LESSON

25 You Light Up My Life

Classifying Substances

Think About It

If you accidentally drop a piece of jewelry into a tub of water, you should have no trouble getting it back again. However, if you drop a cube of sugar into the water, it will dissolve. Some substances dissolve in water and others do not. So, dissolving is one property of matter that you can use to sort substances into general groups.

How can substances be sorted into general categories?

To answer this question, you will explore

1. Dissolving and Conductivity
2. Testing and Sorting Substances

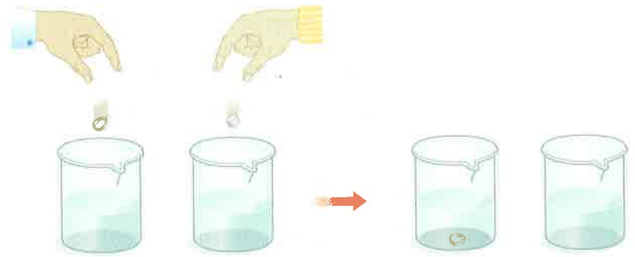
Exploring the Topic

1 Dissolving and Conductivity

There are millions of different substances in our world. Even chemists do not know the identities of all the possible compounds. However, many of the substances that are known can be sorted into general categories by looking at two properties: dissolving and conductivity.

Dissolving Substances in Water

We live on a watery planet. Most substances come into contact with water at some point. Some substances, like sugar, **dissolve** in water to make an aqueous solution. Other substances, like a gold ring, do not dissolve in water and will remain unchanged when placed in water. A substance that dissolves in water is **soluble** in water. A substance that does not dissolve is **insoluble** in water.



Many substances can be sorted into one of two categories based on whether they dissolve in water.

Conductivity

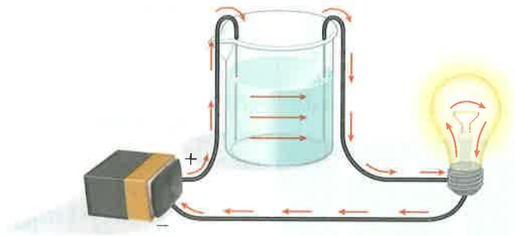
By examining a second property, it is possible to sort matter even further. The property of **conductivity** has to do with whether a substance will conduct electricity. Electrical conductivity requires the movement of ions or electrons. Copper wire is a great conductor of electricity. Your entire home is wired with hundreds of feet of copper or aluminum wiring that carries electricity from the power lines outside to the electrical outlets in your home. The human body is another good conductor of electricity. However, it uses bodily fluids to conduct electricity, not wiring.

Some substances do not conduct electricity. The electrical wires in your house are covered with a coating that does not conduct electricity. That way, you can plug in a stereo or a lamp and not get an electrical shock.

BIOLOGY CONNECTION

It is not only solid substances that are soluble. Gases can dissolve in liquids too. This is how fish are able to survive underwater. The ocean is full of dissolved oxygen that fish can extract from the water using their gills.

The light bulb doesn't light up because there's a break in the wire.

