Unit 2: Atomic Structure and Bonding

Chapter 6: Ionic and Metallic Bonding

# Lesson 1: Formation and Properties of Ions

1. Big Idea:  
  
Ions are atoms or molecules that gain or lose electrons, leading to the formation of charged particles, which are crucial for forming ionic bonds between elements.  
  
  
  
 2. Essential Questions  
  
- **How are ions formed, and what role do they play in chemical bonding?**   
  
**Answer**:   
Ions are formed when atoms either lose or gain electrons. This process happens because atoms want to become stable by having a full outer shell of electrons, usually eight, following the Octet Rule. When an atom loses electrons, it becomes positively charged (a cation), and when it gains electrons, it becomes negatively charged (an anion). Ions play a crucial role in chemical bonding, especially in ionic bonding. In ionic bonds, oppositely charged ions (cations and anions) are strongly attracted to each other, forming stable compounds like salts.  
  
  
  
 3. Phenomenon-Based Learning  
  
**Phenomenon:   
Unit Phenomenon**:   
In northern countries, where winter brings extremely cold weather, streets and roads are often covered in ice and snow. To make the roads safer, salt is spread to melt the ice. When the salt touches the ice, it dissolves, and the ice melts. However, metal street signs and poles exposed to the same ice and snow do not dissolve or melt the ice. Why do salt and metal react differently with water?  
  
**Chapter Phenomenon**:   
When road salt is spread on icy streets, the salt dissolves in water, while metal signs and poles do not dissolve. Why do salt and metal behave differently in water?  
  
  
  
 4. Vocabulary  
  
1. **Octet Rule**: Atoms are most stable when they have eight electrons in their outermost shell.  
2. **Anion**: A negatively charged ion formed when an atom gains electrons.  
3. **Cation**: A positively charged ion formed when an atom loses electrons.  
4. **Electrolyte**: A substance that dissolves in water to produce a solution that can conduct electricity due to the presence of ions.  
5. **Electron Affinity**: The energy change that occurs when an atom gains an electron.  
6. **Ionic Radius**: The size of an ion compared to the size of its parent atom.  
7. **Ionization:** The process in which an atom or molecule gains or loses electrons to become an ion.  
  
  
  
 5. SMART Objectives  
  
By the end of this lesson, students will be able to:  
  
1. Describe how ions are formed by gaining or losing electrons.  
2. Write the symbols and charges of common ions (e.g., Na⁺, Cl⁻).  
3. Predict the charge of an ion based on its position on the periodic table.  
4. Relate the concept of ion formation to real-life phenomena such as the use of road salt in winter.  
  
  
  
 6. Engage (Ignite)  
  
Start the lesson by introducing the phenomenon: "Why does road salt melt ice, while metal street signs do not?"   
  
**Hands-on Experiment: Dissolving Salt in Water**  
  
**Materials**:   
- Table salt (NaCl)   
- A small metal object (e.g., a nail)   
- Two beakers   
- Water   
- Stirring rod   
  
**Procedure**:   
1. Fill two beakers with equal amounts of water.  
2. Add a teaspoon of salt to one beaker and stir until the salt dissolves.  
3. Place a small metal object (like a nail) in the second beaker of water and observe.  
4. Compare the reactions: What happens to the salt? What happens to the metal?  
  
**Follow-up Questions:**   
1. What happens to the salt when it dissolves in water?  
2. Why does the metal object not dissolve in water?  
3. What do you think happens to the salt particles in water that makes it different from the metal?  
  
  
  
 7. Pre-Explore (Direct Instruction)  
  
**Background Information:**   
Atoms are the building blocks of all matter, and they consist of protons, neutrons, and electrons. In their neutral state, atoms have the same number of protons (positive charge) and electrons (negative charge), making them electrically neutral.  
  
However, atoms can become more stable by gaining or losing electrons. This process creates ions. Positively charged ions (cations) form when atoms lose electrons, while negatively charged ions (anions) form when atoms gain electrons. The Octet Rule helps explain this: atoms will gain or lose electrons to achieve a full set of eight outer electrons, making them more stable.  
  
