

12.2 Brønsted-Lowry Acids and Bases

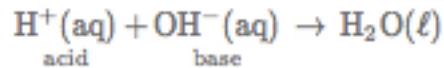
LEARNING OBJECTIVES

1. Identify a Brønsted-Lowry acid and a Brønsted-Lowry base.
2. Identify conjugate acid-base pairs in an acid-base reaction.

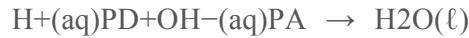
The Arrhenius definition of acid and base is limited to aqueous (that is, water) solutions. Although this is useful because water is a common solvent, it is limited to the relationship between the H^+ ion and the OH^- ion. What would be useful is a more general definition that would be more applicable to other chemical reactions and, importantly, independent of H_2O .

In 1923, Danish chemist Johannes Brønsted and English chemist Thomas Lowry independently proposed new definitions for acids and bases, ones that focus on proton transfer. A **Brønsted-Lowry acid** is any species that can donate a proton (H^+) to another molecule. A **Brønsted-Lowry base** is any species that can accept a proton from another molecule. In short, a Brønsted-Lowry acid is a proton donor (PD), while a Brønsted-Lowry base is a proton acceptor (PA).

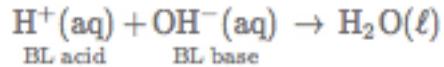
It is easy to see that the Brønsted-Lowry definition covers the Arrhenius definition of acids and bases. Consider the prototypical Arrhenius acid-base reaction:



The acid species and base species are marked. The proton, however, is (by definition) a proton donor (labeled PD), while the OH^- ion is acting as the proton acceptor (labeled PA):



The proton donor is a Brønsted-Lowry acid, and the proton acceptor is the Brønsted-Lowry base:

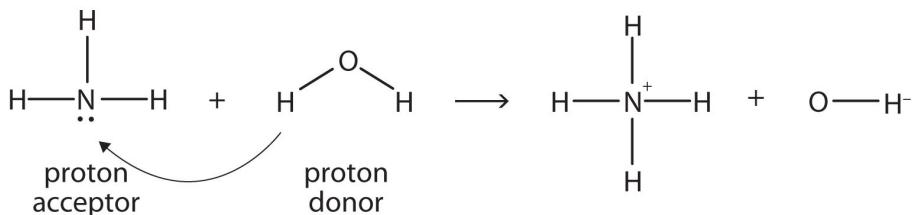


Thus H^+ is an acid by both definitions, and OH^- is a base by both definitions.

Ammonia (NH_3) is a base even though it does not contain OH^- ions in its formula.

Instead, it generates OH^- ions as the product of a proton-transfer reaction with H_2O molecules; NH_3 acts like a Brønsted-Lowry base, and H_2O acts like a Brønsted-Lowry acid:





A reaction with water is called **hydrolysis**; we say that NH_3 hydrolyzes to make NH_4^+ ions and OH^- ions.

Even the dissolving of an Arrhenius acid in water can be considered a Brønsted-Lowry acid-base reaction. Consider the process of dissolving HCl(g) in water to make an aqueous solution of hydrochloric acid. The process can be written as follows:

$$\text{HCl(g)} + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{Cl}^-(\text{aq})$$

HCl(g) is the proton donor and therefore a Brønsted-Lowry acid, while H_2O is the proton acceptor and a Brønsted-Lowry base. These two examples show that H_2O can act as both a proton donor and a proton acceptor, depending on what other substance is in the chemical reaction. A substance that can act as a proton donor or a proton acceptor is called **amphiprotic**. Water is probably the most common amphiprotic substance we will encounter, but other substances are also amphiprotic.

EXAMPLE 3

Identify the Brønsted-Lowry acid and the Brønsted-Lowry base in this chemical equation.