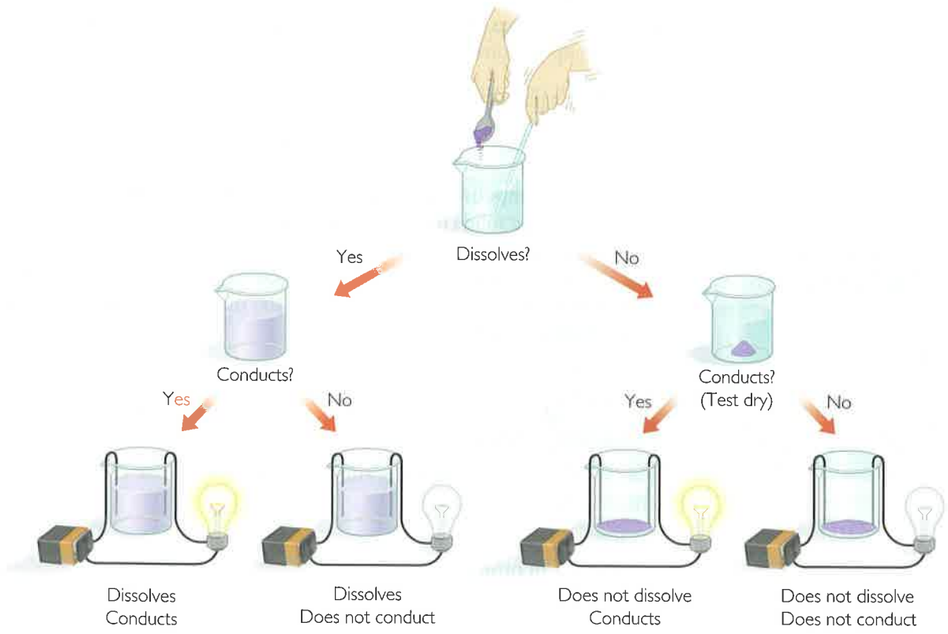


Even though there is a break in the wire, the bulb lights up because the liquid in the beaker conducts electricity.

Electrical conductivity can be tested by setting up a simple electrical circuit. Wires connect the terminals of a battery to a light bulb. When the circuit is complete, and an electrical current is flowing, the bulb will light up. If the flow of current is interrupted by the presence of a substance that does not conduct electricity, the light bulb will not light up.

2 Testing and Sorting Substances

You can use a two-step test to sort substances by both properties. First, drop a substance into water to find out if it dissolves. Next, test it for conductivity. This allows you to sort all matter into four basic categories as shown in the illustration below.



CONSUMER CONNECTION

Water that is 100% pure does not conduct electricity. However, the water that comes from your tap is loaded with dissolved ionic compounds, so it conducts electricity very well. This is why electrical appliances and water are a dangerous combination.

Examples of substances in each of the four categories are given in the table. Take a moment to look for patterns in the chemical formulas of the substances in each category. Note whether substances are made from metal atoms, nonmetal atoms, or some combination.

Types of Substances

Properties	dissolves: yes conducts: yes	dissolves: yes conducts: no	dissolves: no conducts: yes	dissolves: no conducts: no
Examples	salt, NaCl; calcium chloride, $CaCl_2$; copper sulfate, $CuSO_4$	water, H_2O; sugar, $C_{12}H_{22}O_{11}$; ethanol, C_2H_6O	gold, Au; copper, Cu; aluminum, Al	sand, SiO_2; paraffin, $C_{20}H_{42}$
Types of atoms	metal and nonmetal atoms	nonmetal atoms only	metal atoms only	nonmetal atoms only

Here are some patterns you might notice:

- The substances that are *soluble* in water and *conduct* electricity are made up of a metal element and one or more nonmetal elements. Remember, these are called ionic compounds.
- The substances that are *soluble* in water but *do not conduct* electricity are often made up of carbon, hydrogen, and oxygen atoms joined together. These are all nonmetal elements.
- The substances that are *insoluble* in water but *do conduct* electricity are made of metallic elements.
- The substances that are *insoluble* in water and *do not conduct* electricity are made up of nonmetal atoms.

Notice that only substances that contain metal atoms will conduct electricity. Also, substances that are made entirely of metal atoms will not dissolve in water. Many ionic compounds dissolve in water.

Important to Know Ionic compounds conduct electricity only when they are dissolved in water. Dry ionic solids do not conduct electricity. ◄

In Lesson 26: Electron Glue, you will discover that these two properties, solubility and conductivity, are directly related to the manner in which the individual atoms in these substances are linked.

