and bond angle of a covalent molecule based on its Lewis structure. | Molecule Shape Practice Sheet |
| 6             | **Question of the day:** What happens if a covalent molecule contains polar bonds?  
**Activities:**  
- Molecule Polarity PhET Simulation |  
- Predict the bond and molecular polarity for simple covalent molecules with a central atom.  
- Describe the factors that determine if a molecule is polar. | Molecule Polarity Practice Sheet  
Revise Writing/Modeling assignment – What happens when sugar and salt dissolve in water? |
| 7             | **Question of the day:** Why do we care what type of bond is present in molecule?  
**Activities:**  
- Intermolecular Attractions POGIL activity |  
- Describe the types of attractions that can form between molecules using what you know about Coulombic attraction.  
- Explain why some attractions between molecules are stronger than others.  
- Predict the type of intermolecular attraction that would form between two identical molecules.  
- Predict the type of intermolecular attraction that would form between two different molecules. | IMAF Practice Sheet |
| 8             | **Question of the day:** What is the relationship between intermolecular attractions and the physical properties of compounds?  
**Activities:**  
- Physical Properties of Compounds Lab – Part 2  
- Sugar and Salt Solutions PhET Simulation |  
- Explain the differences in physical properties of a compound (melting point, solubility, and the conductivity of the aqueous solution) based on the type of bond present in the compound.  
- Categorize compounds based on their physical properties, citing evidence to justify your categorization.  
- Compare and contrast the dissolving of salt and sugar, including a discussion of the intermolecular forces involved in the dissolving process. | Writing/Modeling activity: Rough draft to answer these questions:  
1) Why can you melt sugar but not salt?  
2) Why can’t you mix oil and water?  
3) Why is oxygen a gas at room temperature but water is a liquid? |
<table>
<thead>
<tr>
<th>Lesson Number</th>
<th>In Class Activity</th>
<th>Learning Objectives</th>
<th>Homework</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td><strong>Question of the day:</strong> What kinds of bonds exist in metals?</td>
<td>Students will be able to:</td>
<td>Writing/Modeling activity: Rough draft to answer these questions: 1) Why are metals used to make electrical wires? 2) Why is plastic used to coat the electrical wires?</td>
</tr>
</tbody>
</table>
|               | **Activities:** | - Describe how valence electrons are involved in metallic bonding.  
- Explain why metals are good conductors of heat and electricity but plastic is not. | |
|               | - Metallic bonding POGIL activity | | |
| 10            | **Assessment Day** | | RAFT assignment |
|               | **RAFT Assignment:** Address the following essential questions for this chapter to complete your RAFT assignment: | | Study for Unit 3 test. |
|               | - What happens when salt or sugar dissolve in water? | | |
|               | - Why does salt dissolve in water but oil does not? | | |
|               | - Why can you melt sugar but not salt? | | |
|               | - Why can’t you mix oil and water? | | |
|               | - Why is oxygen a gas at room temperature but water is a liquid? | | |
Clicker Questions for Molecule Shapes

AUTHORS:
Yuen-ying Carpenter (University of Colorado Boulder)
Robert Parson (University of Colorado Boulder)
Trish Loeblein (University of Colorado Boulder)

COURSE:
Introductory / Preparatory College Chemistry

COPYRIGHT: This work is licensed under a Creative Commons Attribution 4.0 International License.
What shape is water?

a. Tetrahedral
b. Bent
c. Trigonal planar
d. Linear
What is the *electron pair* geometry of NH$_3$?

a. Linear
b. Trigonal Planar
c. Tetrahedral
d. Trigonal Pyramidal

N has 4 groups around it; thus, it is a tetrahedral electron pair geometry.

\[
\text{H} - \text{N} - \text{H} \\
| \\
\text{H}
\]

Answer: C
Which of these molecules has a linear molecule geometry?

a. CO$_2$

b. O$_3$

c. Both

d. Neither
$O_3$ has 18 valence electrons:

The bonding in ozone is best represented as a blend of these two “resonance structures”.
Which molecule could be represented with this diagram?

a. BH$_3$

b. CH$_4$

c. NH$_3$
What is the molecular geometry of $\text{H}_2\text{S}$?

a. Linear
b. Tetrahedral
c. Trigonal pyramidal
d. Bent

Answer: D
What is the **molecule geometry** and **bond angle** for a molecule $AX_2$ which has 3 lone pairs on the central atom?

