Unit 2: Atomic Structure and Bonding

## Chapter 7: Covalent Bonding

# Lesson 4: Electronegativity, Polarity, and Intermolecular Forces

# 1. Big Idea

- **Big Idea**: Differences in electronegativity between atoms determine the polarity of molecules, which in turn affects the strength of intermolecular forces.

# 2. Essential Questions

- **How do differences in electronegativity lead to molecular polarity and affect intermolecular forces?**

### Answer:

Electronegativity is a measure of how strongly an atom attracts electrons in a bond. When two atoms bond, the difference in their electronegativities will determine how evenly or unevenly the electron pair is shared. If the difference is large, the bond will be polar, meaning the electrons are pulled more toward one atom, creating a dipole (a molecule with a positive end and a negative end). These dipoles can interact with each other, resulting in intermolecular forces like dipole-dipole interactions, hydrogen bonds, or London dispersion forces. These forces affect properties like boiling point, melting point, and solubility.

# 3. Phenomenon-Based Learning

### Phenomenon:

In northern countries, people spread road salt on icy streets to help melt the ice and snow. As the salt touches the ice, the ice begins to melt. However, metal street signs and lampposts, which are also exposed to the ice and snow, remain solid and do not melt. Why does road salt affect ice but not metals? Is water the same in its liquid and solid form?

This leads us to explore **why water behaves so differently** compared to other substances. How does the structure of water, its polarity, and its intermolecular forces explain its unique behavior? How can we predict the shape and polarity of molecules, and how do these factors influence the behavior of other molecules?

### Connection to Lesson:

Water is unique due to its molecular shape and polarity. The polarity of water molecules leads to strong hydrogen bonds between water molecules, which explains why water has such high melting and boiling points. Understanding how electronegativity differences lead to polarity will help explain why substances like road salt dissolve in water but not in non-polar substances.

# 4. Vocabulary

1. **Boiling point** – The temperature at which a liquid turns into a gas.

2. **Dipole-dipole forces** – Attractive forces between polar molecules where the positive end of one molecule is attracted to the negative end of another.

3. **Dipole moment** – A measure of the separation of positive and negative charges in a molecule.

4. **Hydrogen bonding** – A strong type of dipole-dipole interaction that occurs when hydrogen is bonded to nitrogen, oxygen, or fluorine.

5. **Intermolecular forces** – Forces of attraction or repulsion between neighboring molecules.

6. **London-dispersion forces** – Weak intermolecular forces caused by temporary dipoles in non-polar molecules.

7. **Melting point** – The temperature at which a solid turns into a liquid.

8. **Polarity** – The distribution of electrical charge over the atoms in a molecule.

9. **Solubility** – The ability of a substance to dissolve in a solvent.

10. **Viscosity** – The resistance of a liquid to flow.

# 5. SMART Objectives

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

1. **Define electronegativity** and describe its trend across the periodic table.

2. **Predict bond polarity** based on the electronegativity differences between bonded atoms.

3. **Analyze molecular geometry** and determine whether a molecule is polar or non-polar.

4. **Connect molecular polarity** to the strength of intermolecular forces and predict how these forces affect physical properties like boiling point, melting point, and solubility.

# 6. Engage (Ignite)

### Phenomenon-Related Question:

Why does road salt cause ice to melt, but it doesn’t affect solid metal objects?

### Hands-On Experiment: Polarity and Water Solubility

**Objective**: To demonstrate how molecular polarity affects solubility in water.

**Materials Needed**:

- Water

- Vegetable oil

- Vinegar

- Salt

- Two clear cups

- Stirring rod

**Procedure**:

1. Fill one cup with water and add a tablespoon of salt. Stir the mixture and observe what happens.

2. In the second cup, mix a small amount of vegetable oil with water. Stir and observe what happens.

3. Add a few drops of vinegar into the water-oil mixture. Stir and observe what happens.

**Follow-Up Questions**:

1. Why does salt dissolve in water but not oil?

2. What happens when you add vinegar to the water-oil mixture?

3. How does this experiment relate to polarity and solubility?

# 7. Pre-Explore (Direct Instruction)

### Background Information:

Electronegativity is the ability of an atom to attract electrons in a bond. It is a periodic trend, meaning it follows a pattern on the periodic table. Electronegativity increases as you move from left to right across a period and decreases as you move down a group. The most electronegative element is fluorine.