Example

Predicting Properties

Predict whether the following substances dissolve in water and whether they conduct electricity.

a. lead, Pb

b. potassium bromide, KBr

Solution

a. Lead is a metal element. Because it is made of only metal atoms, it does not dissolve in water, but it does conduct electricity.

b. Potassium bromide consists of a metal and a nonmetal. It is an ionic compound. Therefore, it does dissolve in water, and the mixture does conduct electricity. The dry compound does not conduct electricity.

Key Terms

dissolve
soluble
insoluble
conductivity

Lesson Summary

How can substances be sorted into general categories?

Most substances on the planet can be sorted into four categories based on two properties: whether they are soluble in water and whether they conduct electricity. As you will discover in coming lessons, the properties of conductivity and solubility are directly related to the way in which atoms are connected to each other.

EXERCISES

Reading Questions

1. What does insoluble mean?
2. Describe a way to determine whether or not a substance conducts electricity.

Reason and Apply

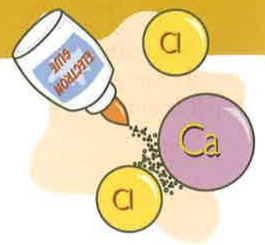
3. What generalization can you make about a substance that is soluble in water and conducts electricity once it has dissolved? Explain your thinking.
4. Do all solid substances containing metals conduct electricity? Explain your reasoning.
5. If a substance does not conduct electricity as a solid, does this mean that it will not conduct electricity if it dissolves? Explain your reasoning.
6. Predict whether each substance listed will conduct electricity, dissolve in water, and/or conduct electricity once it has dissolved. Explain your thinking in each case.
   - **a.** $C_3H_6O(l)$ acetone
   - **b.** $Ti(s)$ titanium
   - **c.** $LiNO_3(s)$ lithium nitrate
   - **d.** $CuZn(s)$ bronze

Coal and diamond are two naturally occurring forms of carbon.

LESSON

26 Electron Glue

Bonding



Think About It

All of the objects in our everyday world, including ourselves, are made up of individual atoms. But what holds those atoms together? Why don't objects just crumble into piles of individual atoms? Something must be holding the atoms together. And why is the desk in your classroom solid, while water simply runs through your fingers? Something about the way atoms are connected must give substances the properties we observe.

HISTORY CONNECTION

Stephanie Kwolek started working for DuPont in 1946. In 1965, she succeeded in creating synthetic fibers of exceptional strength due to their extremely strong bonds. This led to Kevlar, the material used in bulletproof vests.

How are atoms connected to one another?

To answer this question, you will explore

1. Bonds: The "Glue" Between Atoms
2. Types of Bonding
3. Relating Bonds and Properties

Exploring the Topic

1 Bonds: The "Glue" Between Atoms

Chemists call the attraction that holds atoms together a **chemical bond.** As you will discover, several different types of chemical bonds exist. All bonds involve the electrons in some way. A chemical bond is essentially an attraction between the electrons in some way. A chemical bond is essentially an attraction between the positive charges on the nucleus of one atom and the negative charges on the electrons of another atom. This attraction is so great that it keeps the atoms connected to one another.

2 Types of Bonding

Recall from Lesson 25 that most substances can be divided into four categories, based on their physical properties. These four categories can be explained by different models of bonding.

A bond is a force of attraction, so it is not possible to see the actual bonds between atoms. However, a model can help to explain how atoms are bonded in substances. Models can also help us to understand how bonding accounts for certain properties of substances that we observe.

BIG IDEA There are four main types of chemical bonds between atoms.

The types of bonding are called *ionic, molecular covalent, metallic,* and *network covalent.* Take a moment to locate the valence electrons in each model on the next page. The red spheres represent the nuclei of atoms and the core electrons, while the blue areas suggest where the valence electrons are located.

Four Types of Bonding

MODEL 1: IONIC

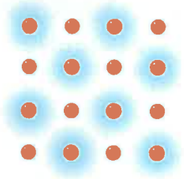
Properties of ionic substances:

Dissolve in water

Conduct electricity when dissolved

Tend to be brittle solids

Made of metal and nonmetal atoms combined



In **ionic bonding,** the valence electrons are *transferred* from one atom to another. Metal atoms transfer their valence electrons to nonmetal atoms.

