Unit 2: Atomic Structure and Bonding

## Chapter 6: Ionic and Metallic Bonding

### Lesson 1: Formation and Properties of Ions

### 1. Big Idea:

- **Main Concept:** Atoms form ions by losing or gaining electrons to achieve a stable electron configuration, playing a key role in ionic bonding.

- **Chapter Big Idea:** Chemical bonds, including ionic and metallic bonds, are formed by the interaction between atoms' electrons and determine the properties of compounds and elements.

### 2. Essential Questions:

- **How are ions formed, and what role do they play in chemical bonding?**

**Answer:** Ions are formed when atoms gain or lose electrons to achieve a stable electron arrangement, usually following the octet rule (having eight electrons in their outer shell). This loss or gain of electrons gives them a charge, making them either positively charged (cations) or negatively charged (anions). These charged ions are crucial in ionic bonding, where oppositely charged ions attract each other to form stable compounds like salts.

### 3.1 Phenomenon-Based Learning

- **Phenomenon:** In cold northern countries, road salt is spread to melt ice and snow on streets. As the salt contacts the ice, the ice melts, and the salt dissolves. However, metal street signs and lampposts exposed to the same conditions do not melt or dissolve. This behavior is due to the different types of bonding in salts and metals. Salt, which is made up of ions, dissolves in water because of its ionic bonds, while metals do not dissolve because of their metallic bonds.

### 3.2 Lesson Phenomenon

- **Lesson Phenomenon:** When salt is added to water, it dissolves and splits into ions, allowing it to conduct electricity (becoming an electrolyte). In contrast, metals, though they can conduct electricity in solid form, do not dissolve in water. This difference arises because salt forms ionic bonds, while metals form metallic bonds. The formation of ions and their behavior in water is crucial to understanding why salt dissolves but metal does not.

### 4. Vocabulary

- **Octet Rule:** The tendency of atoms to prefer having eight electrons in their outer electron shell to achieve stability.

- **Anion:** A negatively charged ion, formed when an atom gains electrons.

- **Cation:** A positively charged ion, formed when an atom loses electrons.

- **Electrolyte:** A substance that dissolves in water to form a solution that conducts electricity, often formed by ionic compounds.

- **Electron Affinity:** The energy change when an atom gains an electron, indicating how strongly an atom attracts additional electrons.

- **Ionic Radius:** The size of an ion after it has gained or lost electrons.

- **Ionization:** The process where an atom loses or gains electrons to form an ion.

### 5. SMART Objectives

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

- Describe how ions are formed.

- Write the symbols and charges of ions.

- Predict the charge of an ion based on its position on the periodic table.

### 6. Engage (Ignite)

**Start with a Phenomenon-Related Question:**

- Ask: "Why does salt dissolve in water, but metal doesn't, even though both are exposed to the same conditions in the winter on icy roads?"

- This question connects the everyday phenomenon of road salt and metal street signs to the formation of ions and bonding.

**Hands-On Experiment: "Salt in Water vs. Metal in Water"**

**Materials Needed:**

- Table salt (NaCl)

- Small metal nail

- Distilled water

- Two beakers

- Conductivity tester or multimeter

**Procedure:**

1. Fill two beakers with distilled water.

2. Dissolve a teaspoon of salt in one beaker and stir.

3. Place the metal nail in the other beaker.

4. Use a conductivity tester to test if either solution conducts electricity.

5. Record your observations.

**Follow-Up Questions:**

1. **What happens when salt dissolves in water?**

- **Answer:** The salt dissociates into sodium (Na⁺) and chloride (Cl⁻) ions, which allows the solution to conduct electricity.

2. **Does the metal conduct electricity when dissolved in water?**

- **Answer:** No, because the metal does not dissolve in water; it remains solid.

3. **Why can the salt solution conduct electricity, but not the metal in water?**

- **Answer:** Salt forms ions in water, which carry charge and conduct electricity. Metals don’t form ions in water, so they don’t conduct electricity in the same way.

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

**Background Information:**

- Atoms are neutral because they have an equal number of protons (positive charge) and electrons (negative charge). However, when atoms gain or lose electrons, they become charged particles called **ions**.

