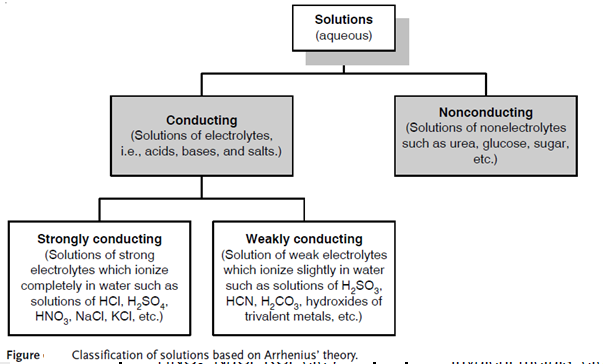
**Electrolytes:**

### LEARNING OBJECTIVES

By the end of this section, you will be able to:

* Define and give examples of electrolytes
* Distinguish between the physical and chemical changes that accompany dissolution of ionic and covalent electrolytes
* Relate electrolyte strength to solute-solvent attractive forces
* When some substances are dissolved in water, they undergo either a physical or a chemical change that yields ions in solution. These substances constitute an important class of compounds called **electrolytes**. Substances that do not yield ions when dissolved are called **nonelectrolytes**. If the physical or chemical process that generates the ions is essentially 100% efficient (all of the dissolved compound yields ions), then the substance is known as a **strong electrolyte**. If only a relatively small fraction of the dissolved substance undergoes the ion-producing process, it is called a **weak electrolyte**.
* Substances may be identified as strong, weak, or nonelectrolytes by measuring the electrical conductance of an aqueous solution containing the substance. To conduct electricity, a substance must contain freely mobile, charged species. Most familiar is the conduction of electricity through metallic wires, in which case the mobile, charged entities are electrons. Solutions may also conduct electricity if they contain dissolved ions, with conductivity increasing as ion concentration increases. Applying a voltage to electrodes immersed in a solution permits assessment of the relative concentration of dissolved ions, either quantitatively, by measuring the electrical current flow,



There are a number of ways by which acids have been classified. On the basis of their molecular constitutions, acids are generally divided into two classes: (i) hydracids and (ii) oxyacids. Acids which contain hydrogen and a nonmetallic element (other than oxygen) or a radical are known as hydracids. It should be noted that the names of the hydracids usually begin with the prefix hydro and end with the suffix ic; for example, HCl (hydrochloric acid), HI (hydroiodic acid), HCN (hydrocyanic acid), and H2SO4 (hydrosulfuric acid). The acids which contain oxygen besides hydrogen and a nonmetallic element or a radical are called oxy-acids. The oxy-acids are named according to the nonmetallic elements present in them and their oxygen content. It is customary that the names of the acids having larger proportions of oxygen terminate in “ic”, and the names of the acids containing smaller proportions of oxygen end in “ous”. If an element forms a series of oxy-acids, the prefixes “hypo” or “per” are added to the names of the acids, respectively. All these points have been conveyed in Table 6.2. Besides these, acids are also classified according to the sources, to the basicity or number of replaceable hydrogen atoms and to their strength. According to their sources, acids may be classified into:

\_ Mineral acids: these are acids derived from mineral substances, such as, for example,

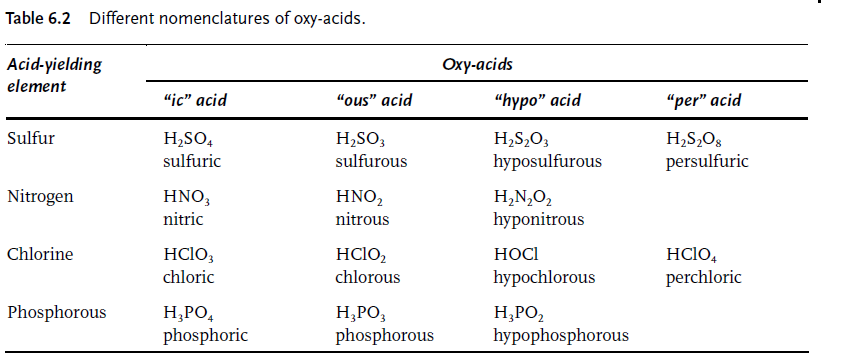
hydrochloric acid which is obtained from common salt, nitric acid from sodium or potassium

nitrate, sulfuric acid from sulfur, phosphoric acid from calcium phosphate, etc.

