Bonding in Ionic, Covalent, and Cluster Solids

Introduction

Matter is most commonly found in three phases: solid, liquid, or gas. Researchers and engineers who design materials such as electronics, are particularly interested in solids. There are many different types of solids. Some solids, such as a piece of silver, are made of just one type of atom. Other types of solids are made from chemical compounds, which can contain many different types of atoms connected by chemical bonds. Three types of solids are especially common in everyday life: ionic solids, molecular solids, and metallic solids.

- **Ionic solids** are made up of chemical compounds held together with ionic bonds. Recall that an ionic bond forms when one atom *transfers* one or more **valence electrons**—electrons in the outermost energy level—to another atom. The charged ions are then held together through electrostatic attractions. An example of this is sodium chloride (NaCl), or table salt. Ionic solids have an ordered structure, with positively and negatively charged ions alternating in a three-dimensional space. Ionic solids are usually poor **electrical conductors**, which means electricity does not flow through them readily, and they are generally very soluble in water.
- **Molecular solids** are made of molecules, compounds made of atoms that *share* their valence electrons in covalent bonds. Some molecular solids are ordered, like ice, but some do not have an order, like the polyethylene that makes plastic sandwich bags. Molecular solids are usually poor electrical conductors. The molecules themselves are held together by intermolecular forces such as hydrogen bonds or London dispersion forces.
- **Metallic solids** are atomic solids made up of metal atoms held together by metallic bonds. Metallic bonds are formed when valence electrons are shared among many metal atoms. Metallic bonds form when valence electrons separate from metal atoms, causing the atoms to become positively charged. The “sea” of negatively charged valence electrons is attracted to the positive atoms, forming the bonds. Due to this large reservoir of delocalized electrons, metallic solids tend to be good conductors of electricity.

The type of solid, particles that make up that solid, and how those particles are held together in the solid are summarized in **Figure 1.**

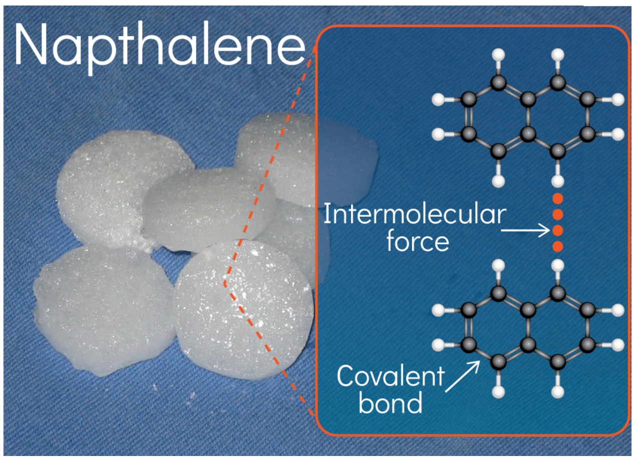
Recently, scientists have created a different type of particle, called a **cluster unit,** that can have properties of both ionic and covalent solids. The materials formed from these cluster units are called **cluster solids.** Cluster solids can do things that molecular and ionic solids can’t.

In this lesson, you will create models of ionic, covalent, and cluster solids, and read about their properties to learn about the unique properties of cluster solids as well as their real-world applications.

Type of Solid: Ionic

Particle: Ion

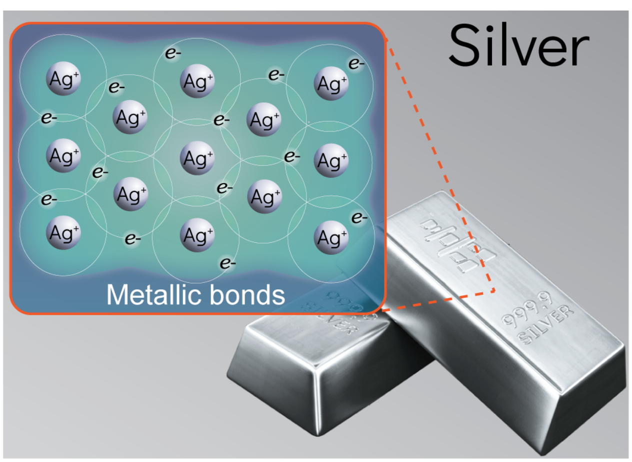
Bond Type: Ionic



Type of Solid: Molecular

Particle: Molecule

Bond Type:
Covalent within the molecule
Intermolecular forces between molecules



Type of Solid: Metallic

Particle: Metal ion

Bond Type: Metallic

Figure 1. Bonding in Three Common Types of Solids. *Please note that the particles in each diagram are not to scale.*

What To Do

Step 1. Obtain a “Models of Solids” template and a set of stickers (colored large 2-inch stickers, white ¾-inch stickers, and colored small ⅜-inch stickers)

Step 2. Choose one color to represent cations and another to represent anions. Fill in the colors on your color key at the top of the sheet. Note that you will use the same color for cations in both the cluster solid model (large stickers) and the ionic solid model (small stickers), and likewise will use the same color for anions in both the cluster solid and ionic solid models.

Step 3. Construct your cluster solid model using the large colored stickers. Be sure to place the correct colors in each space to reflect their charges.

Step 4. Construct your ionic solid model using the small colored stickers. Be sure to place the correct colors in each space to reflect their charges.

Step 5. Construct your molecular solid model using the white colored stickers.

Step 6. Complete the analysis questions, reading the Bite when instructed.

Analysis Questions

1. The table below contains the chemical formula of an ionic solid, a covalent solid and a cluster solid. Use your models and the information in Table 1 and the introduction to match each formula with the type of solid (molecular, ionic, or cluster) it represents, and explain how the chemical formula can help you identify the type of solid.

Chemical Formula	Solid Type	Explanation
$NaCl$		
$C_{10}H_8$		
$[Ni_9Te_6(PEt_3)_8][C_{60}]$		

2. Examining the models you made, compare the ionic solid model to the cluster solid model. What do they have in common? How are they different?

Similarities	Differences

3. Rank the size of the particles in each solid from smallest units to largest units.

4. Use a ruler to measure the diameter of one particle (in cm) of each type of solid model.

Solid Type	Diameter of One Particle in Model (cm)
Cluster	
Ionic	
Molecular	

a. Approximately how many times larger is the diameter of the cluster solid particle model than the ionic solid particle model?

b. How do the diameters of the particles in the molecular solid model and ionic solid model compare?

STOP & read Science Bite: Cluster Solids: Ionic, Covalent, or Both?

5. According to the Bite, cluster solids are held together by electrostatic attractions, just like ionic solids. Why, then, are they not simply classified as ionic solids? Cite evidence from the Bite in your answer.

6. The Bite also states that cluster solids contain covalently bonded atoms. Why can't cluster solids be considered molecular solids?

7. Generally speaking, ionic compounds dissolve in water and molecular compounds do not. Based on this information do you think cluster solids will dissolve in water? Make a claim and justify your claim with evidence from your models and the Bite.

8. Which type of solid (ionic, covalent, or cluster) is more likely to be useful in an application requiring electrical conductivity? Explain your answer based on evidence from the Bite.

9. Does the cluster solid model you created (Model 1) show the ionic and covalent features equally or does it emphasize one or the other? Explain your thinking.

10. How could Model 1 be improved to more accurately reflect both kinds of bonding present in cluster solids?

11. **Connect to the Big Question**. Scientists determined the structures of the cluster solids described in this lesson using x-ray images combined with computer modeling, rather than using their senses, as one typically would do when studying a system in a high school chemistry laboratory. How is the scientists' process similar to and different from more typical modes of observation in chemistry?