Skills to Develop

- To recognize a compound as an Arrhenius acid or an Arrhenius base.

One way to define a class of compounds is by describing the various characteristics its members have in common. In the case of the compounds known as acids, the common characteristics include a sour taste, the ability to change the color of the vegetable dye litmus to red, and the ability to dissolve certain metals and simultaneously produce hydrogen gas. For the compounds called bases, the common characteristics are a slippery texture, a bitter taste, and the ability to change the color of litmus to blue. Acids and bases also react with each other to form compounds generally known as salts.

![Acid and Base Characteristics](image)

Although we include their tastes among the common characteristics of acids and bases, we never advocate tasting an unknown chemical!

Chemists prefer, however, to have definitions for acids and bases in chemical terms. The Swedish chemist Svante Arrhenius developed the first chemical definitions of acids and bases in the late 1800s. Arrhenius defined an acid as a compound that increases the concentration of hydrogen ion (H\(^+\)) in aqueous solution. Many acids are simple compounds that release a hydrogen cation into solution when they dissolve. Similarly, Arrhenius defined a base as a compound that increases the concentration of hydroxide ion (OH\(^-\)) in aqueous solution. Many bases are ionic compounds that have the hydroxide ion as their anion, which is released when the base dissolves in water.

**Table 1**: Formulas and Names for Some Acids and Bases

<table>
<thead>
<tr>
<th>Acids</th>
<th>Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl(aq)</td>
<td>NaOH(aq) sodium hydroxide</td>
</tr>
<tr>
<td>HBr(aq)</td>
<td>KOH(aq) potassium hydroxide</td>
</tr>
<tr>
<td>HI(aq)</td>
<td>Mg(OH)(_2)(aq) magnesium hydroxide</td>
</tr>
<tr>
<td>H(_2)S(aq)</td>
<td>Ca(OH)(_2)(aq) calcium hydroxide</td>
</tr>
<tr>
<td>HC(_2)H(_3)O(_2)(aq)</td>
<td>HNO(_3)(aq) nitric acid</td>
</tr>
<tr>
<td>HNO(_2)(aq)</td>
<td>NH(_3)(aq) ammonia</td>
</tr>
</tbody>
</table>
Many bases and their aqueous solutions are named using the normal rules of ionic compounds that were presented previously; that is, they are named as hydroxide compounds. For example, the base sodium hydroxide (NaOH) is both an ionic compound and an aqueous solution. However, aqueous solutions of acids have their own naming rules. The names of binary acids (compounds with hydrogen and one other element in their formula) are based on the root of the name of the other element preceded by the prefix hydro- and followed by the suffix -ic acid. Thus, an aqueous solution of HCl [designated “HCl(aq)”] is called hydrochloric acid, H₂S(aq) is called hydrosulfuric acid, and so forth. Acids composed of more than two elements (typically hydrogen and oxygen and some other element) have names based on the name of the other element, followed by the suffix -ic acid or -ous acid, depending on the number of oxygen atoms in the acid’s formula. Other prefixes, like per- and hypo-, also appear in the names for some acids. Unfortunately, there is no strict rule for the number of oxygen atoms that are associated with the -ic acid suffix; the names of these acids are best memorized. Table \(\PageIndex{1}\) lists some acids and bases and their names. Note that acids have hydrogen written first, as if it were the cation, while most bases have the negative hydroxide ion, if it appears in the formula, written last.

The name oxygen comes from the Latin meaning “acid producer” because its discoverer, Antoine Lavoisier, thought it was the essential element in acids. Lavoisier was wrong, but it is too late to change the name now.

Example \(\PageIndex{1}\)

Name each substance.

a. HF(aq)
b. Sr(OH)₂(aq)

**SOLUTION**

a. This acid has only two elements in its formula, so its name includes the hydro- prefix. The stem of the other element’s name, fluorine, is fluor, and we must also include the -ic acid ending. Its name is hydrofluoric acid.

b. This base is named as an ionic compound between the strontium ion and the hydroxide ion: strontium hydroxide.
Name each substance.

a. $\text{H}_2\text{Se(aq)}$

b. $\text{Ba(OH)}_2\text{(aq)}$

Notice that one base listed in Table $\PageIndex{1}$—ammonia—does not have hydroxide as part of its formula. How does this compound increase the amount of hydroxide ion in aqueous solution? Instead of dissociating into hydroxide ions, ammonia molecules react with water molecules by taking a hydrogen ion from the water molecule to produce an ammonium ion and a hydroxide ion:

\[
\text{NH}_3\text{(aq)} + \text{H}_2\text{O(ℓ)} \rightarrow \text{NH}^+\text{(aq)} + \text{OH}^-\text{(aq)} \label{Eq1}
\]

Because this reaction of ammonia with water causes an increase in the concentration of hydroxide ions in solution, ammonia satisfies the Arrhenius definition of a base. Many other nitrogen-containing compounds are bases because they too react with water to produce hydroxide ions in aqueous solution.