\_ Organic acids: these are acids which contain carbon as an essential element and are

obtained from either plants or animals, such as, for example, formic acid (HCOOH),

acetic acid (CH3COOH), etc.



According to the second criterion, acids are classified into:

\_ Monobasic acids: these are acids whose molecules contain only one replaceable hydrogen atom, such as, for example, HCl, HNO3, HClO3, etc.; acetic acid (CH3COOH), although containing four hydrogen atoms per molecule, is only monobasic since only one hydrogen atom belonging to it can be replaced by a metal or a group of elements equivalent to a metal.

\_ Dibasic acids: these are acids that have two replaceable hydrogen atoms in each molecule, such as, for example, H2SO4, H2SO3, H2CO3, etc.

\_ Tribasic acids: these are acids which have three replaceable hydrogen atoms in each molecule,

such as, for example, H3PO4.

According to the criterion of the strength of acids they are grouped into two classes: strong

acids and weak acids. Some examples of strong acids include HCl, H2SO4, HNO3, HClO4,

etc., and those of weak acids include H2CO3, CH3COOH, etc.

or qualitatively, by observing the brightness of a light bulb included in the circuit (Figure 1).

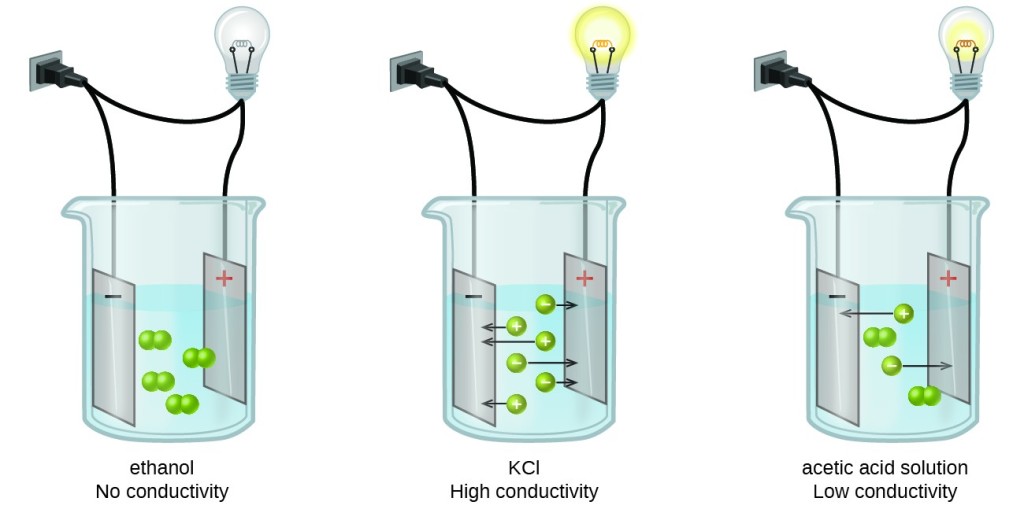
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Figure 1. Solutions of nonelectrolytes such as ethanol do not contain dissolved ions and cannot conduct electricity. Solutions of electrolytes contain ions that permit the passage of electricity. The conductivity of an electrolyte solution is related to the strength of the electrolyte.

## Ionic Electrolytes

Water and other polar molecules are attracted to ions, as shown in Figure 2. The electrostatic attraction between an ion and a molecule with a dipole is called an **ion-dipole attraction**. These attractions play an important role in the dissolution of ionic compounds in water.

When ionic compounds dissolve in water, the ions in the solid separate and disperse uniformly throughout the solution because water molecules surround and solvate the ions, reducing the strong electrostatic forces between them. This process represents a physical change known as **dissociation**. Under most conditions, ionic compounds will dissociate nearly completely when dissolved, and so they are classified as strong electrolytes.