- The **octet rule** states that atoms are most stable when they have eight electrons in their outer shell. To achieve this, atoms will gain or lose electrons.

- **Cations** form when atoms lose electrons and become positively charged.

- **Anions** form when atoms gain electrons and become negatively charged.

- The periodic table helps predict whether an atom will become a cation or anion:

- Metals (left side of the periodic table) tend to lose electrons and form cations.

- Non-metals (right side of the periodic table) tend to gain electrons and form anions.

**Discussion Prompts:**

- "Based on the periodic table, do you think sodium (Na) will lose or gain electrons to form an ion?"

- **Answer:** Sodium will lose one electron to form a Na⁺ ion.

- "What about chlorine (Cl)? Will it lose or gain electrons?"

- **Answer:** Chlorine will gain one electron to form a Cl⁻ ion.

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

**Scaffolded Questions:**

1. **What is the charge of an ion that forms when an atom loses two electrons?**

- **Answer:** The ion will have a charge of 2+, because it has lost two negatively charged electrons.

2. **How does the ionic radius of a cation compare to the atomic radius of the neutral atom?**

- **Answer:** The ionic radius of a cation is smaller than the atomic radius because the atom loses electrons, reducing the electron cloud.

3. **Why do non-metals tend to form anions?**

- **Answer:** Non-metals tend to gain electrons to achieve a full outer shell, forming negatively charged anions.

### 9. Explain (Lightbulb)

**Detailed Explanation of Core Concepts:**

**Formation of Ions:**

Atoms form ions by gaining or losing electrons to achieve a stable electron configuration, typically following the **octet rule**. The octet rule suggests that atoms are most stable when they have eight electrons in their outermost electron shell. However, not all atoms naturally have eight outer electrons, so they tend to gain or lose electrons to reach this stable configuration.

- **Cations:** When an atom loses one or more electrons, it becomes a positively charged ion called a **cation**. This occurs because the atom now has more protons than electrons, giving it a net positive charge. For example, sodium (Na) loses one electron to become Na⁺.

- **Anions:** When an atom gains one or more electrons, it becomes a negatively charged ion called an **anion**. This happens because the atom now has more electrons than protons, giving it a net negative charge. For example, chlorine (Cl) gains one electron to become Cl⁻.

**Sample Problem:**

- **Question:** Predict the ion formed by magnesium (Mg).

- **Solution:** Magnesium is in Group 2 of the periodic table, which means it has two electrons in its outer shell. To achieve a stable electron configuration, magnesium will lose two electrons, forming a Mg²⁺ ion.

**Progress Check:**

- Predict the ion formed by oxygen (O).

- **Answer:** Oxygen is in Group 16, so it will gain two electrons to form O²⁻.

**Symbols and Charges of Ions:**

When representing ions, we write the chemical symbol of the element followed by its charge as a superscript. For example:

- Na⁺ represents a sodium ion with a positive charge.

- Cl⁻ represents a chloride ion with a negative charge.

The charge of an ion is determined by the number of electrons gained or lost:

- If an atom loses electrons, it will have a positive charge (cations).

- If an atom gains electrons, it will have a negative charge (anions).

**Sample Problem:**

- **Question:** Write the symbol for the ion formed by calcium (Ca).

- **Solution:** Calcium is in Group 2 and will lose two electrons, so the ion is written as Ca²⁺.

**Progress Check:**

- Write the symbol for the ion formed by fluorine (F).

- **Answer:** Fluorine gains one electron, so the ion is F⁻.

**Predicting the Charge of Ions:**

The periodic table is a powerful tool for predicting the charge of ions:

- **Group 1 elements** (alkali metals) lose one electron to form 1⁺ ions.

- **Group 2 elements** (alkaline earth metals) lose two electrons to form 2⁺ ions.

- **Group 16 elements** (oxygen group) gain two electrons to form 2⁻ ions.

- **Group 17 elements** (halogens) gain one electron to form 1⁻ ions.

**Sample Problem:**

- **Question:** Predict the charge of an ion formed by potassium (K).

- **Solution:** Potassium is in Group 1, so it will lose one electron to form K⁺.

