Unit 2: Atomic Structure and Bonding

Chapter 7: Covalent Bonding

# Lesson 3: VSEPR Theory and Molecular Geometry

# 1. Big Idea:

**Molecules have specific shapes, and VSEPR theory helps to predict these shapes based on the repulsion between electron pairs.**

# 2. Essential Questions

This section encourages curiosity and critical thinking by asking the following essential question:

- **How does VSEPR theory help us predict the shapes of molecules?**

- Answer: VSEPR (Valence Shell Electron Pair Repulsion) theory predicts the shape of molecules by considering how electron pairs around a central atom repel each other. These electron pairs arrange themselves to minimize repulsion, which leads to predictable molecular shapes.

# 3. Phenomenon-Based Learning

**Phenomenon**:

In northern countries, road salt is used to melt ice and snow on streets during winter. Water, in its liquid form, can dissolve salt, but in solid form (ice), it cannot. Although water looks different as a liquid and as a solid, it is still the same substance. This leads us to question whether the shape of the water molecule changes and how we can predict the shape of molecules in general.

**Phenomenon Connection**:

The phenomenon highlights the importance of understanding molecular shapes. The shape of water molecules plays a role in their behavior as a solid (ice) and as a liquid. Using VSEPR theory, we can understand how the shape of water molecules influences their properties and interactions with other substances, like salt.

# 4. Vocabulary

Define these key terms to support understanding:

1. **Bent**: A molecular shape where the bond angles between atoms are less than 180°, typically formed when there are lone pairs on the central atom.

2. **Electron Geometry**: The arrangement of electron pairs (bonding and non-bonding) around a central atom.

3. **Linear**: A molecular shape where atoms are arranged in a straight line with a bond angle of 180°.

4. **Molecular Geometry**: The 3D arrangement of atoms in a molecule, determined by the number of bonds and lone pairs around the central atom.

5. **Tetrahedral**: A molecular shape where four atoms are symmetrically arranged around a central atom with bond angles of 109.5°.

6. **Trigonal Pyramidal**: A molecular shape where three atoms are arranged around a central atom with one lone pair, forming a pyramid-like shape.

7. **Trigonal Planar**: A molecular shape where three atoms are arranged around a central atom in a flat, triangular shape with bond angles of 120°.

# 5. SMART Objectives

By the end of this lesson, students will be able to:

1. **Draw Lewis structures** for covalent molecules, accurately representing bonding pairs and lone pairs.

2. **Predict the shape of a molecule** using the VSEPR theory by counting electron pairs around the central atom.

3. **Analyze how the shape of a molecule** affects its properties, such as boiling point, solubility, and reactivity.

# 6. Engage (Ignite)

**Phenomenon-Related Question**:

"Why does road salt melt ice but not metal street signs during winter? How might the shape of water molecules play a role in this?"

**Hands-On Experiment**:

**Activity**: Investigating Molecular Models with VSEPR

**Materials**: Marshmallows (representing atoms), toothpicks (representing bonds), and small candy (representing lone pairs).

**Procedure**:

1. **Step 1**: Build a water molecule (H₂O) using marshmallows and toothpicks. Use small candies to represent lone pairs on the oxygen atom.

2. **Step 2**: Build models of different molecules: methane (CH₄), ammonia (NH₃), and carbon dioxide (CO₂).

3. **Step 3**: Observe and compare the shapes of the molecules. Discuss how the lone pairs affect the shape.

**Follow-Up Questions**:

1. How do lone pairs of electrons affect the shape of the water molecule?

2. What is the difference between the shape of carbon dioxide and methane?

3. How might the shape of a molecule affect its ability to dissolve in water?

### 7**. Pre-Explore (Direct Instruction)**

**Background Information**:

Atoms in a molecule arrange themselves in a way that minimizes repulsion between their electron pairs. This is the foundation of VSEPR theory. Electron pairs, both bonding and lone pairs, repel each other and arrange themselves as far apart as possible around the central atom. This creates predictable shapes for molecules.

**Interactive Discussion**:

- **Note**: VSEPR stands for **Valence Shell Electron Pair Repulsion**. This theory is used to predict the 3D shape of molecules.

- **Scaffolded Question**: How do electron pairs "repel" each other? Have you ever tried pushing two magnets together? What happens?

### 8. Evaluate (Progress Check) - Pre-Explore

**Scaffolded Questions**:

1. **DOK 1**: What does VSEPR theory stand for?

2. **DOK 2**: Why do lone pairs affect the shape of a molecule more than bonding pairs?

3. **DOK 3**: How does the shape of the water molecule differ from that of carbon dioxide, and why?

# 9. Explain (Lightbulb)

Now, let’s dive deeper into the **VSEPR Theory** and how it helps us predict molecular shapes.

### The Basics of VSEPR Theory

VSEPR theory is all about how electrons around atoms "push" each other. Electrons are negatively charged, and like charges repel each other. In a molecule, the electrons want to be as far from each other as possible. These electrons can be involved in bonds between atoms, or they might sit as lone pairs (non-bonding electrons) on an atom.

