1.3 Breaking Bonds

Figure A1.8: Alchemy dates back to the ancient Egyptians.

Humans have been attempting to manipulate matter since the time of the ancient Egyptians, when the pseudoscience called *alchemy* developed. The goal of alchemy was to find some way to change non-precious metals, like lead, into gold—turning a resource of lesser value into a product of greater value. Alchemists were unsuccessful in many of their goals, but they did learn much about matter and became the forerunners of chemistry.

The alchemist's mind-set—wanting to turn resources into products of greater value—is still very much alive in modern societies. Today, industries take resources from Earth and chemically change them into the products you buy as a consumer. Industries are able to carry out this transformation because of their knowledge of matter. They change matter from raw materials into finished products by applying chemical properties.

How are raw materials transformed into products? In Lesson 1.2 you explored the different ways in which atoms bond with each other to form matter. You also found that the different categories of matter are made up of different combinations of atoms. To make a specific material, you need to create a specific combination of atoms. To create a specific combination of atoms, you need to do the following:

1) Find a natural source of the atoms you want. These atoms most likely will be bonded in a way that is different from what you want.
2) Break the existing bonds between the atoms in the natural source to separate them.
3) Create new bonds between the atoms required to form your product.

Assuming you have a natural source of the atoms you require, how can the existing chemical bonds between atoms be broken? For many substances, it is just a matter of adding water.

Practice

13. Outline the similarities and differences between the goals and methods of alchemy and the goals and methods of modern industry.

14. List the steps that must occur for you to successfully change a resource into a desired product.

15. Explain why it is necessary to disassemble the bonds of a resource before you assemble the bonds required for a desired product.

Observing Chemical Change

You can tell a **chemical change** is occurring if a new substance is produced, accompanied by a change in colour, odour, state, or energy. Changes in state usually involve the formation of a gas or a solid. Changes in energy may be **exothermic**—energy is released—or **endothermic**—energy is absorbed. Chemical changes indicate that bonds between atoms in the original substances have been broken and that bonds have been formed to create new substances. In the next activity you will observe chemical change.

- **chemical change:** a change in which one or more new substances with different properties is formed
- **exothermic change:** a chemical change in which energy, usually in the form of heat, is released into the surroundings
- **endothermic change:** a chemical change in which energy is absorbed from the surroundings

Try This Activity

Water Helps Break Chemical Bonds

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will observe a chemical change.

Materials

- 4, 100-mL beakers
- 10 mL (2 teaspoons) of cobalt(II) nitrate, $Co(NO_3)_2(s)$ (powder)
- 10 mL (2 teaspoons) of sodium carbonate, $Na_2CO_3(s)$ (washing soda)
- 20 mL of distilled water

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Carefully add 5 mL of cobalt(II) nitrate, $Co(NO_3)_2(s)$, to a beaker.

step 2: Add 5 mL of sodium carbonate, $Na_2CO_3(s)$, to the beaker with the cobalt(II) nitrate. Stir the two solids together and note any signs of chemical change.

step 3: Add 5 mL of cobalt(II) nitrate, $Co(NO_3)_2(s)$, to another beaker.

step 4: Add 10 mL of water to the beaker with the cobalt(II) nitrate, and dissolve the crystals.

step 5: Repeat steps 3 and 4 with sodium carbonate, $Na_2CO_3(s)$.

step 6: Combine the two solutions, and note any evidence of chemical change.

Analysis

1. Compare your observations in step 2 with those in step 6.

2. Describe the effect water appears to have on solid cobalt(II) nitrate and solid sodium carbonate. Describe the effect water has on this chemical reaction between the two substances.