**A**  
**Bent**  
Bond angle $\approx 90^\circ$

**B**  
**Bent**  
Bond angle $\approx 120^\circ$

**C**  
**Linear**  
Bond angle $\approx 180^\circ$

*Explain your reasoning.*
In a system with 4 atoms and 1 lone pair, predict the position of the lone pair.

A. One of the A locations
B. One of the B locations

Explain your reasoning.
Which of these molecules would you expect to have *different bond angles in the real world* than are predicted by the model?

**A**

\[
\text{F} \quad \text{C} \quad \text{F}
\]

**B**

\[
\text{F} \quad \text{S} \quad \text{F}
\]

**C**

\[
\text{F} \quad \text{Xe} \quad \text{F}
\]

*Explain your reasoning.*
TITLE
Molecule Polarity

AUTHORS
Timothy Herzog (Weber State University)
Emily Moore (University of Colorado Boulder)

COURSE
General Chemistry I

TYPE
In-Class Guided-Inquiry Activity

TEACHING MODE
Facilitated Group Inquiry

LEARNING GOALS
Students will be able to:
• Explain the relationship between bond dipoles and molecule dipole.
• Accurately predict and explain the bond dipoles and molecule dipoles of simple, real molecules.

COPYRIGHT
This work is licensed under a Creative Commons Attribution 4.0 International License. This license allows users to share and adapt the materials, as long as appropriate attribution is given (with a link to the original), an indication if changes have been made, and an indication of the original licensing.
MOLECULE POLARITY

PART I: TWO ATOMS SCREEN

1. Explain all the ways you can change the polarity of the two-atom molecule.

2. Record your ideas in the table below.

<table>
<thead>
<tr>
<th>Representation</th>
<th>How does each change as electronegativity changes?</th>
<th>How does each help you understand the polarity of molecules?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond Dipole</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial Charges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrostatic Potential</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PART II: THREE ATOMS SCREEN

3. Explain any new ways to change the molecule polarity of the three-atom molecule.


5. Explain the relationship between the bond dipoles and the molecule dipole.

6. Can a non-polar molecule contain polar bonds? Use an example to explain your answer.

Commented [EM1]: This style of question encourages students to complete a full exploration of the sim and to articulate their findings, without having to give instructions for each interaction. The teacher could ask students to share out their list with the class.

Commented [TH2]: Part 1 and 2 are focus on students exploring the simulation. The instructor should allow for free exploration of the simulation in this section of the activity with minimal intervention with the student groups. A brief reporting out of student groups can occur after part 2 to make sure that all students understand the concepts.

Commented [EM3]: This is an example of a Concept Table. Here, students are prompted (with minimal wording) to explore the relationships between representations in the sim and the content topic. This question provides the opportunity to formalize interpretations of each representation, and to ensure students explore representations most relevant to the learning goals – without having to write out repetitive questions. Student responses can be reviewed by the teacher in class and discussed.

Commented [EM4]: This question prompts students to compare sim tabs. Tabs are used in sims to scaffold student learning, with 2nd and 3rd tabs providing access to different or increased conceptual challenges. This prompt asks students to determine what new complexity is being addressed that they can explore.

Commented [EM5]: Rather than telling students why and how to interact with the “ABC-bond angle change” feature, this question simultaneously asks students to find the feature, and relate what they learn from using the feature to the activity’s learning goals.

Commented [EM6]: Here, students are prompted to explain a key idea in the sim, and one of the learning goals. The teacher could lead a discussion around student responses.