**Progress Check:**

- Predict the charge of an ion formed by sulfur (S).

- **Answer:** Sulfur is in Group 16, so it will gain two electrons to form S²⁻.

**Conclusion:**

Through this lesson, we have explored how ions are formed, their symbols and charges, and how to predict their charge using the periodic table. Ions play a crucial role in chemical bonding, especially in ionic bonds, where oppositely charged ions come together to form compounds. The phenomenon of salt dissolving in water, but metal not dissolving, is a direct result of the way ions behave in different environments.

### 10. Evaluate (Progress Check) - Explain

In this section, we will assess students' understanding of the key concepts covered in the previous lessons. The questions are scaffolded to progressively test the depth of their knowledge.

**Question 1:**

What is the atomic number of an element and how is it related to the number of protons in an atom?

**Answer:**

The atomic number of an element is the number of protons in the nucleus of an atom. It defines the identity of the element. For example, the atomic number of hydrogen is 1, meaning it has 1 proton.

**Question 2:**

Explain why elements in the same group of the periodic table have similar chemical properties.

**Answer:**

Elements in the same group of the periodic table have similar chemical properties because they have the same number of electrons in their outermost shell (valence electrons). These valence electrons determine how the element reacts with other substances. For example, all alkali metals (Group 1) have one valence electron, making them highly reactive.

**Question 3:**

Describe how an ionic bond is formed between a metal and a non-metal.

**Answer:**

An ionic bond is formed when a metal atom transfers one or more of its electrons to a non-metal atom. This transfer occurs because metals tend to lose electrons and non-metals tend to gain electrons to achieve a stable electron configuration (usually a full valence shell). For example, in sodium chloride (NaCl), sodium (a metal) donates one electron to chlorine (a non-metal), leading to the formation of Na⁺ and Cl⁻ ions, which are held together by electrostatic forces.

### 11. Elaborate (Power Up)

In this section, we will encourage deeper thinking by posing mini-tasks and open-ended questions that prompt students to elaborate on their understanding.

**Mini-task 1:**

Consider a scenario where you have magnesium (Mg) and sulfur (S). Predict the type of bond they will form and write the chemical formula of the resulting compound.

**Answer:**

Magnesium (Mg) is a metal, and sulfur (S) is a non-metal. Therefore, they will form an ionic bond. Magnesium will lose two electrons to form Mg²⁺, and sulfur will gain two electrons to form S²⁻. The resulting compound will be magnesium sulfide with the formula MgS.

**Mini-task 2:**

Why do noble gases (Group 18) typically not form bonds with other elements?

**Answer:**

Noble gases have a full valence shell of electrons, making them highly stable and unreactive. Since they already have a stable electron configuration, they do not need to gain or lose electrons, and thus, they typically do not form chemical bonds with other elements. For example, helium (He) has a complete outer shell with 2 electrons, and neon (Ne) has a complete shell with 8 electrons.

**Mini-task 3:**

How would the solubility of ionic compounds in water be affected if water were a non-polar solvent instead of a polar one?

**Answer:**

Water is a polar solvent and is effective at dissolving ionic compounds because the positive and negative ends of the water molecules interact with the positive and negative ions, respectively, pulling them apart. If water were non-polar, it would not be able to effectively interact with the charged ions, and ionic compounds would be much less soluble in water.

### 12. Final Evaluation

**Debate Question:**

Should scientists continue to experiment with creating synthetic elements, even though some of these elements are highly unstable and have no known practical applications?

**Arguments For:**

- Expanding scientific knowledge: Discovering new elements helps us understand the limits of the periodic table and the forces that hold atoms together.

- Potential future applications: Even if no current applications exist, synthetic elements could lead to new technologies or materials in the future.

- Advancing technology: The tools and methods developed in creating synthetic elements can have other scientific benefits.

**Arguments Against:**

- Cost and safety: Creating synthetic elements is expensive and can be dangerous due to the radioactivity of some elements.

- Limited practical use: Many synthetic elements have such short half-lives that they may not have any practical applications.

- Ethical considerations: There are concerns about the impact on the environment, human health, and the potential for misuse.

