Skills to Develop

1. Recognize a compound as a Brønsted-Lowry acid or a Brønsted-Lowry base.
2. Illustrate the proton transfer process that defines a Brønsted-Lowry acid-base reaction.

Ammonia (NH₃) increases the hydroxide ion concentration in aqueous solution by reacting with water rather than releasing hydroxide ions directly. In fact, the Arrhenius definitions of an acid and a base focus on hydrogen ions and hydroxide ions. Are there more fundamental definitions for acids and bases?

In 1923, the Danish scientist Johannes Brønsted and the English scientist Thomas Lowry independently proposed new definitions for acids and bases. Rather than considering both hydrogen and hydroxide ions, they focused on the hydrogen ion only. A Brønsted-Lowry acid is a compound that supplies a hydrogen ion in a reaction. A Brønsted-Lowry base, conversely, is a compound that accepts a hydrogen ion in a reaction. Thus, the Brønsted-Lowry definitions of an acid and a base focus on the movement of hydrogen ions in a reaction, rather than on the production of hydrogen ions and hydroxide ions in an aqueous solution.

Let us use the reaction of ammonia in water to demonstrate the Brønsted-Lowry definitions of an acid and a base. Ammonia and water molecules are reactants, while the ammonium ion and the hydroxide ion are products:

\[\text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightarrow \text{NH}_4^+(aq) + \text{OH}^-(aq) \]

What has happened in this reaction is that the original water molecule has donated a hydrogen ion to the original ammonia molecule, which in turn has accepted the hydrogen ion. We can illustrate this as follows:

Because the water molecule donates a hydrogen ion to the ammonia, it is the Brønsted-Lowry acid, while the ammonia molecule—which accepts the hydrogen ion—is the Brønsted-Lowry base. Thus, ammonia acts as a base in both the Arrhenius sense and the Brønsted-Lowry sense.

Is an Arrhenius acid like hydrochloric acid still an acid in the Brønsted-Lowry sense? Yes, but it requires us to understand what really happens when HCl is dissolved in water. Recall that the hydrogen atom is a single proton surrounded by a single electron. To make the hydrogen ion, we remove the electron, leaving a bare proton. Do we really have bare protons floating around in aqueous solution? No, we do not. What really happens is that the H⁺ ion attaches itself to H₂O to make H₃O⁺, which is called the hydronium ion. For most purposes, H⁺ and H₃O⁺ represent the same species, but writing H₃O⁺ instead of H⁺ shows that we understand that there are no bare protons floating around in solution. Rather, these protons are actually attached to solvent molecules.

A proton in aqueous solution may be surrounded by more than one water molecule, leading to formulas like H₅O₂⁺ or...
H$_9$O$_4^+$ rather than H$_3$O$^+$. It is simpler, however, to use H$_3$O$^+$.

With this in mind, how do we define HCl as an acid in the Brønsted-Lowry sense? Consider what happens when HCl is dissolved in H$_2$O:

$$[\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-]$$

We can depict this process using Lewis electron dot diagrams:

Now we see that a hydrogen ion is transferred from the HCl molecule to the H$_2$O molecule to make chloride ions and hydronium ions. As the hydrogen ion donor, HCl acts as a Brønsted-Lowry acid; as a hydrogen ion acceptor, H$_2$O is a Brønsted-Lowry base. So HCl is an acid not just in the Arrhenius sense but also in the Brønsted-Lowry sense. Moreover, by the Brønsted-Lowry definitions, H$_2$O is a base in the formation of aqueous HCl. So the Brønsted-Lowry definitions of an acid and a base classify the dissolving of HCl in water as a reaction between an acid and a base—although the Arrhenius definition would not have labeled H$_2$O a base in this circumstance.

All Arrhenius acids and bases are Brønsted-Lowry acids and bases as well. However, not all Brønsted-Lowry acids and bases are Arrhenius acids and bases.

Example

Aniline (C$_6$H$_5$NH$_2$) is slightly soluble in water. It has a nitrogen atom that can accept a hydrogen ion from a water molecule just like the nitrogen atom in ammonia does. Write the chemical equation for this reaction and identify the Brønsted-Lowry acid and base.