MODEL 2: MOLECULAR COVALENT

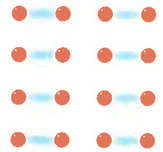
Properties of molecular covalent substances:

Some dissolve in water, some do not

Do not conduct electricity

Some are liquids or gases

Made entirely of nonmetal atoms



In **molecular covalent bonding,** the valence electrons are shared between pairs or groups of atoms. This creates small stable units, called molecules, within the substance.

MODEL 3: METALLIC

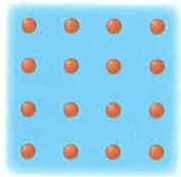
Properties of metallic substances:

Do not dissolve in water

Conduct electricity

Bendable, malleable solids

Made entirely of metal atoms



In **metallic bonding,** the valence electrons are free to move about the substance.

MODEL 4: NETWORK COVALENT

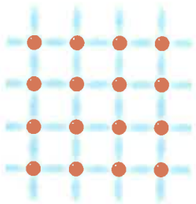
Properties of network covalent substances:

Do not dissolve in water

Do not conduct electricity

Extremely hard solids

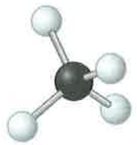
Made entirely of nonmetal atoms



Network covalent bonding is similar to molecular covalent bonding, but the valence electrons are shared throughout the entire substance.

You have already been introduced to ionic compounds. These all have ionic bonding in which metal atoms transfer valence electrons to nonmetal atoms. The resulting oppositely charged ions are strongly attracted to each other. This attraction is what holds the ions together.

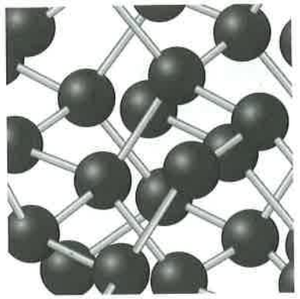
In **covalent bonding,** the nucleus of one atom is attracted to the valence electrons of another atom. Unlike ionic bonding, one atom does not transfer an electron to the other. Instead both atoms *share* the valence electrons between them.



Methane, CH_4

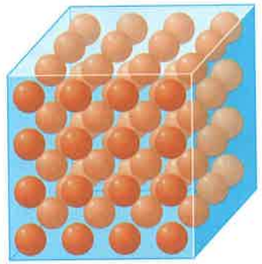
Covalent bonding can happen in two different ways. In molecular covalent bonding, the atoms bond to form individual clusters called **molecules,** such as the methane molecule shown here.

In network covalent bonding, the valence electrons are shared between atoms but form a highly regular extended network, creating a very durable structure. Diamond consists of carbon atoms that are covalently bonded in a network.



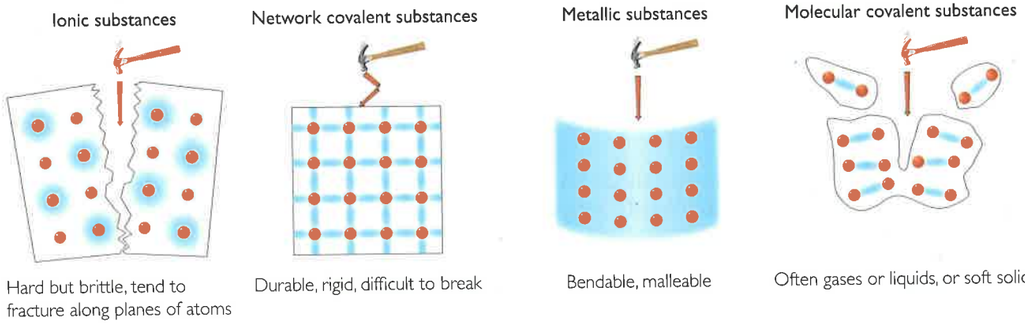
Diamond consists of carbon atoms that are covalently bonded in a network.