**Multiple-Choice Questions:**

1. Which of the following best describes a covalent bond?

a) Transfer of electrons between atoms

b) Sharing of electrons between atoms

c) Electrons being lost from both atoms

d) Formation of ions

**Answer:** b) Sharing of electrons between atoms

**Explanation:** A covalent bond is formed when two atoms share electrons to achieve stable electron configurations.

2. What is the charge on the ion formed by an atom of calcium (Ca)?

a) +1

b) +2

c) -1

d) -2

**Answer:** b) +2

**Explanation:** Calcium is in Group 2 of the periodic table, so it loses two electrons to form a Ca²⁺ ion.

3. In the periodic table, elements in Group 17 (halogens) typically form which type of ion?

a) +1

b) +2

c) -1

d) -2

**Answer:** c) -1

**Explanation:** Halogens have seven valence electrons and tend to gain one electron to form a -1 ion.

4. Which of the following molecules is non-polar?

a) H₂O

b) CH₄

c) NH₃

d) HF

**Answer:** b) CH₄

**Explanation:** CH₄ (methane) is non-polar because the molecule is symmetrical, and the bond dipoles cancel each other out.

**Long-Answer Questions:**

1. Explain how the electron configuration of an atom determines its position in the periodic table and its chemical reactivity.

**Answer:**

The electron configuration of an atom determines its position in the periodic table based on the number of electrons and how they are arranged in shells and subshells. Elements are arranged in order of increasing atomic number, which corresponds to the number of protons and electrons. The number of valence electrons (electrons in the outermost shell) determines an element’s chemical reactivity. For example, elements in Group 1 have one valence electron and are highly reactive, while elements in Group 18 have full valence shells and are unreactive.

2. Describe the differences between ionic, covalent, and metallic bonds, and provide an example of each.

**Answer:**

- **Ionic bonds** are formed when electrons are transferred from one atom (usually a metal) to another atom (usually a non-metal), creating oppositely charged ions that attract each other. Example: NaCl (sodium chloride).

- **Covalent bonds** are formed when two non-metal atoms share electrons to achieve stable electron configurations. Example: H₂O (water).

- **Metallic bonds** are formed between metal atoms, where electrons are shared in a "sea of electrons," allowing metals to conduct electricity and be malleable. Example: Iron (Fe).

3. Predict the product of a reaction between potassium (K) and chlorine (Cl), and explain the type of bond formed.

**Answer:**

Potassium (K) will lose one electron to form a K⁺ ion, and chlorine (Cl) will gain one electron to form a Cl⁻ ion. The bond formed between K⁺ and Cl⁻ is an ionic bond, as it involves the transfer of electrons from a metal (potassium) to a non-metal (chlorine). The product is potassium chloride (KCl).

4. Why do metals conduct electricity, and how does this relate to the bonding in metals?

**Answer:**

Metals conduct electricity because they have a "sea of electrons" that are free to move throughout the metal structure. In metallic bonding, metal atoms release some of their electrons, which are not bound to any specific atom and can move freely. This mobility of electrons allows metals to conduct electrical current.

### 13. Extend (Beyond the Lesson)

**Suggested Tasks and Readings:**

1. **Reading:** "The Role of Valence Electrons in Chemical Reactions"

- Explore how valence electrons determine the reactivity of elements and predict chemical reactions.

2. **Mini-task:** Research and present a case study on how alloys (mixtures of metals) are used in real-world applications, such as in the construction of aircraft or medical devices. Discuss how the properties of alloys differ from those of pure metals.

3. **Challenge Question:**

Imagine you are designing a new material that needs to be both lightweight and strong. Based on your knowledge of bonding and elements, which elements or types of bonds would you prioritize in your design? Explain your choices.

**Spaced Practice:**

- Revisit the concept of ionic and covalent bonding after a week by completing a worksheet that involves drawing Lewis dot structures for compounds like H₂O, CO₂, NaCl, and MgO.

- After two weeks, create a concept map that links periodic table trends (atomic radius, electronegativity) to bonding types and reactivity.

This approach allows students to apply their knowledge to new situations, reinforcing their understanding over time.