Commented [EM7]: The sim provides the opportunity to explore a dynamic model to aid in constructing an answer to a particularly challenging component of the concept. The teacher could lead a discussion around student responses.
7. **Predict** the polarity of four real molecules in the simulation. Explain your reasoning before you check your predictions with the simulation.

<table>
<thead>
<tr>
<th>YOUR PREDICTION</th>
<th>CHECK Your Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draw Molecule - Include Bond Dipoles &amp; Molecule Dipole</td>
<td>Explain Your Reasoning: Correct? Explain any differences.</td>
</tr>
</tbody>
</table>

8. **Discuss** with your group the method(s) that you used to determine the bond dipoles and the molecule dipole. Write your method(s) in complete sentences below.

**Commented [TH8]:** This section models the scientific method. Encourage students to draw their prediction and explain their reasoning. Have students report some of their predictions and reasoning before they are tested. Later have students discuss some differences between prediction and experiment and provide explanations for the differences.

**Commented [TH9]:** Have a few groups share-out and write their methods on the board.
### EXERCISES

Determine the Molecule Geometry and Polarity of the following molecules.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{H} - \overset{\cdot}{\text{O}} - \text{H} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \overset{\cdot}{\text{C}} - \overset{\cdot}{\text{C}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \text{H} - \overset{\cdot}{\text{N}} - \text{H} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \text{Cl} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \text{H} - \overset{\cdot}{\text{C}} - \text{H} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \left[ \overset{\cdot}{\text{H}} \atop \overset{\cdot}{\text{H}} \right]^{+} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \left[ \overset{\cdot}{\text{S}} \overset{\cdot}{\text{F}} \overset{\cdot}{\text{F}} \overset{\cdot}{\text{F}} \right]^{-} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \left[ \overset{\cdot}{\text{S}} \overset{\cdot}{\text{F}} \overset{\cdot}{\text{F}} \overset{\cdot}{\text{F}} \right]^{-} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \overset{\cdot}{\text{O}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \text{Cl} \overset{\cdot}{\text{C}} \overset{\cdot}{\text{Cl}} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \overset{\cdot}{\text{O}} \overset{\cdot}{\text{C}} \overset{\cdot}{\text{H}} \overset{\cdot}{\text{C}} \overset{\cdot}{\text{H}} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Commented [EM10]: The following is a link to a complete VSEPR table.

[http://upload.wikimedia.org/wikipedia/commons/a/a9/VSEPR_geometries.PNG](http://upload.wikimedia.org/wikipedia/commons/a/a9/VSEPR_geometries.PNG)

In the interest of time, it may be best to have students use the table to complete the molecule geometry column here. This way students can focus their in-class time and discussion on molecule polarity.

Completing the molecule geometry column with the link does still give an opportunity to practice VSEPR so it is a valuable exercise.
**CHALLENGE PROBLEMS:**

For each molecule below: Determine the Lewis structure and molecule geometry. Draw the molecule using wedges to show three-dimensionality. Finally, determine if the molecule is polar. If so, draw an arrow to show the molecule dipole.

1. CHO₂⁻¹

2. PF₃

3. AlCl₃

4. CHBr₃

5. H₂S

6. SiCl₄

7. HCCBr

8. CH₂CHCH₂

9. BrF₄⁺ (Br is central atom and has 10e⁻ in its valance shell)
MOLECULE POLARITY

PART I: TWO ATOMS SCREEN

1. Explain all the ways you can change the polarity of the two-atom molecule.

2. Record your ideas in the table below.

<table>
<thead>
<tr>
<th>Representation</th>
<th>How does each change as electronegativity changes?</th>
<th>How does each help you understand the polarity of molecules?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond Dipole</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial Charges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrostatic Potential</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PART II: THREE ATOMS SCREEN

3. Explain any new ways to change the molecule polarity of the three-atom molecule.


5. Explain the relationship between the bond dipoles and the molecule dipole.

6. Can a non-polar molecule contain polar bonds? Use an example to explain your answer.
PART III: REAL MOLECULES SCREEN

7. **Predict** the polarity of four real molecules in the simulation. Explain your reasoning before you check your predictions with the simulation.