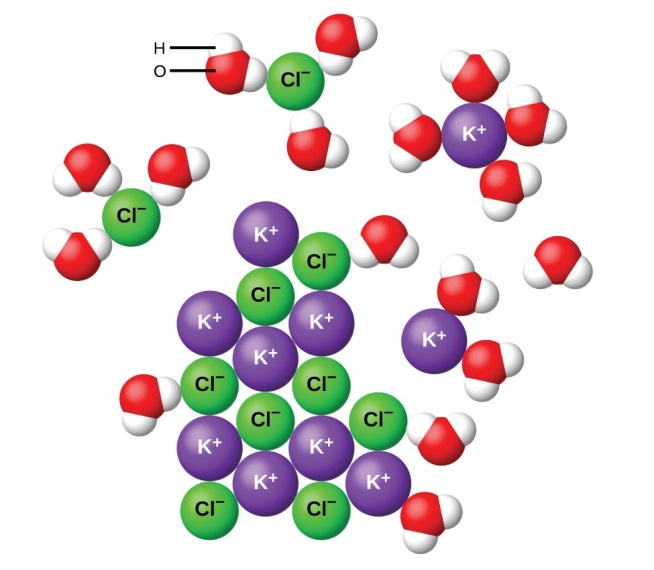


Figure 2. As potassium chloride (KCl) dissolves in water, the ions are hydrated. The polar water molecules are attracted by the charges on the K+ and Cl− ions. Water molecules in front of and behind the ions are not shown.

Let us consider what happens at the microscopic level when we add solid KCl to water. Ion-dipole forces attract the positive (hydrogen) end of the polar water molecules to the negative chloride ions at the surface of the solid, and they attract the negative (oxygen) ends to the positive potassium ions. The water molecules penetrate between individual K+ and Cl– ions and surround them, reducing the strong interionic forces that bind the ions together and letting them move off into solution as solvated ions, as Figure 2 shows. The reduction of the electrostatic attraction permits the independent motion of each hydrated ion in a dilute solution, resulting in an increase in the disorder of the system as the ions change from their fixed and ordered positions in the crystal to mobile and much more disordered states in solution. This increased disorder is responsible for the dissolution of many ionic compounds, including KCl, which dissolve with absorption of heat.

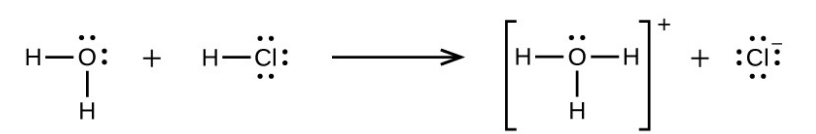
In other cases, the electrostatic attractions between the ions in a crystal are so large, or the ion-dipole attractive forces between the ions and water molecules are so weak, that the increase in disorder cannot compensate for the energy required to separate the ions, and the crystal is insoluble. Such is the case for compounds such as calcium carbonate (limestone), calcium phosphate (the inorganic component of bone), and iron oxide (rust).

## Covalent Electrolytes

Pure water is an extremely poor conductor of electricity because it is only very slightly ionized—only about two out of every 1 billion molecules ionize at 25 °C. Water ionizes when one molecule of water gives up a proton to another molecule of water, yielding hydronium and hydroxide ions.

In some cases, we find that solutions prepared from covalent compounds conduct electricity because the solute molecules react chemically with the solvent to produce ions. For example, pure hydrogen chloride is a gas consisting of covalent HCl molecules. This gas contains no ions. However, when we dissolve hydrogen chloride in water, we find that the solution is a very good conductor. The water molecules play an essential part in forming ions: Solutions of hydrogen chloride in many other solvents, such as benzene, do not conduct electricity and do not contain ions.

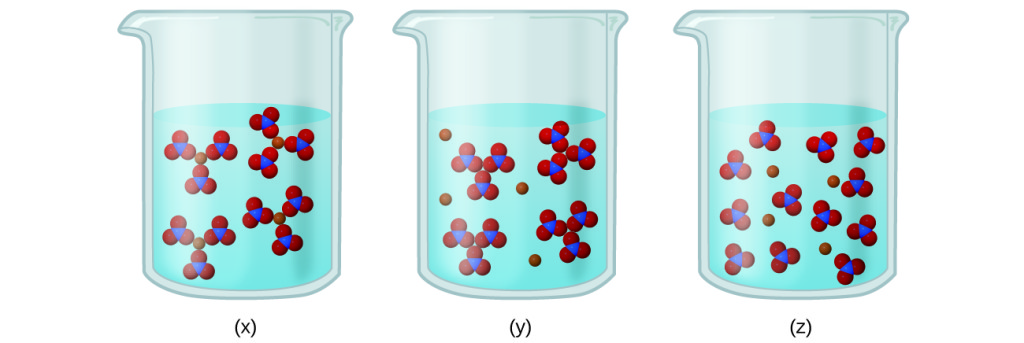
Hydrogen chloride is an *acid*, and so its molecules react with water, transferring H+ ions to form hydronium ions (H3O+) and chloride ions (Cl–):