In a metal, the valence electrons are distributed throughout the substance in what is sometimes called a "sea" of electrons. The valence electrons are free to move throughout the substance. The atoms are bonded by the attraction between the positively charged atoms and the negatively charged "sea" of electrons.



3 Relating Bonds and Properties

Some properties of substances, such as solubility and conductivity, are directly related to the type of bonds the atoms in the substances have. Therefore, it is possible to match the bonding with the physical properties observed in different substances. Examine what happens to each type of substance when it is struck by a hypothetical hammer.



Hard but brittle, tend to fracture along planes of atoms

Durable, rigid, difficult to break

Bendable, malleable

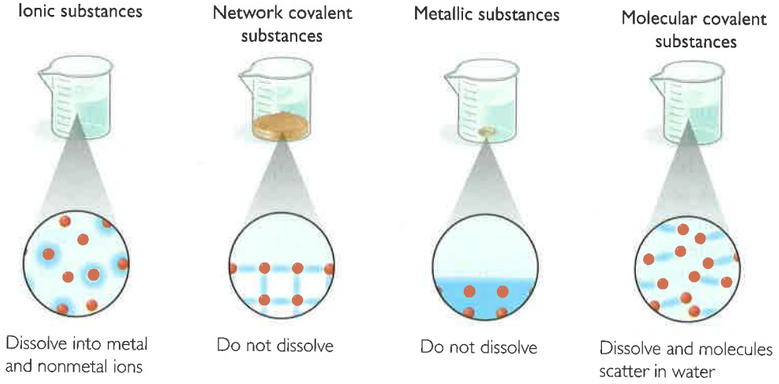
Often gases or liquids, or soft solids

Notice that the hardest substance is a solid with network covalent bonding. This is because bonding in these substances is in an organized network.

Bonding can also help to explain the properties of dissolving and conductivity. Examine the illustration on the top of the next page representing dissolving. Water is represented by the lighter blue areas. Ionic solids and molecular covalent substances dissolve in water. Metallic solids and network covalent solids do not.

INDUSTRY CONNECTION

Metals can be combined into alloys. For example, CuZn is brass, a copper-zinc alloy. Chrome-moly is an alloy of steel, chrome, and molybdenum, used to make bicycle frames that are stronger and lighter than those made of steel. Steel itself is an alloy of iron and carbon.



Dissolve into metal and nonmetal ions

Do not dissolve

Do not dissolve

Dissolve and molecules scatter in water

Conduction requires the movement of a charged particle, either an ion or an electron. Metals conduct electricity because the valence electrons are free to move throughout the solid. Ionic compounds that have been dissolved in water conduct electricity because the cations and anions are free to move in the solution. Network covalent solids and molecular covalent substances do not conduct electricity. The charge cannot move in these substances because the electrons are "stuck" between the atoms and are not available to move.

The periodic table is a valuable tool in figuring out bonding. You can use the table to determine if the elements in a compound are metals, nonmetals, or both.

- Ionic compounds, such as salts, are made from metal and nonmetal elements.
- Metallic compounds, such as brass, are made only of metal atoms.
- Network covalent compounds, such as diamonds, and molecular covalent compounds, such as methane, are made from nonmetals.

CONSUMER CONNECTION

Chalk, which is brittle, is an example of an ionic substance. The chemical name and formula for chalk is calcium carbonate, $CaCO_3$.

Example

Identifying the Type of Bonding

Determine the bonding in each of the following substances. What general physical properties can you expect of each substance?

a. magnesium chloride, $MgCl_2$

b. rubbing alcohol, C_3H_8O

Solution

a. Magnesium chloride, $MgCl_2$, is an ionic compound with ionic bonding because it is made of a metal and a nonmetal element. It is probably brittle, dissolves in water, and conducts electricity when dissolved.

b. Rubbing alcohol, C_3H_8O, is a molecular covalent substance with molecular covalent bonding because it is made entirely of nonmetal atoms and is a liquid.