When atoms with different electronegativities form a bond, the more electronegative atom pulls the shared electrons closer to itself, creating a **polar bond**. A polar bond has a partial positive charge on one end and a partial negative charge on the other. If a molecule contains polar bonds and has an asymmetrical shape, the entire molecule will be polar.

**Polarity** leads to **intermolecular forces**, which are forces between molecules. These forces affect the physical properties of substances, like their boiling and melting points. Strong intermolecular forces, like hydrogen bonds, lead to higher boiling points, while weaker forces, like London-dispersion forces, result in lower boiling points.

### Interactive Elements:

- **Discussion Question**: Why do you think water is considered a polar molecule?

- **Scaffolded Question**: How does the shape of a molecule affect its overall polarity?

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

1. **What is electronegativity?**

2. **How does electronegativity change across the periodic table?**

3. **If two atoms have a large difference in electronegativity, what kind of bond will they form?**

### **9. Explain (Lightbulb)**

### What is Electronegativity?

Electronegativity is a property of an atom that describes how strongly it pulls on electrons in a chemical bond. Some atoms, like fluorine, have a very high electronegativity, meaning they are very good at attracting electrons. Other atoms, like cesium, have low electronegativity, meaning they do not attract electrons as strongly.

The trend in electronegativity on the periodic table is as follows:

- **Across a period** (left to right), electronegativity increases.

- **Down a group** (top to bottom), electronegativity decreases.

**Example**:

- Fluorine (F) is the most electronegative element.

- Cesium (Cs) is one of the least electronegative elements.

### Bond Polarity and Electronegativity Differences

When two atoms bond, the difference in their electronegativities will determine if the bond is polar or non-polar.

- **Non-polar bond**: If both atoms have the same or very similar electronegativities, they will share the electrons equally. For example, in a molecule of oxygen (O₂), both oxygen atoms have the same electronegativity, so the bond is non-polar.

- **Polar bond**: If one atom has a higher electronegativity than the other, it will pull the electrons closer to itself. This creates a bond with a partial negative charge on one side and a partial positive charge on the other. For example, in a water molecule (H₂O), oxygen is more electronegative than hydrogen, so the bonds are polar.

### Molecular Polarity and Geometry

Even if a molecule has polar bonds, it may not always be a polar molecule. The overall polarity of a molecule depends on its **geometry** or shape. If the polar bonds are arranged symmetrically, their charges may cancel each other out, resulting in a non-polar molecule. However, if the polar bonds are arranged asymmetrically, the molecule will be polar.

**Example**:

- **Carbon dioxide (CO₂)**: The bonds between carbon and oxygen are polar, but because the molecule is linear, the charges cancel out, making the molecule non-polar.

- **Water (H₂O)**: The bonds between oxygen and hydrogen are polar, and because the molecule is bent, the charges do not cancel out, making water a polar molecule.

### Intermolecular Forces and Physical Properties

- **Dipole-dipole forces**: These occur between polar molecules. The positive end of one molecule is attracted to the negative end of another.

- **Hydrogen bonding**: A special type of dipole-dipole force that occurs when hydrogen is bonded to nitrogen, oxygen, or fluorine. These bonds are very strong and give water its high boiling point.

- **London-dispersion forces**: These are weak forces that occur between non-polar molecules due to temporary dipoles. These forces are weaker than dipole-dipole interactions but become stronger in larger molecules.

### How Electronegativity Affects Physical Properties

The strength of intermolecular forces affects many physical properties, such as boiling point, melting point, and solubility:

- **Boiling and Melting Points**: Substances with strong intermolecular forces, like hydrogen bonds, have higher boiling and melting points because more energy is needed to break these bonds.