- **Bonding Pairs**: Electrons shared between atoms to form a bond.

- **Lone Pairs**: Electrons that are not involved in bonding but still occupy space around the atom.

The shape of a molecule depends on the number of bonding pairs and lone pairs around the central atom.

### Lewis Structures and VSEPR Theory

Before we can predict the shape of a molecule, we need to understand how to **draw Lewis structures**. Lewis structures show the arrangement of electrons in a molecule, including bonding pairs and lone pairs.

**Steps to Drawing Lewis Structures**:

1. **Determine the total number of valence electrons** in the molecule.

2. **Arrange the atoms** with the least electronegative atom in the center (usually).

3. **Distribute the electrons** to form bonds between atoms.

4. **Place remaining electrons** as lone pairs on the atoms, starting with the outer atoms.

5. **Check octets**: Make sure each atom has a full outer shell (usually 8 electrons, except for hydrogen, which needs 2).

**Example 1**: Water (H₂O)

1. **Step 1**: Count valence electrons.

Oxygen has 6, and each hydrogen has 1, so there are 8 electrons total.

2. **Step 2**: Oxygen is the central atom, and hydrogens are attached on either side.

3. **Step 3**: Use 2 electrons for each bond (O-H).

4. **Step 4**: Place lone pairs on oxygen. Oxygen will have 2 lone pairs.

The Lewis structure looks like this:

H - O (with two lone pairs on oxygen) - H

Now let's use VSEPR theory to predict the shape.

### Predicting Shapes with VSEPR Theory

Using the Lewis structure, we can predict the shape of the molecule by counting the number of bonding pairs and lone pairs around the central atom.

1. **Water (H₂O)**:

- 2 bonding pairs (O-H bonds)

- 2 lone pairs on oxygen

The electron pairs repel each other, leading to a **bent** shape. The bond angle is about 104.5°, which is less than 109.5° due to the repulsion from the lone pairs.

2. **Methane (CH₄)**:

- 4 bonding pairs (C-H bonds)

No lone pairs on carbon. The electron pairs arrange themselves symmetrically, leading to a **tetrahedral** shape with bond angles of 109.5°.

3. **Ammonia (NH₃)**:

- 3 bonding pairs (N-H bonds)

- 1 lone pair on nitrogen

The lone pair pushes the bonding pairs, creating a **trigonal pyramidal** shape with bond angles less than 109.5°.

4. **Carbon Dioxide (CO₂)**:

- 2 bonding pairs (C=O bonds)

No lone pairs on carbon. The bonding pairs are opposite each other, resulting in a **linear** shape with a bond angle of 180°.

### How Does Shape Affect Properties?

The shape of a molecule can affect its physical and chemical properties, including:

- **Polarity**: Molecules with asymmetrical shapes, like water, tend to be polar, which means they have a positive and negative end. This affects how they interact with other substances. For example, water’s bent shape makes it polar, which helps it dissolve salts.

- **Boiling and Melting Points**: Molecules with strong intermolecular forces (like hydrogen bonding in water) have higher boiling and melting points. The shape determines how molecules interact with each other.

- **Solubility**: Polar molecules, like water, are good at dissolving other polar substances (like salt). Nonpolar molecules, like oil, do not dissolve well in water.

**Sample Problem**:

**Question**: Draw the Lewis structure for ammonia (NH₃) and predict its molecular shape using VSEPR theory.

**Solution**:

1. Nitrogen has 5 valence electrons, and each hydrogen has 1, so there are 8 electrons total.

2. Nitrogen is the central atom with 3 hydrogen atoms attached.

3. Use 2 electrons for each N-H bond.

4. Place the remaining 2 electrons as a lone pair on the nitrogen atom.

5. The shape is **trigonal pyramidal** because of the lone pair on nitrogen.

### Progress Check Question:

**Question**: Draw the Lewis structure for carbon dioxide (CO₂) and predict its molecular shape.

# 10. Evaluate (Progress Check)

### Scaffolded Questions (DOK Levels 1-3)

1. **DOK 1: Recall**

Question: What is the definition of a chemical reaction?

Answer: A chemical reaction is a process where substances (reactants) change into new substances (products) with different chemical properties.

2. **DOK 2: Conceptual Understanding**

Question: How can you tell that a chemical reaction has occurred based on observable evidence?

Answer: You can tell that a chemical reaction has occurred if you observe signs like a change in color, temperature, the formation of a gas, or the formation of a precipitate (solid).

3. **DOK 3: Strategic Thinking**

Question: Predict what would happen if you mixed baking soda and vinegar. Explain why this reaction occurs.

Answer: When baking soda (a base) is mixed with vinegar (an acid), a chemical reaction occurs that produces carbon dioxide gas, causing bubbling or fizzing. This reaction happens because acids and bases neutralize each other, releasing gas as a byproduct.

# 11. Elaborate (Power Up)

### Mini-tasks and Open-ended Questions (DOK Levels 2-3)

1. **Mini-task (DOK 2):**

Task: Create a chart showing at least three different types of chemical reactions and give an example of each.