<table>
<thead>
<tr>
<th>YOUR PREDICTION</th>
<th>CHECK Your Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draw Molecule - Include Bond Dipoles &amp; Molecule Dipole</td>
<td>Explain Your Reasoning:</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. Discuss with your group the method(s) that you used to determine the bond dipoles and the molecule dipole. Write your method(s) in complete sentences below.
## EXERCISES
Determine the Molecule Geometry and Polarity of the following molecules.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H−O−H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O=C=O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H−N−H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H−C−H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHALLENGE PROBLEMS:
For each molecule below: Determine the Lewis structure and molecule geometry. Draw the molecule using wedges to show three-dimensionality. Finally, determine if the molecule is polar. If so, draw an arrow to show the molecule dipole.

1. CHO₂⁻¹

2. PF₃

3. AlCl₃

4. CHBr₃

5. H₂S

6. SiCl₄

7. HCCBr

8. CH₂CHCHCH₂

9. BrF₄⁺ (Br is central atom and has 10e⁻ in its valance shell)
Molecule Shapes

Learning Goals: Students will be able to:

• Identify substances to which “Molecular geometry” applies.

• Name molecule and electron geometries for basic molecules.

• Explain the model being used to predict molecule geometry.

• Predict common molecular geometry from the number of electron pairs and bonded atoms around a central atom of basic compounds.

by Trish Loeblein updated October 2011
1. Which is a molecule?
   A. $\text{CO}_2$
   B. $\text{CaCl}_2$
   C. $\text{NH}_4\text{Cl}$
   D. $\text{Li}_2\text{SO}_4$
2. Which would have a linear shape?

A. HBr
B. CO₂
C. Both are linear
3. Which has only single bonds?

A. HBr
B. CO$_2$
C. Both have all single bonds
4. What shape is water?

A. Tetrahedral
B. Bent
C. Trigonal planar
D. Linear
5. Which is an example of an exception to the octet rule?

A. $\text{O}_2$
B. $\text{N}_2$
C. $\text{BF}_3$
D. $\text{I}_2$
E. More than one of these
5ans. Which is an example of an exception to the octet rule?

A. $\text{O}_2$
B. $\text{N}_2$
C. $\text{BF}_3$
D. $\text{I}_2$
E. More than one of these
6. Which molecule could be represented with this diagram?

A. BH$_3$
B. CH$_4$
C. NH$_3$

6b. What would the structural formula look like?
7. Which molecule could be represented with this diagram?
   A. HCl
   B. CH₄
   C. NH₃
   D. F₂

7b. What would the structural formula look like?
Clicker Questions for Molecule Polarity

AUTHORS
Trish Loeblein (University of Colorado Boulder)
Robert Parson (University of Colorado Boulder)

COURSE
Introductory / Preparatory College Chemistry

COPYRIGHT: This work is licensed under a Creative Commons Attribution 4.0 International License.
Which is the best description for this bond?

a. nonpolar covalent
b. polar covalent

Red Box:
c. Ionic
The molecule shown would be described as:

a. polar bonds, nonpolar molecule
b. nonpolar bonds, nonpolar molecule
c. polar bonds, polar molecule
d. nonpolar bonds, polar molecule
The molecule shown would be described with

a. polar bonds, nonpolar molecule
b. nonpolar bonds, nonpolar molecule
c. polar bonds, polar molecule
d. nonpolar bonds, polar molecule
How would you describe the trigonal planar molecule BF$_3$?

a. polar bonds, nonpolar molecule  
b. nonpolar bonds, nonpolar molecule  
c. polar bonds, polar molecule  
d. nonpolar bonds, polar molecule
How would you describe the trigonal pyramidal molecule NH$_3$?

a. polar bonds, nonpolar molecule
b. nonpolar bonds, nonpolar molecule
c. polar bonds, polar molecule
d. nonpolar bonds, polar molecule
Which of the following molecules are polar?