**Interactive Element** (Discussion Prompt):   
The salt you added to the water in the experiment dissolved. But what does that really mean? Did the salt particles just disappear, or did something else happen? Discuss with a partner.  
  
**Scaffolded Question:**   
How do you think the behavior of salt in water relates to the concept of ions?  
  
  
  
 8. Evaluate (Progress Check) - Pre-Explore  
  
**Scaffolded Questions**:   
1. What happens to sodium (Na) atoms during the formation of Na⁺ ions?   
2. How does chlorine (Cl) become Cl⁻?   
3. Why do sodium (Na⁺) and chlorine (Cl⁻) attract each other to form salt?  
  
  
  
 9. Explain (Lightbulb)  
  
**Core Concept**: How are ions formed?  
  
**Formation of Ions**:   
Atoms form ions to achieve a more stable electron configuration. For most atoms, this means having a full outer shell of electrons, usually eight, which is explained by the Octet Rule.  
  
- **Cation Formation**: When an atom loses one or more electrons, it becomes a cation. For example, sodium (Na) has one electron in its outermost shell. By losing that one electron, sodium achieves a stable electron configuration and becomes Na⁺, a positively charged ion.  
   
- **Anion Formation**: When an atom gains one or more electrons, it becomes an anion. For example, chlorine (Cl) needs one more electron to complete its outer shell. By gaining an electron, chlorine becomes Cl⁻, a negatively charged ion.  
  
**Predicting Ion Charges**:   
The position of elements on the periodic table helps predict the charge of ions they form:  
- Group 1 elements (e.g., sodium, potassium) form 1⁺ cations by losing one electron.  
- Group 17 elements (e.g., chlorine, fluorine) form 1⁻ anions by gaining one electron.  
- Group 2 elements (e.g., calcium, magnesium) form 2⁺ cations by losing two electrons.  
  
**Real-Life Connection**: Road Salt  
Let’s return to our road salt example. Salt is made of sodium ions (Na⁺) and chloride ions (Cl⁻). When you sprinkle salt on ice, the salt dissolves in the water, breaking up into its ions. These ions disrupt the structure of the ice, lowering its melting point and helping to melt it even at cold temperatures. But why don’t the metal street signs dissolve? Metal atoms do not form ions as easily in water, which is why they remain solid and do not interact with the ice in the same way.  
  
  
  
Sample Problem 1:   
**Question**: Predict the charge of the following elements based on their position on the periodic table:   
- Lithium (Li)   
- Oxygen (O)   
  
**Solution**:   
- Lithium (Li) is in Group 1, so it loses one electron to form a 1⁺ ion: Li⁺.   
- Oxygen (O) is in Group 16, so it gains two electrons to form a 2⁻ ion: O²⁻.  
  
Progress Check:   
Predict the charges of the following elements based on their positions on the periodic table:   
- Magnesium (Mg)   
- Fluorine (F)  
  
  
  
**Core Concept**: What role do ions play in chemical bonding?  
  
**Ionic Bonding**:   
When a metal atom (like sodium) loses electrons and becomes a cation, and a nonmetal atom (like chlorine) gains electrons and becomes an anion, they attract each other due to their opposite charges. This attraction forms an ionic bond. Ionic bonds are strong and lead to the formation of ionic compounds, like sodium chloride (NaCl), commonly known as table salt.  
  
  
  
Sample Problem 2:   
**Question**: Explain how calcium (Ca) and sulfur (S) would bond to form an ionic compound.   
  
**Solution**:   
- Calcium (Ca) is in Group 2 and loses two electrons to form Ca²⁺.  
- Sulfur (S) is in Group 16 and gains two electrons to form S²⁻.  
- The Ca²⁺ and S²⁻ ions attract each other to form the ionic compound calcium sulfide (CaS).  
  
Progress Check:   
Explain how magnesium (Mg) and chlorine (Cl) would bond to form an ionic compound.  
  
