5.4: Acids, Bases, and Neutralization Reactions

Learning Objectives

- Identify an acid-base neutralization reaction and predict its products.

Previously, you learned that an acid is any compound that produces hydrogen ions (H^+) in an aqueous solution, and the chemical opposite of an acid is a base, which is a compound that produces hydroxide ions (OH^-) in an aqueous solution. These original definitions were proposed by Arrhenius (the same person who proposed ion dissociation) in 1884, so they are referred to as the **Arrhenius definition** of an acid and a base, respectively.

You may recognize that, based on the description of a hydrogen atom, an H^+ ion is a hydrogen atom that has lost its lone electron; that is, H^+ is simply a proton. Do we really have bare protons moving about in aqueous solution? No. What is more likely is that the H^+ ion has attached itself to one (or more) water molecule(s). To represent this chemically, we define the **hydronium ion** as H_3O^+, which represents an additional proton attached to a water molecule. We use the hydronium ion as the more logical way that a hydrogen ion appears in an aqueous solution, although in many chemical reactions H^+ and H_3O^+ are treated equivalently.

The reaction of an acid and a base is called a **neutralization reaction**. Although acids and bases have their own unique chemistries, the acid and base "cancel" each other's chemistry to produce a rather innocuous substance, water. In fact, the general reaction between an acid and a base is:

$$\text{acid} + \text{base} \rightarrow \text{water} + \text{salt}$$

where the term **salt** is generally used to define any ionic compound (soluble or insoluble) that is formed from a reaction between an acid and a base. (In chemistry, the word *salt* refers to more than just table salt.) For example, the balanced chemical equation for the reaction between HCl(aq) and KOH(aq) is

$$\text{HCl(aq)} + \text{KOH(aq)} \rightarrow \text{H}_2\text{O}(\ell) + \text{KCl(aq)}$$

where the salt is KCl. By counting the number of atoms of each element, we find that only one water molecule is formed as a product. However, in the reaction between HCl(aq) and $Mg(OH)_2$(aq), additional molecules of HCl and H_2O are required to balance the chemical equation:

$$2\,\text{HCl(aq)} + \text{Mg(OH)}_2\text{(aq)} \rightarrow 2\,\text{H}_2\text{O}(\ell) + \text{MgCl}_2\text{(aq)}$$

Here, the salt is $MgCl_2$. (This is one of several reactions that take place when a type of antacid, a base, is used to treat stomach acid.)

Example 5.4.1:

Write the neutralization reactions between each acid and base.

a. HNO_3(aq) and $Ba(OH)_2$(aq)
b. H_3PO_4(aq) and $Ca(OH)_2$(aq)

Solution

First, we will write the chemical equation with the formulas of the reactants and the expected products; then we will balance the equation.

a. The expected products are water and barium nitrate, so the initial chemical reaction is

$$\text{HNO}_3\text{(aq)} + \text{Ba(OH)}_2\text{(aq)} \rightarrow \text{H}_2\text{O}(\ell) + \text{Ba(NO}_3\text{)}_2\text{(aq)}$$

To balance the equation, we need to realize that there will be two H_2O molecules, so two HNO_3 molecules are required:

$$2\,\text{HNO}_3\text{(aq)} + \text{Ba(OH)}_2\text{(aq)} \rightarrow 2\,\text{H}_2\text{O}(\ell) + \text{Ba(NO}_3\text{)}_2\text{(aq)}$$

This chemical equation is now balanced.

b. The expected products are water and calcium phosphate, so the initial chemical equation is

$$H_3PO_4(aq) + Ca(OH)_2(aq) \rightarrow H_2O(\ell) + Ca_3(PO_4)_2(s)$$

According to the solubility rules, $Ca_3(PO_4)_2$ is insoluble, so it has an (s) phase label. To balance this equation, we need two phosphate ions and three calcium ions. We end up with six water molecules to balance the equation:

$$2\,H_3PO_4(aq) + 3\,Ca(OH)_2(aq) \rightarrow 6\,H_2O(\ell) + Ca_3(PO_4)_2(s)$$

This chemical equation is now balanced.

? Exercise 5.4.1

Write the neutralization reaction between $H_2SO_4(aq)$ and $Sr(OH)_2(aq)$.

Answer

$$H_2SO_4(aq) + Sr(OH)_2(aq) \rightarrow 2\,H_2O(\ell) + SrSO_4(aq)$$

Neutralization reactions are one type of chemical reaction that proceeds even if one reactant is not in the aqueous phase. For example, the chemical reaction between HCl(aq) and $Fe(OH)_3(s)$ still proceeds according to the equation:

$$3\,HCl(aq) + Fe(OH)_3(s) \rightarrow 3\,H_2O(\ell) + FeCl_3(aq)$$

even though $Fe(OH)_3$ is not soluble. When one realizes that $Fe(OH)_3(s)$ is a component of rust, this explains why some cleaning solutions for rust stains contain acids; the neutralization reaction produces products that are soluble and wash away. (Washing with acids like HCl is one way to remove rust and rust stains, but HCl must be used with caution!)

Key Takeaways

- The Arrhenius definition of an acid is a substance that increases the amount of H^+ in an aqueous solution.
- The Arrhenius definition of a base is a substance that increases the amount of OH^- in an aqueous solution.
- Neutralization is the reaction of an acid and a base, which forms water and a salt.