- **Solubility**: Polar molecules tend to dissolve in polar solvents (like water), while non-polar molecules dissolve in non-polar solvents. This is known as "like dissolves like."

- **Viscosity**: Liquids with strong intermolecular forces, like honey, are more viscous (thicker) and flow more slowly than liquids with weaker forces.

### 10. Solved Sample Problem

**Problem**:

Predict whether the molecule CH₃Cl (chloromethane) is polar or non-polar.

**Solution**:

1. Chlorine (Cl) is more electronegative than carbon (C) or hydrogen (H), so the C-Cl bond is polar.

2. The shape of the molecule is tetrahedral, but since chlorine is more electronegative, the molecule is asymmetrical.

3. Therefore, CH₃Cl is a polar molecule.

**Progress Check**:

Predict whether the molecule CO₂ (carbon dioxide) is polar or non-polar.

### Conclusion

By understanding electronegativity and molecular polarity, we can predict how molecules will interact with each other through intermolecular forces. These forces determine many of the physical properties of substances, such as their boiling points, melting points, and solubility. The next time you see salt melting ice, you’ll know that it’s all because of the unique properties of water and its ability to dissolve polar substances!

# 10. Evaluate (Progress Check) - Explain

In this section, we will ask some scaffolded questions to check if you understand the key concepts from the "Explain" section. Each question builds on the previous ones, helping you to confirm your understanding.

1. **What is the chemical formula for water?**

- **Answer:** The chemical formula for water is H₂O. This means each water molecule is made up of two hydrogen atoms and one oxygen atom.

2. **Why do atoms bond together to form molecules like H₂O?**

- **Answer:** Atoms bond together to achieve a more stable electronic configuration. Hydrogen and oxygen bond because sharing electrons allows them to fill their outer electron shells, making them more stable.

3. **Explain why water is considered a polar molecule.**

- **Answer:** Water is considered a polar molecule because the oxygen atom is more electronegative than the hydrogen atoms. This means that the oxygen pulls the shared electrons closer to itself, creating a partial negative charge on the oxygen and partial positive charges on the hydrogen atoms. The uneven distribution of charges makes water polar.

# 11. Elaborate (Power Up)

To deepen your understanding, try these open-ended tasks. These questions encourage you to think more critically about the concepts.

1. **What would happen if water was a nonpolar molecule?**

- **Answer:** If water were nonpolar, it would not have the unique properties it does, such as its ability to dissolve many substances (like salts and sugars). Nonpolar molecules do not mix well with polar substances. As a result, life as we know it, which relies on water's solvent abilities, might not exist.

2. **Explore how the polarity of water affects its ability to support life.**

- **Answer:** Water's polarity allows it to dissolve a wide range of substances, which is crucial for transporting nutrients and waste in living organisms. Water can also form hydrogen bonds, which give it a high specific heat capacity. This means it can absorb a lot of heat without changing temperature quickly, helping to regulate the Earth's climate and the temperature inside living organisms.

**Space for Additional Questions:**

- How might the properties of water change if it had a different molecular structure?

- Why is the ability of water to dissolve substances important for chemical reactions in cells?

# 12. Final Evaluation

**Debate Question:**

- **Should we invest more resources into discovering water on other planets to support future human colonies?**

- Arguments for: Water is essential for life, and finding it on other planets could support future human colonies. Water could also be used for growing food, drinking, and generating oxygen.

- Arguments against: The cost of space exploration is very high, and some argue that we should focus on solving Earth's water and climate issues first.

**Multiple-Choice Questions:**

1. **What is the main reason why water is a polar molecule?**

- a) Water contains hydrogen.

- b) Oxygen is more electronegative than hydrogen.

- c) Water molecules are symmetrical.

- d) Water is a liquid at room temperature.

- **Answer:** b) Oxygen is more electronegative than hydrogen.

Explanation: This difference in electronegativity causes an uneven distribution of charge, making water polar.