  
  
 Conclusion  
  
**Summary**:   
Ions form when atoms lose or gain electrons to achieve a stable electron configuration, usually following the Octet Rule. The resulting charged particles, cations and anions, are crucial in forming ionic bonds, which hold compounds like salt together. Understanding how ions form and interact allows us to predict the properties of ionic compounds, including their behavior in real-world scenarios like the melting of ice by road salt.  
  
 10. Evaluate (Progress Check) - Explain  
Here are three scaffolded questions based on three different Depth of Knowledge (DOK) levels to help evaluate understanding of the key concepts.  
  
 DOK 1: Recall and Reproduction (Basic Recall)  
**Question: What is the chemical symbol for water?**- Answer: The chemical symbol for water is H₂O. This is a basic recall question as students are expected to remember the symbol for a common compound.  
  
 DOK 2: Skills and Concepts (Understanding)  
**Question: Explain why water (H₂O) is considered a compound and not an element**.  
- Answer: Water is considered a compound because it is made up of two different elements, hydrogen (H) and oxygen (O), chemically combined in a fixed ratio. An element only consists of one type of atom, but a compound has two or more different elements bonded together.  
  
 DOK 3: Strategic Thinking (Application)  
**Question: Predict what will happen to the boiling point of water if salt is added to it. Explain your reasoning.**- Answer: The boiling point of water will increase if salt is added. This is because the salt (a solute) disrupts the formation of vapor bubbles, requiring more heat to reach the boiling point. This change is an example of a colligative property, which depends on the number of solute particles in the solution.  
  
  
  
 11. Elaborate (Power Up)  
Encourage deeper thinking with mini-tasks or open-ended questions:  
  
 Mini-Task 1:  
**Question: How does breaking chemical bonds require energy, and how does forming bonds release energy? Provide real-life examples.**- Answer: Breaking chemical bonds requires energy because it takes effort to separate atoms that are held together. For example, when you dissolve salt in water, energy is needed to break the ionic bonds between sodium and chloride ions. On the other hand, forming chemical bonds releases energy because the atoms move to a lower energy state. For instance, when hydrogen and oxygen combine to form water, energy is released in the form of heat and light (as seen in a hydrogen combustion reaction).  
  
 Mini-Task 2:  
**Question: How might understanding chemical reactions help in designing eco-friendly products**?  
- Answer: Understanding chemical reactions can help in designing eco-friendly products by allowing scientists to choose reactions that produce fewer harmful by-products or use renewable resources. For example, using biodegradable materials that break down into non-toxic substances can minimize environmental pollution.  
  
 Mini-Task 3:  
**Question: Design a simple experiment to test whether a substance is a compound or a mixture. What steps would you take, and what would be your expected results?**- Answer: A simple experiment could involve trying to separate the components of the substance. In a mixture, the components can often be separated physically (like filtering sand from water). However, in a compound, the elements are chemically bonded, so you would need a chemical reaction (like electrolysis) to separate them. The expected result for a mixture would be that you can separate the components without changing their chemical identity, but a compound would require a chemical change for separation.  
  
  
  
 12. Final Evaluation  
  
 Debate Question:  
**Question: Should we prioritize chemical research for renewable energy sources over traditional fossil fuels?**- Arguments for: Renewable energy sources, such as solar and wind, produce less pollution and are more sustainable in the long run. They help combat climate change and reduce dependency on finite fossil fuel resources.  
- Arguments against: Fossil fuels are currently more accessible and provide a reliable energy supply. Transitioning to renewable sources requires significant investment and infrastructure changes which may not be feasible for all economies.  
  
 Multiple-choice Questions:  
  
1. **What is the primary difference between an element and a compound?** a) A compound is made of one type of atom, while an element consists of multiple atoms.   
 b) An element is made of one type of atom, while a compound consists of two or more different types of atoms.   
 c) An element can be broken down into simpler substances, but a compound cannot.   
 d) There is no difference between elements and compounds.  
 - **Correct Answer: b) An element is made of one type of atom, while a compound consists of two or more different types of atoms.**  
 - Explanation: This option clearly explains that an element is pure, while a compound is a combination of different elements chemically bonded.  
  