Key Terms

chemical bond
ionic bonding
molecular covalent bonding
metallic bonding
network covalent bonding
covalent bonding
molecule

Lesson Summary

How are atoms connected to one another?

Atoms in substances are held together by chemical bonds. Chemists have identified four main types of bonding within substances: ionic, network covalent, molecular covalent, and metallic. Many properties of substances correspond to the type of bonding that is present.

EXERCISES

Reading Questions

1. Explain why substances do not simply crumble into piles of atoms.
2. Name the four types of bonding and explain them in your own words. Be specific about the location of the valence electrons.

SCILINKS NSTA

Topic: Chemical Bonding
Visit: www.SciLinks.org
Web code: KEY-126

Reason and Apply

3. Determine the type of bonding in each substance.
   a. zinc, $Zn(s)$
   b. propane, $C_3H_8(l)$
   c. calcium carbonate, $CaCO_3(s)$
4. Based on physical properties, which of these substances is an ionic compound? Explain your reasoning.
   A. hair gel **B.** silver bracelet **C.** motor oil **D.** baking soda
5. You observed nitrogen dioxide, $NO_2(g)$, when you dissolved copper, $Cu(s)$, in nitric acid in the Lab: The Copper Cycle. How would you classify the bonding in $NO_2(g)$? Explain.
6. Which statement is true?
   A. Aqueous solutions of calcium chloride, $CaCl_2$, conduct electricity.
   B. Glass, made of silicon dioxide, SiO_2, does not dissolve in water.
   C. Ethanol, C_2H_6O, dissolves in water but does not conduct electricity.
   D. Brass, also called copper zinc, CuZn, conducts electricity.
   E. All of the above are true.
7. Suppose you have a mixture of sodium chloride, NaCl, and carbon, C. Explain how you can use water to separate the two substances.
8. Explain why copper is used as wire, but copper chloride is not.
9. Explain why carbon is a solid and not a gas.
10. Will each of these substances dissolve in water? Explain your thinking.
    a. Ca **b.** $NaNO_3$ **c.** Si **d.** CH_4 **e.** $CuSO_4$

LAB

Electroplating Metals

Safety Instructions

Wear safety goggles at all times.

The solution contains acid. Handle carefully. Rinse the nickel strips after they have been in the copper solution.

Purpose

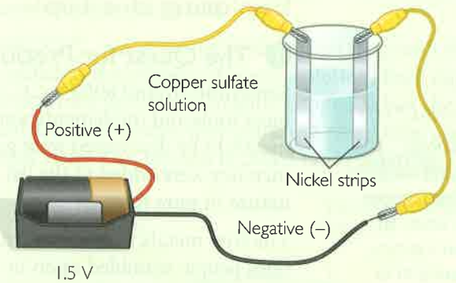
To use electrochemistry to extract metals from ionic compounds in solution.

Materials

- copper sulfate plating solution
- 250 mL beaker
- 2 nickel strips (cut into about 1-by-3-in. strips)
- 1.5-volt D-cell battery with holder
- 2 insulated wires with alligator clips

Procedure

1. Set up the electroplating apparatus as shown. Observe what happens.



2. Switch the sides of the battery to which the two alligator clips are attached. Wait at least one minute or until you notice a change.
3. Reverse the wiring back to its original position.

Observations

1. What did you observe when you hooked up the nickel strips to the battery?
2. What happened when you reversed the flow of electricity?
3. Where does the copper come from that ends up on the nickel strip?
4. What is in the copper sulfate solution?
5. Write a short paragraph explaining your observations.
6. **Making Sense** Are copper atoms and copper ions the same element? Explain your thinking.
7. **If You Finish Early** Consider a sample of gold chloride, $AuCl_3$. Explain what procedure you might follow in order to extract solid gold from the compound.