a. CF$_4$

b. CH$_3$F

c. CH$_2$F$_2$

d. Both (a) and (b)

d. Both (b) and (c)
TITLE
Molecule Shapes

AUTHORS
Timothy Herzog (Weber State University)
Emily Moore (University of Colorado Boulder)

COURSE
General Chemistry I

TYPE
In-Class Guided-Inquiry Activity

TEACHING MODE
Facilitated Group Inquiry

LEARNING GOALS
Students will be able to:
• Determine electron geometry and molecule geometry for molecules using VSEPR theory.
• Explain the role that nonbonding electron pairs play in determining molecule geometry.
• Predict bond angles in covalent molecules as well as deviations from idealized bond angles.

COPYRIGHT
This work is licensed under a Creative Commons Attribution 4.0 International License.
This license allows users to share and adapt the materials, as long as appropriate attribution is given (with a link to the original), an indication if changes have been made, and an indication of the original licensing.
MOLECULAR SHAPES

Molecule Shapes

MODEL 1:

Molecule Shapes Simulation
(http://phet.colorado.edu/en/simulation/molecule-shapes)

PART I: ELECTRON DOMAINS

1. Explore the Model screen of the simulation. As you explore, answer the following questions.
   a. How does adding an atom affect the position of existing atoms or lone pairs?
   b. How does adding a lone pair affect the position of existing atoms and lone pairs?

2. Is the effect of adding bonded atoms and lone pairs to the central atom similar? Explain why this could be the case.

   We can think of a bond or a lone pair of electrons as a “domain” of electrons. Single bonds, double bonds, and triple bonds each count as one domain.

3. How do the electrons in bonds (bonding domains) differ from lone pairs (non-bonding domains)?

4. What happens to the bond angle when you add or remove an electron domain?

5. Can you force the atoms into new configurations by pushing atoms around? What does this suggest about the configuration of atoms in real molecules?

6. What is the difference between Electron Geometry and Molecule Geometry?

7. In one or two grammatically correct sentences, write a definition for the term Molecule Geometry.

Comment [1]: Learning Goals:
Students will be able to:
• Determine electron geometry and molecule geometry for molecules using VSEPR theory.
• Explain the role that nonbonding electron pairs play in determining molecule geometry.
• Predict bond angles in covalent molecules as well as deviations from idealized bond angles.

Comment [2]: Give students time to explore the simulation and then answer questions 1-7 in small groups. When most of the groups have completed question 7, have groups report answers. 1 and 2 will likely be quick, but questions 3-7 should take more time.
PART 2: DRAWING MOLECULES TO SHOW 3-DIMENSIONALITY

MODEL 2:

Line, Wedge and Dash Drawings

- Line: In the plane of the paper: ——
- Wedge: Coming forward, in front of the plane of the paper: ——
- Dash: Going backward, behind the plane of the paper: ———

8. Where is each of the 5 atoms in the molecule CHFClBr?
   - In the plane of the paper ______ ______ ______
   - In front of the plane of the paper ______
   - Behind the plane of the paper ______

9. Using the Model screen, add bonding domains (●) to the central atom (○). Using lines, wedges and dashes from Model 2, draw each molecule’s shape.

<table>
<thead>
<tr>
<th>Bonding Domains Around Central Atom</th>
<th>Drawing of Shape</th>
<th>Electron Geometry</th>
<th>Bond Angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>● — ○ — ●</td>
<td>Linear</td>
<td>180º</td>
</tr>
<tr>
<td>3</td>
<td>○</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>○</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>○</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>○</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comment [3]: It is important to help students validate their answers to question 9. Since it is more visual, this is a great place to borrow a student’s paper and show it on a document camera. Get feedback from the rest of the groups to see if they agree with the answers.
10. In the Model screen, build a molecule with 5 atoms attached to the central atom. Look at the molecule geometry and electron geometry. **Predict** what will happen to the molecule geometry as you replace atoms with lone pairs.