 This reaction is essentially 100% complete for HCl (i.e., it is a strong acid and, consequently, a strong electrolyte). Likewise, weak acids and bases that only react partially generate relatively low concentrations of ions when dissolved in water and are classified as weak electrolytes. The reader may wish to review the discussion of strong and weak acids provided in the earlier chapter of this text on reaction classes and stoichiometry.

### KEY CONCEPTS AND SUMMARY

Substances that dissolve in water to yield ions are called electrolytes. Electrolytes may be covalent compounds that chemically react with water to produce ions (for example, acids and bases), or they may be ionic compounds that dissociate to yield their constituent cations and anions, when dissolved. Dissolution of an ionic compound is facilitated by ion-dipole attractions between the ions of the compound and the polar water molecules. Soluble ionic substances and strong acids ionize completely and are strong electrolytes, while weak acids and bases ionize to only a small extent and are weak electrolytes. Nonelectrolytes are substances that do not produce ions when dissolved in water.

### EXERCISES

1. Explain why the ions Na+ and Cl− are strongly solvated in water but not in hexane, a solvent composed of nonpolar molecules.
2. Explain why solutions of HBr in benzene (a nonpolar solvent) are nonconductive, while solutions in water (a polar solvent) are conductive.
3. Consider the solutions presented:  
   
   1. Which of the following sketches best represents the ions in a solution of Fe(NO3)3(aq)?
   2. Write a balanced chemical equation showing the products of the dissolution of Fe(NO3)3.
4. Compare the processes that occur when methanol (CH3OH), hydrogen chloride (HCl), and sodium hydroxide (NaOH) dissolve in water. Write equations and prepare sketches showing the form in which each of these compounds is present in its respective solution.
5. What is the expected electrical conductivity of the following solutions?
   1. NaOH(aq)
   2. HCl(aq)
   3. C6H12O6(aq) (glucose)
   4. NH3(l)
6. Why are most solid ionic compounds electrically nonconductive, whereas aqueous solutions of ionic compounds are good conductors? Would you expect a liquid (molten) ionic compound to be electrically conductive or nonconductive? Explain.
7. Indicate the most important type of intermolecular attraction responsible for solvation in each of the following solutions:
   1. the solutions in Figure 2
   2. methanol, CH3OH, dissolved in ethanol, C2H5OH
   3. methane, CH4, dissolved in benzene, C6H6
   4. the polar halocarbon CF2Cl2 dissolved in the polar halocarbon CF2ClCFCl2
   5. O2(l) in N2(l)

**Show Selected Answers**

1. Crystals of NaCl dissolve in water, a polar liquid with a very large dipole moment, and the individual ions become strongly solvated. Hexane is a nonpolar liquid with a dipole moment of zero and, therefore, does not significantly interact with the ions of the NaCl crystals.

3. The answers are as follows:

1. Fe(NO3)3 is a strong electrolyte, thus it should completely dissociate into Fe3+ and (NO3−) ions. Therefore, (*z*) best represents the solution.
2. Fe(NO3)3(*s*) ⟶ Fe3+(*aq*) + 3NO3−(*aq*)

5. The expected electrical conductivity is as follows:

1. high conductivity (solute is an ionic compound that will dissociate when dissolved);
2. high conductivity (solute is a strong acid and will ionize completely when dissolved);
3. nonconductive (solute is a covalent compound, neither acid nor base, unreactive towards water);
4. low conductivity (solute is a weak base and will partially ionize when dissolved)

7. The types of intermolecular attraction are as follows:

1. ion-dipole;
2. hydrogen bonds;
3. dispersion forces;
4. dipole-dipole attractions;
5. dispersion forces