3. Write the chemical equations for step 2 and for step 6. Be sure to communicate the states of each substance.

4. Provide an explanation for both of your observations in this activity.

Solutions: An Excellent Medium for Chemical Changes

A **solution** is a mixture made up of more than one type of particle, where the particles intermingle with one another. Solutions appear as though they are composed of only one substance, even though they contain more than one species within them. Many of the reactions that occur in the world occur when matter is dissolved in water, forming an **aqueous solution**.

solution: a homogeneous mixture of dissolved substances that contains a solute and a solvent

aqueous solution: a solution in which water is the solvent

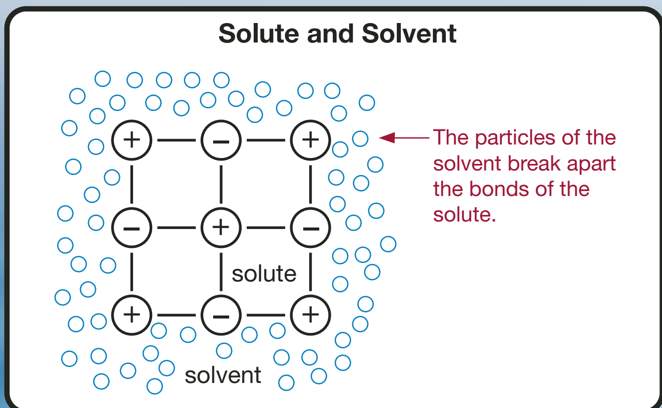
Figure A1.9: The salt crystals are no longer visible because the water broke the bonds of the ionic crystal.

Why does the salt solution shown in Figure A1.9 appear transparent? Where have the particles of the ionic crystal gone? In the "Water Helps Break Chemical Bonds" activity—where you added water to solid cobalt(II) nitrate—the ionic bonds between the positive cobalt(II) ions, Co^{2+}, and the negative nitrate ions, NO_3^-, were broken. The particles of the ionic crystal became dispersed throughout the water. The cobalt ions are responsible for the pink colour of the solution. The ionic compound has dissolved, but why does it appear to break apart?

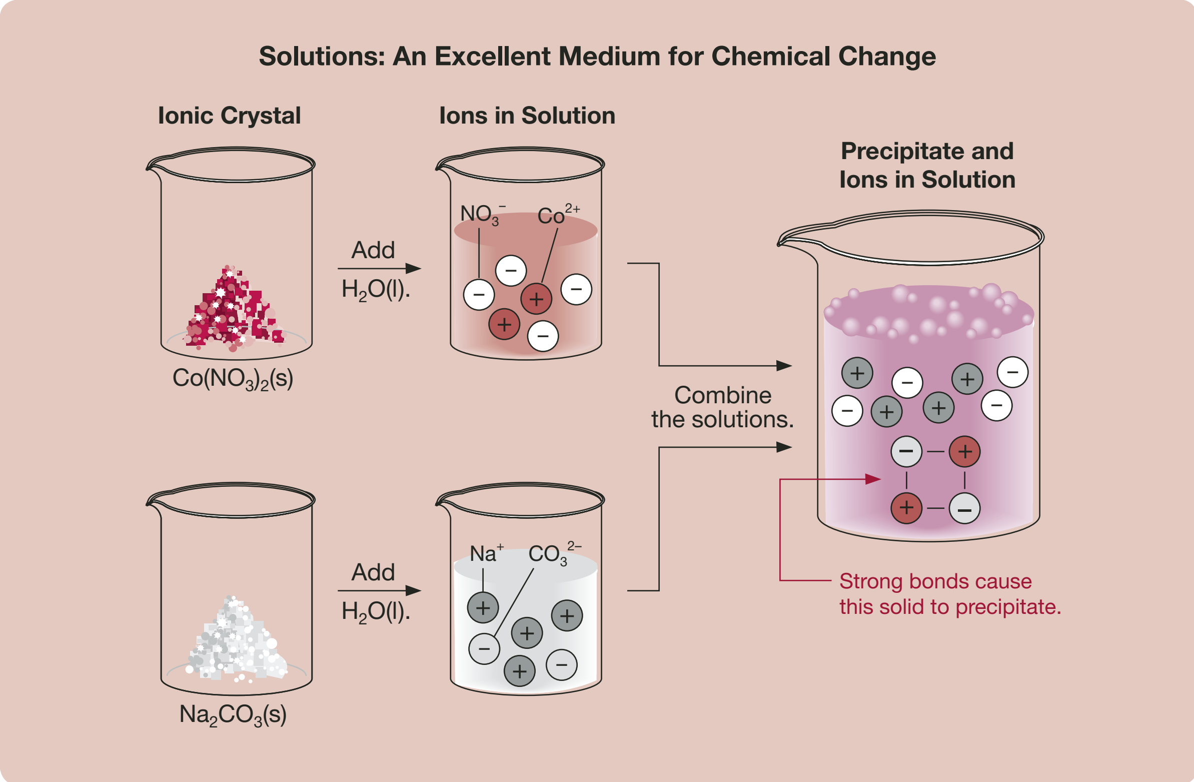
When something becomes dissolved, its bonds have been broken down in some way. As the bonds break, the particles separate and are then free to move as individuals throughout the solution. These particles can be either molecules or ions. The substance that is broken down is called the **solute**, and the substance that breaks the bonds of the solute is called the **solvent**. Remember, a solute dissolves in a solvent.