<table>
<thead>
<tr>
<th>Your Prediction:</th>
</tr>
</thead>
</table>

11. In the following table draw the **molecule geometry**. As a group, make a **prediction for each first**, and then compare your answers with the simulation.

<table>
<thead>
<tr>
<th>Number of Domains Around Central Atom</th>
<th>1 Lone Pair</th>
<th>2 Lone Pairs</th>
<th>3 Lone Pairs</th>
<th>4 Lone Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Comment [4]:** Question 10-11 provide an opportunity to model the scientific method. Have students write their predictions on the board before they do any experiments. After they have had a chance to complete the table in question 11, have students share their answers with a document camera or on the board. If necessary, model some correct structures, but it is best if students get coaching to come up with the structures themselves.
PART 3: COMPARING MODEL VS. REAL MOLECULES

12. Explore the Real Molecules screen.
   c. List the molecules that show a **difference in bond angle** between "Real" and "Model".
      Note: differences in bond angle may be small.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Number of Lone Pair Domains</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   d. What do all of the molecules in the table have in common?

   e. What trend do you observe that distinguishes lone pairs from bonding domains?

13. Use the simulation to build a system with 5 domains. This is called a trigonal bipyramidal structure. The two different sites in a trigonal bipyramid are labeled as A and B in the drawing to the right.

   f. Each A atom is adjacent to 3 B atoms. What is the A-C-B bond angle?

   g. Each B atom is adjacent to 2 A atoms and 2 B atoms. What is the B-C-B bond angle.

   h. In a system with 4 atoms and 1 lone pair, predict whether the lone pair will be in a B site or an A site? Explain.

   i. Examine the molecule SF₄ in the Real Molecules screen to check your prediction from question c. Which interactions are more important in determining where the lone pair will go?
EXERCISES:

1. A molecule has 2 double bonds on the central atom and no lone pairs. Predict the electron geometry. Predict the molecule geometry. What do you think the bond angles would be?

2. For each of the molecules below, determine the electron geometry, molecule geometry, and bond angles. Draw pictures to show your geometries.
   a. CCl₄ (4 Cl atoms, no lone pairs on C)
   b. PF₃ (3 F atoms, 1 lone pair on P)
   c. OF₂ (2 F atoms, 2 lone pairs on O)
   d. I₂⁻ (2 I atoms and 3 lone pairs on central I)

3. Use any resources required to add names to all the geometries in the table on page 3.

CHALLENGE QUESTION:
Imagine a molecule with 7 electron domains.

The geometry is called pentagonal bipyramidal. This has a lot of similarities to a 6-coordinate molecule except there are 5 domains in one plane. Predict the following based on this information:

a. Draw the structure of a molecule with 7 bonding domains.

b. List all the bond angles possible between adjacent atoms.

c. Predict the electron and molecule geometry for a molecule with 6 bonding domains and a single lone pair.

d. Predict the electron and molecule geometry for a molecule with 5 bonding domains and two lone pairs.
Molecule Shapes

MODEL 1:

Molecule Shapes Simulation
(http://phet.colorado.edu/en/simulation/molecule-shapes)

PART I: ELECTRON DOMAINS

1. Explore the Model screen of the simulation. As you explore, answer the following questions.
   a. How does adding an atom affect the position of existing atoms or lone pairs?
   b. How does adding a lone pair affect the position of existing atoms and lone pairs?

2. Is the effect of adding bonded atoms and lone pairs to the central atom similar? Explain why this could be the case.

   We can think of a bond or a lone pair of electrons as a “domain” of electrons. Single bonds, double bonds, and triple bonds each count as one domain.

3. How do the electrons in bonds (bonding domains) differ from lone pairs (non-bonding domains)?

4. What happens to the bond angle when you add or remove an electron domain?

5. Can you force the atoms into new configurations by pushing atoms around? What does this suggest about the configuration of atoms in real molecules?