2. **What is the role of a catalyst in a chemical reaction?**  
 a) It increases the temperature of the reaction.   
 b) It speeds up the reaction without being consumed.   
 c) It changes the products of the reaction.   
 d) It slows down the reaction.  
 - **Correct Answer: b) It speeds up the reaction without being consumed.  
 - Explanation:** A catalyst lowers the activation energy required for the reaction to proceed, speeding it up without being used up itself.  
  
3. **Which of the following is an example of a physical change?**  
 a) Burning wood   
 b) Rusting of iron   
 c) Melting of ice   
 d) Baking a cake  
 - **Correct Answer: c) Melting of ice  
 - Explanation:** Melting ice is a physical change because it changes the state of water from solid to liquid without altering its chemical composition.  
  
4. **Which statement best describes an exothermic reaction?**  
 a) It absorbs heat from the surroundings.   
 b) It releases heat to the surroundings.   
 c) It requires more energy to start than it releases.   
 d) It causes a decrease in the temperature of the surroundings.  
 - **Correct Answer: b) It releases heat to the surroundings.  
 - Explanation:** In an exothermic reaction, energy is released as heat, causing the surroundings to warm up.  
  
 Long-answer Questions:  
  
1. **Explain how the Law of Conservation of Mass applies to chemical reactions, and provide an example**.  
 - Answer: The Law of Conservation of Mass states that mass is neither created nor destroyed in a chemical reaction. This means that the total mass of reactants must equal the total mass of products. For example, in the combustion of methane (CH₄ + 2O₂ → CO₂ + 2H₂O), the mass of methane and oxygen before the reaction equals the mass of carbon dioxide and water after the reaction.  
  
2. **Describe how temperature affects the rate of a chemical reaction.**  
 - Answer: Increasing the temperature typically increases the rate of a chemical reaction. This is because higher temperatures provide reactant particles with more energy, which increases the frequency and energy of collisions between them. As a result, a greater number of collisions have enough energy to overcome the activation energy barrier, speeding up the reaction.  
  
3. **Discuss the environmental impact of using fossil fuels for energy production.**  
 - Answer: Using fossil fuels for energy production releases large amounts of carbon dioxide (CO₂) and other greenhouse gases into the atmosphere, contributing to global warming. It also leads to air pollution, which can harm human health and the environment. Furthermore, the extraction of fossil fuels can cause habitat destruction and water contamination.  
  
4. **In what ways can understanding chemical reactions contribute to advancements in medicine?**  
 - Answer: Understanding chemical reactions allows scientists to design new drugs and therapies that can target specific diseases. For example, knowledge of biochemical reactions in the body helps in developing medications that can inhibit harmful reactions or enhance beneficial ones. This understanding also aids in the creation of diagnostic tools and treatments for various medical conditions.  
  
  
  
 13. Extend (Beyond the Lesson)  
  
 Additional Tasks:  
1. **Research Task:** Research green chemistry and write a short report on how it aims to reduce the environmental impacts of chemical processes. How can green chemistry be applied in industries like pharmaceuticals or agriculture?  
   
2. **Real-World Application**: Investigate how knowledge of chemical reactions is used in creating sustainable agricultural practices, such as the development of fertilizers that minimize environmental harm.  
  
3. **Challenge Question**: Can you think of a real-world problem that could be solved by understanding chemical reactions? How might scientists approach solving this problem?  
  
 Spaced Practice:  
- **Revisit the Concept**: Over the next week, review examples of endothermic and exothermic reactions in your daily life. For each example, identify whether energy is absorbed or released.  
- **Practice Problem:** After one week, try this problem: Predict how increasing the concentration of reactants affects the rate of a chemical reaction. What real-life applications could benefit from this knowledge?