solute: a substance in a solution whose bonds are broken by a solvent; a substance that dissolves

solvent: a substance in a solution that breaks down the bonds of a solute; a substance that does the dissolving and is in greater proportion in the mixture



Using a solvent, like water, is an excellent way to break down certain types of bonds in a substance. For this reason, many reactions naturally occur in solution. When a solute has been broken down into its individual parts, these parts are no longer bonded to other ions. This allows each ion to collide with and form new bonds with substances introduced into the solution. In the "Water Helps Break Chemical Bonds" activity, you purposely broke the bonds between the cobalt(II) ions and the nitrate ions and the bonds between the sodium ions and the carbonate ions with the addition of water, which acted as a solvent. Once the old bonds were broken, the particles were free to collide and form new bonds, some of which resulted in the formation of the precipitate cobalt(II) carbonate, $CoCO_3(s)$.



Practice

16. Define and provide an example for the following terms.
    a. solution
    b. solute
    c. solvent
17. Explain why solutions look as though they are only one substance.
18. Compare and contrast the concept of dissolving with the concept of melting.
19. Explain how water is an excellent medium for chemical change.
20. Refer to the "Water Helps Break Chemical Bonds" activity on page 25. Identify the solvents and solutes you encountered.

Why Is Water a Good Solvent?

Take an inflated balloon and rub it on your head to produce a static charge on the balloon. Turn on a faucet just enough to get a small stream of water. Now, slowly place the balloon close to the stream of water. What happens to the stream?

Figure A1.10: A balloon that is statically charged will bend a stream of water without touching it.

You will notice that the stream of water bends toward the balloon. In fact, it doesn't matter whether the charged object is negative—like the balloon—or positive. The stream of water will always bend toward the charged object. The bending of the stream of water, and its apparent attraction to positive or negative objects, means that water molecules contain both negative and positive charges. How does this property connect to water's ability to act as a solvent?

Lewis Dot Diagram of Water

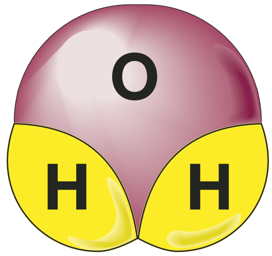
H : Ö : H

To answer this question, it helps to look at the atomic structure of a water molecule. A water molecule is composed of two hydrogen atoms covalently bonded to an oxygen atom. The covalent bonds within a water molecule involve oxygen and hydrogen sharing electrons so each obtains a full outer energy level.

Although the Lewis dot diagram communicates that the oxygen atom and both hydrogen atoms have full outer energy levels, it has limitations. A Lewis dot diagram is a simplified two-dimensional representation of a three-dimensional object.

A three-dimensional diagram reveals that a water molecule has a bent shape.