Answer:

**1. Synthesis Reaction:** Two or more substances combine to form one product (e.g., \( 2H\_2 + O\_2 \rightarrow 2H\_2O \)).

**2. Decomposition Reaction:** A single compound breaks down into two or more simpler substances (e.g., \( 2H\_2O \rightarrow 2H\_2 + O\_2 \)).

**3. Combustion Reaction:** A substance combines with oxygen, releasing energy in the form of heat and light (e.g., \( CH\_4 + 2O\_2 \rightarrow CO\_2 + 2H\_2O \)).

2. **Open-ended Question (DOK 3):**

**Question:** How might understanding different types of chemical reactions help in real-world applications like cooking or medicine?

Answer: Understanding chemical reactions allows us to control and predict how substances will behave. In cooking, for example, knowing how ingredients react can help improve recipes. In medicine, understanding chemical reactions is vital for creating drugs that react properly in the body to treat diseases.

# 12. Final Evaluation

### Debate Question (DOK 3)

Debate Question: Should the production of synthetic chemicals be limited due to environmental concerns?

Arguments For:

- Synthetic chemicals can have harmful environmental impacts, such as pollution and damage to ecosystems.

- Limiting production could encourage the development of greener, more sustainable alternatives.

Arguments Against:

- Synthetic chemicals are essential for many industries, including medicine and agriculture.

- With proper regulation and disposal, their negative impact can be minimized.

### Assessment Questions

### Multiple-Choice Questions (DOK 1-2)

1. **Question:** Which of the following is a sign of a chemical reaction?

a) Change in state

b) Formation of a gas

c) Melting of ice

d) Dissolving sugar in water

Correct Answer: b) Formation of a gas

Explanation: The formation of a gas during a reaction (like bubbles) indicates a chemical change, not just a physical change like melting or dissolving.

2. **Question:** What type of chemical reaction occurs when two elements combine to form a compound?

a) Decomposition

b) Synthesis

c) Combustion

d) Single displacement

Correct Answer: b) Synthesis

Explanation: In a synthesis reaction, two or more substances combine to form a single compound.

3. **Question:** Which of the following is FALSE about chemical reactions?

a) They always produce new substances.

b) They can absorb or release energy.

c) They can be reversed easily like physical changes.

d) They involve changes in the arrangement of atoms.

Correct Answer: c) They can be reversed easily like physical changes.

Explanation: Chemical reactions are not easily reversible compared to physical changes, which often can be reversed.

4. **Question:** When hydrogen and oxygen react to form water, what type of reaction is this?

a) Combustion

b) Synthesis

c) Decomposition

d) Double displacement

Correct Answer: b) Synthesis

Explanation: Hydrogen and oxygen combine to form water, which is an example of a synthesis reaction.

### Long-answer Questions (DOK 3-4)

1. **Question:** Explain the difference between an endothermic and exothermic reaction. Provide an example of each.

Answer: In an endothermic reaction, energy is absorbed from the surroundings, causing the surroundings to cool down (e.g., photosynthesis). In an exothermic reaction, energy is released into the surroundings, usually in the form of heat or light (e.g., combustion of wood).

2. **Question:** How does the Law of Conservation of Mass apply to chemical reactions?

Answer: The Law of Conservation of Mass states that mass cannot be created or destroyed in a chemical reaction. This means that the total mass of the reactants must equal the total mass of the products. For example, if you start with 10 grams of reactants, you must end with 10 grams of products, even if they are in different forms.

3. **Question:** Describe how catalysts affect the rate of a chemical reaction.

Answer: Catalysts increase the rate of a chemical reaction by lowering the activation energy needed for the reaction to occur. They do not get used up in the reaction, which means they can be used repeatedly. For example, enzymes in the human body act as catalysts to speed up vital biological reactions.

4. **Question:** A student mixes two chemicals, and the temperature of the solution decreases. What type of reaction is this, and why does the temperature drop?

Answer: This is an endothermic reaction. The temperature drops because the reaction absorbs heat from the surroundings, causing the solution to become cooler.

# 13. Extend (Beyond the Lesson)

### Additional Tasks and Readings

1. **Task:** Research how chemical reactions are used in everyday products, such as baking soda in toothpaste or antacids. Write a short report explaining how the reaction helps the product work.

2. **Reading:** Read about how scientists use chemical reactions to create medicines. Focus on how reactions are controlled to make sure they are safe and effective.

3. **Challenge:** Design an experiment to test the factors that affect the rate of a chemical reaction, such as temperature or concentration. Record your observations and explain your findings using the concepts learned in this unit.

4. **Spaced Practice Activity:** Over the next few weeks, revisit the types of chemical reactions and practice identifying them in different situations (e.g., cooking, cleaning, or in nature). Keep a journal where you note examples of synthesis, decomposition, and combustion reactions you observe.

These activities are designed to help you apply your knowledge of chemical reactions to real-world situations and reinforce your learning over time.