**Neutralization**

As we noted previously, acids and bases react chemically with each other to form salts. A salt is a general chemical term for any ionic compound formed from an acid and a base. In reactions where the acid is a hydrogen ion containing compound and the base is a hydroxide ion containing compound, water is also a product. The general reaction is as follows:

\[
\text{acid + base} \rightarrow \text{water + salt}
\]

The reaction of acid and base to make water and a salt is called **neutralization**. Like any chemical equation, a neutralization chemical equation must be properly balanced. For example, the neutralization reaction between sodium hydroxide and hydrochloric acid is as follows:

\[
\text{NaOH(aq)} + \text{HCl(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(ℓ)} \label{Eq2}
\]

with coefficients all understood to be one. The neutralization reaction between sodium hydroxide and sulfuric acid is as follows:

\[
2\text{NaOH(aq)} + \text{H}_2\text{SO}_4\text{(aq)} \rightarrow \text{Na}_2\text{SO}_4\text{(aq)} + 2\text{H}_2\text{O(ℓ)} \label{Eq3}
\]

Once a neutralization reaction is properly balanced, we can use it to perform stoichiometry calculations, such as the ones we practiced earlier.

**Example** $\PageIndex{2}$

Nitric acid $[\text{HNO}_3\text{(aq)}]$ can be neutralized by calcium hydroxide $[\text{Ca(OH)}_2\text{(aq)}]$.

a. Write a balanced chemical equation for the reaction between these two compounds and identify the salt it produces.

b. For one reaction, 16.8 g of HNO$_3$ is present initially. How many grams of Ca(OH)$_2$ are needed to neutralize that much HNO$_3$?
c. In a second reaction, 805 mL of 0.672 M Ca(OH)₂ is present initially. What volume of 0.432 M HNO₃ solution is necessary to neutralize the Ca(OH)₂ solution?

**SOLUTION**

a. Because there are two OH⁻ ions in the formula for Ca(OH)₂, we need two moles of HNO₃ to provide H⁺ ions. The balanced chemical equation is as follows:

$$\text{Ca(OH)}_2(aq) + 2\text{HNO}_3(aq) \rightarrow \text{Ca(NO}_3)_2(aq) + 2\text{H}_2\text{O(l)}$$

The salt formed is calcium nitrate.

b. This calculation is much like the calculations we did in Chapter 6 "Quantities in Chemical Reactions". First we convert the mass of HNO₃ to moles using its molar mass of $1.01 + 14.00 + 3(16.00) = 63.01 \text{ g/mol}$; then we use the balanced chemical equation to determine the related number of moles of Ca(OH)₂ needed to neutralize it; and then we convert that number of moles of Ca(OH)₂ to the mass of Ca(OH)₂ using its molar mass of $40.08 + 2(1.01) + 2(16.00) = 74.10 \text{ g/mol}$.

\[
16.8 \text{ g HNO}_3 \times \frac{1 \text{ mol HNO}_3}{63.01 \text{ g HNO}_3} \times \frac{1 \text{ mol Ca(OH)}_2}{2 \text{ mol HNO}_3} \times \frac{74.10 \text{ g Ca(OH)}_2}{1 \text{ mol Ca(OH)}_2} = 9.88 \text{ g Ca(OH)}_2 \text{ needed}
\]

c. Having concentration information allows us to employ the skills we developed in Chapter 9. First, we use the concentration and volume data to determine the number of moles of Ca(OH)₂ present. Recognizing that 805 mL = 0.805 L,

\[
0.672 \text{ M Ca(OH)}_2 \times 0.805 \text{ L soln} = \text{ mol Ca(OH)}_2 = 0.541 \text{ mol Ca(OH)}_2
\]

We combine this information with the proper ratio from the balanced chemical equation to determine the number of moles of HNO₃ needed:

\[
0.541 \text{ mol Ca(OH)}_2 \times \frac{2 \text{ mol HNO}_3}{1 \text{ mol Ca(OH)}_2} = 1.08 \text{ mol HNO}_3
\]

Now, using the definition of molarity one more time, we determine the volume of acid solution needed:

\[
0.432 \text{ M HNO}_3 \times \frac{1.08 \text{ mol HNO}_3}{\text{volume of soln: of HNO}_3} = 2.50 \times 10^{-3} \text{ mL}
\]

Exercise \(\PageIndex{2}\))

Hydrocyanic acid [HCN(aq)] can be neutralized by potassium hydroxide [KOH(aq)].

a. Write a balanced chemical equation for the reaction between these two compounds and identify the salt it produces.

b. For one reaction, 37.5 g of HCN is present initially. How many grams of KOH are needed to neutralize that much HCN?
c. In a second reaction, 43.0 mL of 0.0663 M KOH is present initially. What volume of 0.107 M HCN solution is necessary to neutralize the KOH solution?

Hydrocyanic acid (HCN) is one exception to the acid-naming rules that specify using the prefix hydro- for binary acids (acids composed of hydrogen and only one other element).

Concept Review Exercises

1. Give the Arrhenius definitions of an acid and a base.
2. What is neutralization?

Answers

1. Arrhenius acid: a compound that increases the concentration of hydrogen ion (H+) in aqueous solution; Arrhenius base: a compound that increases the concentration of hydroxide ion (OH−) in aqueous solution.
2. The reaction of an acid and a base

Key Takeaway

• An Arrhenius acid increases the H+ ion concentration in water, while an Arrhenius base increases the OH− ion concentration in water.