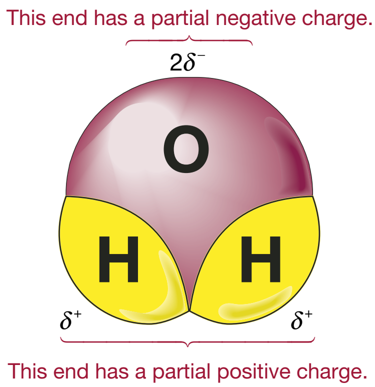
Water Molecule



This shape becomes significant because the sharing of electrons between a hydrogen atom and an oxygen atom is unequal. The oxygen atom tends to keep the shared pairs of electrons from its bonds to the two hydrogen atoms closer to itself. By keeping the electrons close to itself, the unequal sharing of electrons results in a partial negative charge on the oxygen atom and a partial positive charge on each of the hydrogen atoms. The bent shape, combined with the unequal sharing of electrons, results in a water molecule that has a partial positive charge on one end and a partial negative charge on the other end.

The symbol for a partial positive charge is δ^{+} (read as "delta positive"), whereas the symbol for a partial negative charge is δ^{-} (read as "delta negative"). Note that the two single partial positive charges are balanced by the partial negative charge. This results in a neutral water molecule.

Charge Distribution Within a Water Molecule

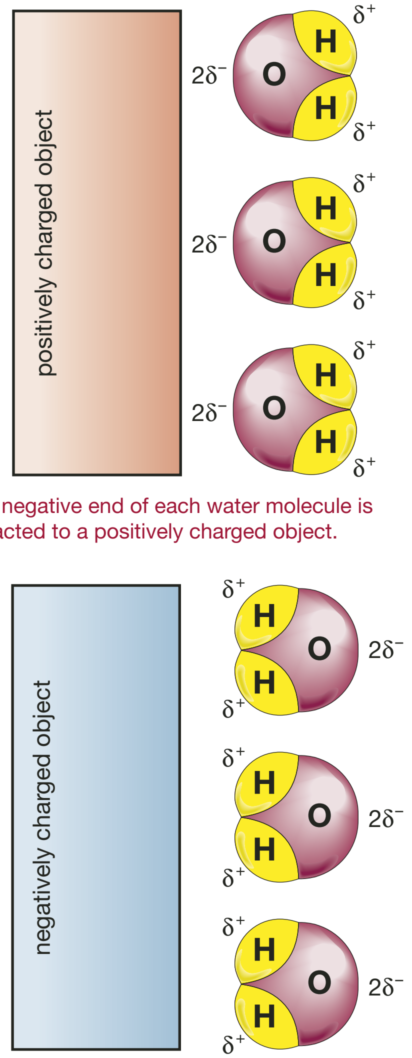


The uneven charge distribution is why water is called a **polar molecule**. As you learned in previous courses, many of water's special properties are due to its polar nature.

polar molecule: a molecule with a partial positive charge at one end and a partial negative charge at the other end

Because water molecules are polar, slightly positive on one side and slightly negative on the other side, they can be attracted to objects that are either positively or negatively charged. The following graphic shows this.