**SOLUTION**

C$_6$H$_5$NH$_2$ and H$_2$O are the reactants. When C$_6$H$_5$NH$_2$ accepts a proton from H$_2$O, it gains an extra H and a positive charge and leaves an OH$^-$ ion behind. The reaction is as follows:

$$\text{C}_6\text{H}_5\text{NH}_2(\text{aq}) + \text{H}_2\text{O}(\ell) \rightarrow \text{C}_6\text{H}_5\text{NH}_3^+(\text{aq}) + \text{OH}^-(\text{aq})$$

Because C$_6$H$_5$NH$_2$ accepts a proton, it is the Brønsted-Lowry base. The H$_2$O molecule, because it donates a proton, is the Brønsted-Lowry acid.

The Brønsted-Lowry definitions of an acid and a base can be applied to chemical reactions that occur in solvents other than water. The following example illustrates.

Example

Sodium amide (NaNH$_2$) dissolves in methanol (CH$_3$OH) and separates into sodium ions and amide ions (NH$_2^-$). Normally
alcohols, like methanol, are not significantly acidic. However in the presence of an extremely strong base, like the amide anion, alcohols will behave as acids. Write a balanced chemical equation for the reaction $\text{NH}_2^-$ with $\text{CH}_3\text{OH}$. Identify the Brønsted-Lowry acid and base. Hint: Pay attention to changes in charges as the proton ($H^+$) is exchanged.

**SOLUTION**

The equation for the reaction is between $\text{NH}_2^-$ and $\text{CH}_3\text{OH}$ to make $\text{NH}_3$ and $\text{CH}_3\text{O}^-$

$$\text{NH}_2^-(\text{solv}) + \text{CH}_3\text{OH}(\ell) \rightarrow \text{NH}_3(\text{solv}) + \text{CH}_3\text{O}^-(\text{solv})$$

The label (solv) indicates that the species are dissolved in some solvent, in contrast to (aq), which specifies an aqueous ($H_2O$) solution.

In this reaction, $\text{NH}_2^-$ gains $H^+$ to make $\text{NH}_3$. As the proton acceptor, $\text{NH}_2^-$ is the Brønsted-Lowry base.

$\text{CH}_3\text{OH}$ loses $H^+$ to make $\text{CH}_3\text{O}^-$. As the proton donor, $\text{CH}_3\text{OH}$ is the Brønsted-Lowry acid.

---

**To Your Health: Brønsted-Lowry Acid-Base Reactions in Pharmaceuticals**

There are many interesting applications of Brønsted-Lowry acid-base reactions in the pharmaceutical industry. For example, drugs often need to be water soluble for maximum effectiveness. However, many complex organic compounds are not soluble or are only slightly soluble in water. Fortunately, those drugs that contain proton-accepting nitrogen atoms (and there are a lot of them) can be reacted with dilute hydrochloric acid [HCl(aq)]. The nitrogen atoms—acting as Brønsted-Lowry bases—accept the hydrogen ions from the acid to make an ion, which is usually much more soluble in water. The modified drug molecules can then be isolated as chloride salts:

$$\text{RN(sl aq)} + H^+(aq) \rightarrow \text{RNH}^+(aq) \xrightarrow{\text{Cl}^-(aq)} \text{RNHCl(s)} \tag{Eq3}$$

where RN represents some organic compound containing nitrogen. The label (sl aq) means “slightly aqueous,” indicating that the compound RN is only slightly soluble. Drugs that are modified in this way are called hydrochloride salts. Examples include the powerful painkiller codeine, which is commonly administered as codeine hydrochloride. Acids other than hydrochloric acid are also used. Hydrobromic acid, for example, gives hydrobromide salts. Dextromethorphan, an ingredient in many cough medicines, is dispensed as dextromethorphan hydrobromide. The accompanying figure shows another medication as a hydrochloride salt.
A Brønsted-Lowry acid is a proton donor, while a Brønsted-Lowry base is a proton acceptor.