2. **Which property of water allows it to regulate temperature?**

- a) Low boiling point

- b) High specific heat capacity

- c) Low freezing point

- d) High density

- **Answer:** b) High specific heat capacity.

Explanation: Water can absorb a lot of heat without changing temperature quickly, which helps regulate temperatures in the environment.

3. **What type of bond forms between water molecules?**

- a) Covalent bonds

- b) Ionic bonds

- c) Hydrogen bonds

- d) Metallic bonds

- **Answer:** c) Hydrogen bonds.

Explanation: The slightly negative oxygen atom of one water molecule is attracted to the slightly positive hydrogen atom of another water molecule, forming a hydrogen bond.

4. **Why is water considered a good solvent?**

- a) It has a low boiling point.

- b) It is nonpolar.

- c) It can dissolve both polar and ionic substances.

- d) It absorbs heat well.

- **Answer:** c) It can dissolve both polar and ionic substances.

Explanation: The polar nature of water allows it to interact with and dissolve other polar molecules and ionic compounds.

**Long-Answer Questions:**

1. **Describe how the structure of water molecules contributes to its unique properties.**

- **Answer:** The structure of water, with its two hydrogen atoms bonded to one oxygen atom, makes it a polar molecule. The oxygen atom, being more electronegative, pulls the shared electrons closer to itself, creating a partial negative charge on the oxygen and partial positive charges on the hydrogen atoms. This polarity allows water to form hydrogen bonds with other water molecules, contributing to properties like high surface tension, high specific heat, and its ability to dissolve many substances.

2. **Explain the role of water in maintaining stable temperatures on Earth.**

- **Answer:** Water has a high specific heat capacity, which means it can absorb a large amount of heat without a significant rise in temperature. This property helps to regulate temperatures on Earth, preventing extreme fluctuations. Large bodies of water, like oceans and lakes, absorb heat during the day and release it slowly at night, stabilizing the climate.

3. **How does water’s polarity affect its behavior as a solvent in biological systems?**

- **Answer:** Water’s polarity allows it to interact with and dissolve other polar substances and ionic compounds, which is essential in biological systems. For instance, it dissolves salts, sugars, and gases, facilitating their transport and reactions in cells. This property of water is crucial for processes like nutrient absorption, waste removal, and biochemical reactions.

4. **Predict how life on Earth would be different if water did not have a high specific heat capacity.**

- **Answer:** If water did not have a high specific heat capacity, temperatures on Earth would fluctuate much more rapidly. This could make the environment less stable and harder for life to survive. Organisms would need to adapt to extreme temperature changes, and ecosystems might look very different. Additionally, Earth's climate would likely be harsher, with hotter days and colder nights.

# 13. Extend (Beyond the Lesson)

To further your understanding of these concepts, here are some additional tasks and challenges:

1. **Readings:**

- Read about the water cycle and how it connects with water's properties. Focus on how water's ability to evaporate and condense helps regulate the Earth's climate.

- Explore scientific articles on the search for water on Mars and other planets. What does the presence of water tell us about the possibility of life elsewhere?

2. **Activities:**

- **Water as a Solvent Experiment:** Try dissolving different substances (e.g., salt, sugar, oil) in water. Record your observations and explain why some substances dissolve easily while others do not.

- **Temperature Regulation Challenge:** Research how animals living in extreme environments (e.g., deserts, polar regions) use water to regulate their body temperatures.

3. **Spaced Practice:**

- Over the next few weeks, return to the key concepts of water's properties. Try explaining how water's polarity and hydrogen bonding contribute to different phenomena in nature, like capillary action in plants or the floating of ice on water.

**Real-World Application:**

- **Question:** How could understanding water's properties help in the development of new technologies, such as water purification systems or climate control solutions?

- **Challenge:** Design a simple water filtration system using household materials. Consider how water’s ability to dissolve substances plays a role in filtration.

By engaging with these tasks and questions, you will deepen your understanding of water's critical role in both chemistry and life on Earth.