Attractive Properties of Water Molecules



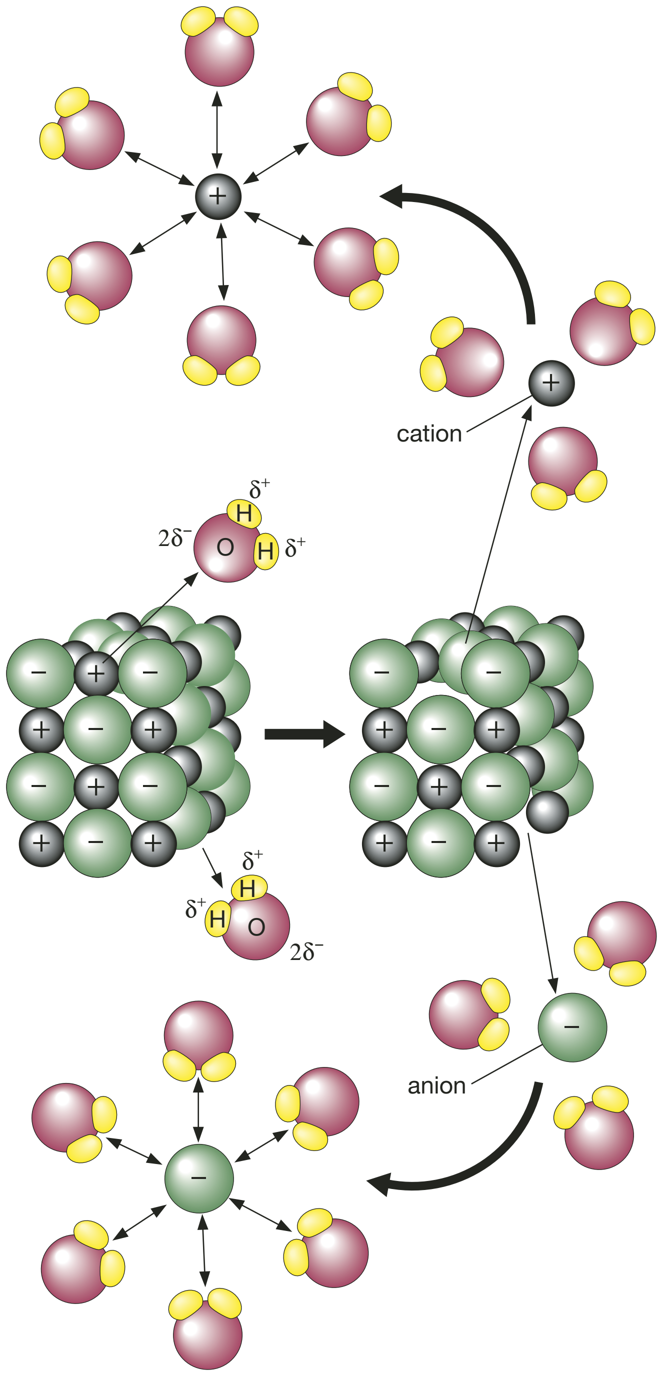
The negative end of each water molecule is attracted to a positively charged object.

The positive end of each water molecule is attracted to a negatively charged object.

Understanding the partial charges on a water molecule helps explain why the water from the tap was attracted to the statically charged balloon. Static electrical charges are produced when electrons are transferred. The balloon becomes negatively charged because it picks up some electrons when it is rubbed against your hair. When the stream of water is exposed to the negatively charged balloon, the positive ends of the water molecules are attracted to the balloon and the stream of water is drawn toward the balloon.

Does the fact that water is a polar molecule help explain why water is a powerful solvent? To answer this question, you need to look at the process of dissolving on a microscale.

Water Molecules Dissolving an Ionic Crystal



Water is a very powerful solvent. It has the ability to dissolve most ionic crystals because they are all made up of positively and negatively charged ions. Some ionic compounds have lower solubility in water than others, but all ionic compounds dissolve in water to some extent.

Some substances held together by covalent bonds, like oil, do not dissolve in water; but others, like glucose, readily dissolve in water. Could dissolving a molecular compound in water be related to the compound's charge? As described earlier, in some covalent bonds, electrons are not shared equally and the molecule ends up with an uneven charge distribution (just like water). Water molecules are electrostatically attracted to these molecules. Water molecules will surround the slightly charged particle and cause it to dissolve. Some molecules, however, will not have areas with different charges. As a result, they will not attract water molecules and, therefore, will not dissolve in water.