6. What is the difference between Electron Geometry and Molecule Geometry?

7. In one or two grammatically correct sentences, write a definition for the term Molecule Geometry.
PART 2: DRAWING MOLECULES TO SHOW 3-DIMENSIONALITY

MODEL 2:

Line, Wedge and Dash Drawings

Line: In the plane of the paper: 

Wedge: Coming forward, in front of the plane of the paper: 

Dash: Going backward, behind the plane of the paper: 

8. Where is each of the 5 atoms in the molecule CHFClBr?
   In the plane of the paper ______ ______ ______
   In front of the plane of the paper ______
   Behind the plane of the paper ______

9. Using the Model screen, add bonding domains ● to the central atom ○. Using lines, wedges and dashes from Model 2, draw each molecule’s shape.

<table>
<thead>
<tr>
<th>Bonding Domains Around Central Atom</th>
<th>Drawing of Shape</th>
<th>Electron Geometry</th>
<th>Bond Angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>● — ○ — ●</td>
<td>Linear</td>
<td>180°</td>
</tr>
<tr>
<td>3</td>
<td>○</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>○</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>○</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>○</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10. In the *Model* screen, build a molecule with 5 atoms attached to the central atom. Look at the molecule geometry and electron geometry. **Predict** what will happen to the molecule geometry as you replace atoms with lone pairs.

Your Prediction:

11. In the following table draw the **molecule geometry**. As a group, make a **prediction for each** first, and then compare your answers with the simulation.

<table>
<thead>
<tr>
<th>Number of Domains Around Central Atom</th>
<th>1 Lone Pair</th>
<th>2 Lone Pairs</th>
<th>3 Lone Pairs</th>
<th>4 Lone Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**PART 3: COMPARING MODEL VS. REAL MOLECULES**

12. Explore the *Real Molecules* screen.
   c. List the molecules that show a **difference in bond angle** between “Real” and “Model”.
      Note: differences in bond angle may be small.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Number of Lone Pair Domains</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   d. What do all of the molecules in the table have in common?

   e. What trend do you observe that distinguishes lone pairs from bonding domains?

13. Use the simulation to build a system with 5 domains. This is called a trigonal bipyramidal structure. The two different sites in a trigonal bipyramid are labeled as A and B in the drawing to the right.

   ![Trigonal Bipyramidal Structure Diagram]

   f. Each A atom is adjacent to 3 B atoms. What is the A-C-B bond angle?

   g. Each B atom is adjacent to 2 A atoms and 2 B atoms. What is the B-C-B bond angle.

   h. In a system with 4 atoms and 1 lone pair, predict whether the lone pair will be in a B site or an A site? Explain.

   i. Examine the molecule SF$_4$ in the Real Molecules screen to check your prediction from question c. Which interactions are more important in determining where the lone pair will go?
EXERCISES:

1. A molecule has 2 double bonds on the central atom and no lone pairs. Predict the electron geometry. Predict the molecule geometry. What do you think the bond angles would be?

2. For each of the molecules below, determine the electron geometry, molecule geometry, and bond angles. Draw pictures to show your geometries.
   a. CCl₄ (4 Cl atoms, no lone pairs on C)
   b. PF₃ (3 F atoms, 1 lone pair on P)
   c. OF₂ (2 F atoms, 2 lone pairs on O)
   d. I₃⁻ (2 I atoms and 3 lone pairs on central I)

3. Use any resources required to add names to all the geometries in the table on page 3.

**Challenge Question:**
Imagine a molecule with 7 electron domains.

The geometry is called pentagonal bipyramidal. This has a lot of similarities to a 6-coordinate molecule except there are 5 domains in one plane. Predict the following based on this information:

a. Draw the structure of a molecule with 7 bonding domains.

b. List all the bond angles possible between adjacent atoms.

c. Predict the electron and molecule geometry for a molecule with 6 bonding domains and a single lone pair.

d. Predict the electron and molecule geometry for a molecule with 5 bonding domains and two lone pairs.