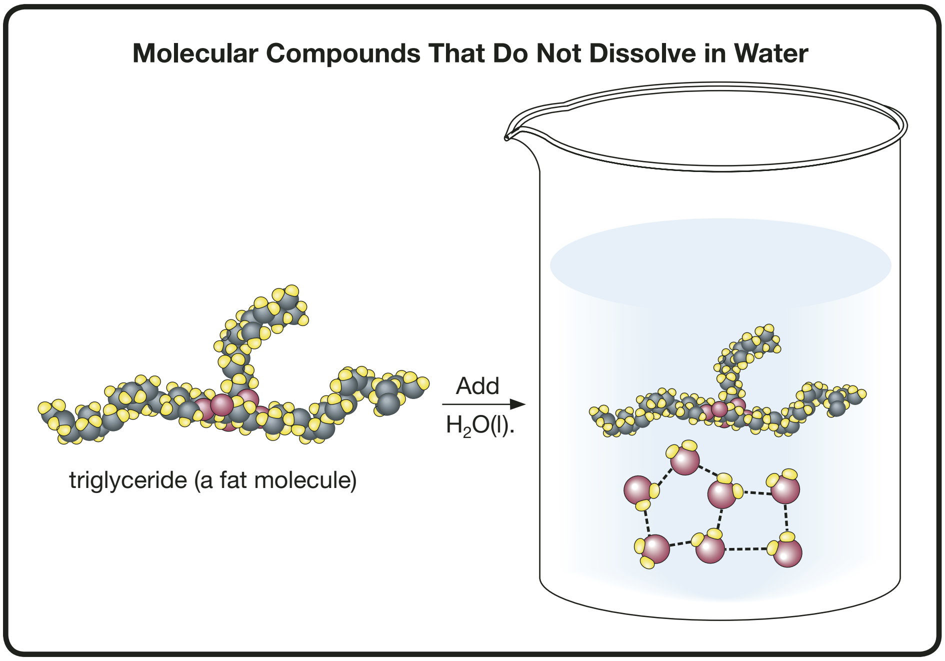


Figure A1.11: The positive and negative ends of the water molecules attract each other instead of being attracted to the triglyceride molecule.

Practice

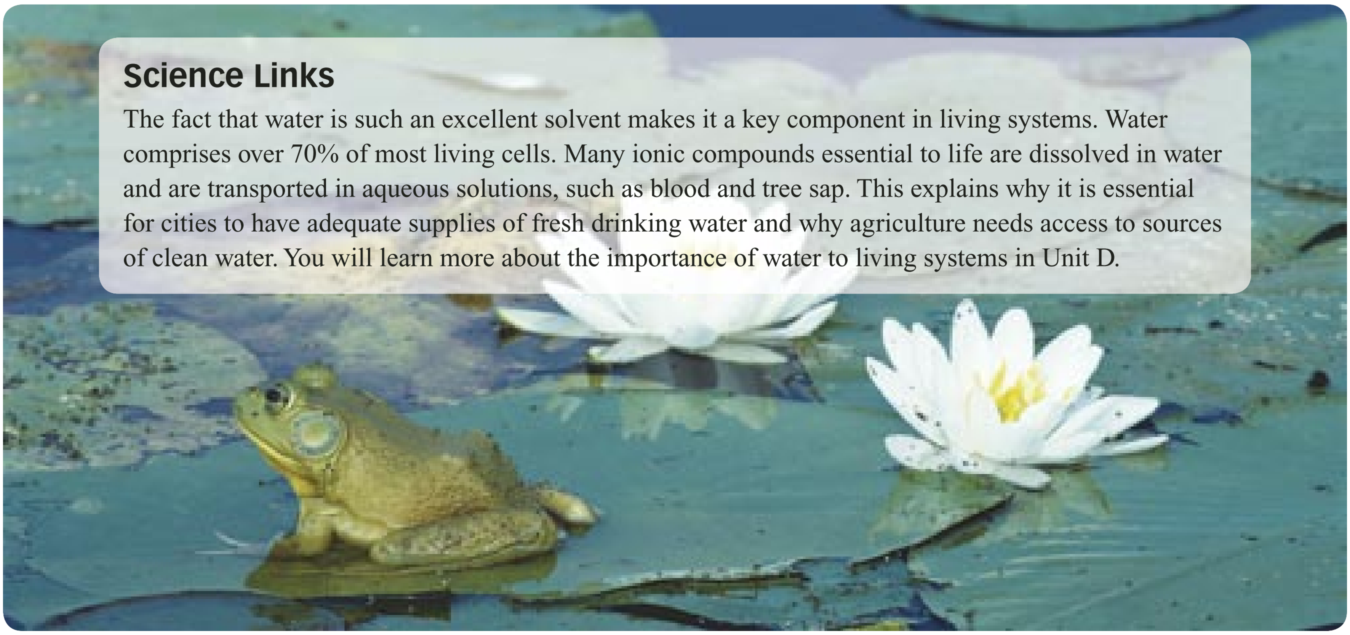
21. Explain why water is an effective solvent for ionic compounds.

22. Draw a diagram outlining the process of water dissolving a solute.

23. Explain why it is difficult to wash oil-based paints off your hands using only water.

Science Links

The fact that water is such an excellent solvent makes it a key component in living systems. Water comprises over 70% of most living cells. Many ionic compounds essential to life are dissolved in water and are transported in aqueous solutions, such as blood and tree sap. This explains why it is essential for cities to have adequate supplies of fresh drinking water and why agriculture needs access to sources of clean water. You will learn more about the importance of water to living systems in Unit D.



The Dissociation of Ionic Compounds

Figure A1.12: Many factories are located near water because of water's dissolving capabilities.

Did you ever wonder why many industrial factories are located by a source of water? The simple answer is that plant processes often require large amounts of water for the chemical reactions that occur within the plant. Water is a major requirement for most chemical industries because it effectively breaks down bonds and allows chemical reactions to occur.

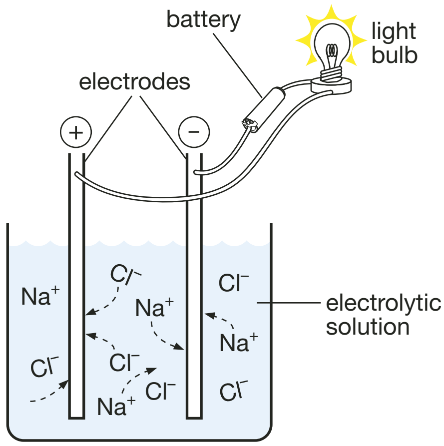
When an ionic compound dissolves in water, the bonds between ions within the ionic solid are broken by water molecules. As a result, free ions exist in the water. The breaking down of an ionic compound into its smaller parts is called **dissociation**.

Notice that when ionic compounds dissociate, they produce negatively charged and positively charged particles within the solution. If you have negatively charged and positively charged particles within a solution, the particles can move in response to other charged objects. A simple conductivity test involves placing two electrodes of a conductivity apparatus in a solution. The different charges of each electrode attract different ions. If the ions are dissociated and free to move, they can move toward one of the electrodes. The resulting movement of ions acts to move charged particles, completing the electrical circuit of the conductivity meter. Solutes that conduct an electrical current when in a solution are called **electrolytes**.

dissociation: the separation of an ionic compound into individual ions in a solution

electrolyte: a solute that forms a solution that conducts electricity

Conductivity Meter and an Electrolyte



Dissociated ions can move toward the oppositely charged electrodes of the conductivity meter. The movement of ions (charges) completes the circuit of the conductivity meter.

Non-electrolytes

Water cannot break the covalent bonds between atoms in molecular compounds, yet many dissolve in water. Molecular compounds do not dissociate like ionic compounds. Water simply separates the molecules of the solute if they have an uneven distribution of charge due to the unequal sharing of electrons in the covalent bonds.

A Dissolving Equation for a Molecular Compound

$$C_{12}H_{22}O_{11}(s) \xrightarrow{H_2O(l)} C_{12}H_{22}O_{11}(aq)$$

solid molecular compound | aqueous molecular compound

A solution of a molecular compound does not contain negative and positive ions. Because of the lack of oppositely charged particles in the solution, the electrical circuit of the conductivity apparatus will not be completed. A substance that forms a non-conducting solution is called a **non-electrolyte**.

non-electrolyte: a solute in a solution that does not conduct an electric current

Practice

24. Identify each compound as either an ionic compound or a molecular compound. List the ions that each ionic compound would dissociate into. State whether the compound would be classified as an electrolyte or a non-electrolyte if it was added to water.

a. $KBr(s)$ **b.** $AgNO_3(s)$
c. $Li_3PO_4(s)$ **d.** $CO_2(g)$
e. $Al_2(SO_4)_3(s)$ **f.** $Na_2S(s)$

Investigation

Aqueous Solutions

Purpose

You will design and perform an experiment that will allow you to classify solutions as either electrolytes or non-electrolytes.

Prediction

Make predictions for each solution using what you know about the different types of compounds.

Science Skills

✓ Initiating and Planning
✓ Performing and Recording
✓ Analyzing and Interpreting
✓ Communication and Teamwork

Materials

- conductivity meter
- multi-well dish, watch glasses, or Petri dishes
- the following solutions in dropper bottles:
  – 0.100-mol/L aqueous sodium chloride, $NaCl(aq)$
  – 0.100-mol/L aqueous sucrose, $C_{12}H_{22}O_{11}(aq)$
  – 0.100-mol/L hydrochloric acid, $HCl(aq)$
  – 0.100-mol/L aqueous ethanol, $C_2H_5OH(aq)$
  – 0.100-mol/L aqueous sodium hydroxide, $NaOH(aq)$
  – 0.100-mol/L aqueous sodium sulfate, $Na_2SO_4(aq)$
  – 0.100-mol/L aqueous acetone, $CH_3OCH_3(aq)$
- **MSDS** information for each solution

MSDS: Material Safety Data Sheet

CAUTION!

Use gloves, safety glasses, and a lab apron for this investigation.

Procedure

step 1: Predict which solutions are electrolytes and which are non-electrolytes. Use the information that has been presented in this chapter to support your predictions.

step 2: Develop an experimental design that includes the following considerations:

- **Safety:** Identify solutions that contain compounds that are irritants or that may cause some other safety concern. Consult the MSDS information for each solution.
- **Manipulation of apparatus:** You have already used a conductivity meter in Lesson 1.1; but if necessary, seek further instruction from your teacher.
- **Clean-up:** Learn the proper procedure for the disposal of chemical wastes. Determine how the conductivity meter and the glassware should be cleaned and put away.

step 3: Have your teacher approve your procedure before you begin.

step 4: Follow your procedure, and record the results.

step 5: Compare your results with the findings of other groups. Identify which of your results are consistent with those collected by other groups. Identify the results that are inconsistent.

Analysis

1. Compare your predictions with your results. Did they match? Were there some solutions that surprised you?
2. Discuss any difficulties you came across as you carried out your investigations. Did these difficulties affect your ability to draw conclusions?
3. Suggest two ways to improve your investigation. How can you make your results more accurate?
4. Account for any inconsistencies between the results your group obtained and the findings of other groups.

1.3 Summary

People have been attempting to manipulate matter for a very long time. The first step in making a specific compound from a resource is to break the existing bonds and then produce the desired bonds.

Dissolving a substance in water can be an effective way of breaking bonds. Water is a strong solvent because it has a partial positive charge on one end and a partial negative charge on the other end.

All ionic compounds dissociate into separate ions in aqueous solutions, whereas only some molecular compounds dissolve into separate molecules in aqueous solutions. This is because in order for a substance to dissolve in water, it must be attracted to water molecules. Substances that are not attracted to water molecules do not dissolve in water.

Electrolytes are solutes that form solutions that conduct electricity. Non-electrolytes are solutes that form solutions that do not conduct electricity.

1.3 Questions

Knowledge

1. Define the following terms.
   a. solubility
   b. dissolving
   c. aqueous solution
   d. dissociation
   e. electrolyte
   f. non-electrolyte
2. Describe what occurs when something dissolves in water.
3. Compare and contrast how an ionic compound dissolves with how a molecular compound dissolves.

Applying Concepts

4. State at least three ways in which you use aqueous solutions.
5. Medication is often given to patients in the form of a solid pill that must be swallowed. An alternative method is to administer the medication in an intravenous solution. Concisely explain why medications administered in a solid pill acts much more slowly than those administered in an intravenous solution.
6. Pure water does not conduct electricity. Explain why you still need to be careful about electricity near water.

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Legend: t = top, m = middle, b = bottom, l = left, r = right

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