Solution

The $\text{C}_6\text{H}_5\text{OH}$ molecule is losing an H^+ ; it is the proton donor and the Brønsted-Lowry acid. The NH_2^- ion (called the amide ion) is accepting the H^+ ion to become NH_3 , so it is the Brønsted-Lowry base.

Test Yourself

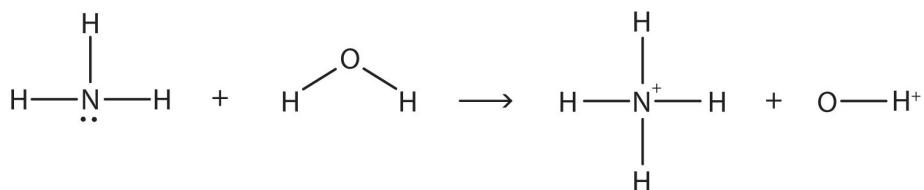
Identify the Brønsted-Lowry acid and the Brønsted-Lowry base in this chemical equation.



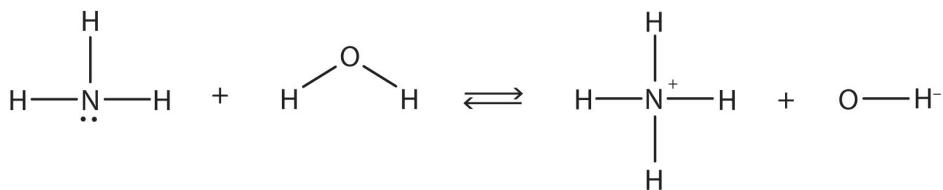
Answer

Brønsted-Lowry acid: $\text{Al}(\text{H}_2\text{O})_6^{3+}$; Brønsted-Lowry base: H_2O

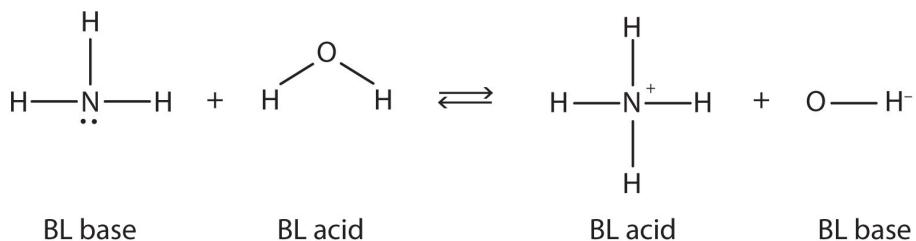
In the reaction between NH_3 and H_2O ,



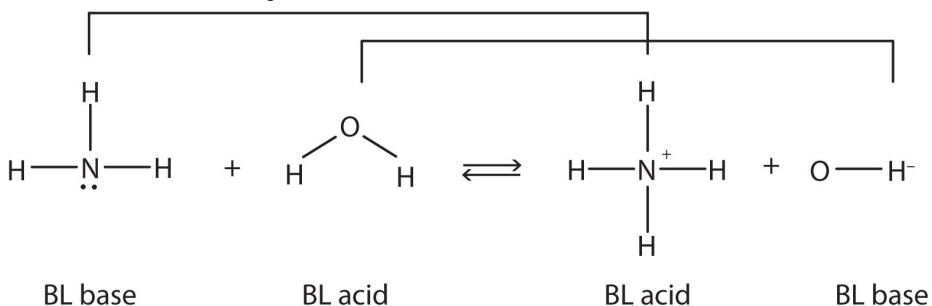
the chemical reaction does not go to completion; rather, the reverse process occurs as well, and eventually the two processes cancel out any additional change. At this point, we say the chemical reaction is at *equilibrium*. Both processes still occur, but any net change by one process is countered by the same net change by the other process; it is *adynamic*, rather than a *static*, equilibrium. Because both reactions are occurring, it makes sense to use a double arrow instead of a single arrow:



What do you notice about the reverse reaction? The NH_4^+ ion is donating a proton to the OH^- ion, which is accepting it. This means that the NH_4^+ ion is acting as the proton donor, or Brønsted-Lowry acid, while OH^- ion, the proton acceptor, is acting as a Brønsted-Lowry base. The reverse reaction is also a Brønsted-Lowry acid base reaction:



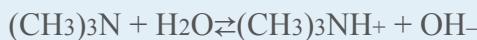
This means that both reactions are acid-base reactions by the Brønsted-Lowry definition. If you consider the species in this chemical reaction, two sets of similar species exist on both sides. Within each set, the two species differ by a proton in their formulas, and one member of the set is a Brønsted-Lowry acid, while the other member is a Brønsted-Lowry base. These sets are marked here:



The two sets— $\text{NH}_3/\text{NH}_4^+$ and $\text{H}_2\text{O}/\text{OH}^-$ —are called conjugate acid-base pairs. We say that NH_4^+ is the conjugate acid of NH_3 , OH^- is the conjugate base of H_2O , and so forth. Every Brønsted-Lowry acid-base reaction can be labeled with two conjugate acid-base pairs.

EXAMPLE 4

Identify the conjugate acid-base pairs in this equilibrium.



Solution

One pair is H_2O and OH^- , where H_2O has one more H^+ and is the conjugate acid, while OH^- has one less H^+ and is the conjugate base. The other pair consists of $(\text{CH}_3)_3\text{N}$ and $(\text{CH}_3)_3\text{NH}^+$, where $(\text{CH}_3)_3\text{NH}^+$ is the

conjugate acid (it has an additional proton) and $(\text{CH}_3)_3\text{N}$ is the conjugate base.

Test Yourself

Identify the conjugate acid-base pairs in this equilibrium.



Answer

H_2O (acid) and OH^- (base); NH_2^- (base) and NH_3 (acid)

Chemistry Is Everywhere: Household Acids and Bases

Many household products are acids or bases. For example, the owner of a swimming pool may use muriatic acid to clean the pool. Muriatic acid is another name for $\text{HCl}(\text{aq})$. In [Chapter 4 "Chemical Reactions and Equations", Section 4.5 "Neutralization Reactions"](#), vinegar was mentioned as a dilute solution of acetic acid [$\text{HC}_2\text{H}_3\text{O}_2(\text{aq})$]. In a medicine chest, one may find a bottle of vitamin C tablets; the chemical name of vitamin C is ascorbic acid ($\text{HC}_6\text{H}_7\text{O}_6$).

One of the more familiar household bases is NH_3 , which is found in numerous cleaning products. NH_3 is a base because it increases the OH^- ion concentration by reacting with H_2O :



Many soaps are also slightly basic because they contain compounds that act as Brønsted-Lowry bases, accepting protons from H_2O and forming excess OH^- ions. This is one explanation for why soap solutions are slippery.

Perhaps the most dangerous household chemical is the lye-based drain cleaner. Lye is a common name for NaOH, although it is also used as a synonym for KOH. Lye is an extremely caustic chemical that can react with grease, hair, food particles, and other substances that may build up and clog a water pipe. Unfortunately, lye can also attack body tissues and other substances in our bodies. Thus when we use lye-based drain cleaners, we must be very careful not to touch any of the solid drain cleaner or spill the water it was poured into. Safer, nonlye drain cleaners (like the one in the accompanying figure) use peroxide compounds to react on the materials in the clog and clear the drain.

KEY TAKEAWAYS

- A Brønsted-Lowry acid is a proton donor; a Brønsted-Lowry base is a proton acceptor.
- Acid-base reactions include two sets of conjugate acid-base pairs.

EXERCISES

1. Define *Brønsted-Lowry acid*. How does it differ from an Arrhenius acid?
2. Define *Brønsted-Lowry base*. How does it differ from an Arrhenius base?
3. Write the dissociation of hydrogen bromide in water as a Brønsted-Lowry acid-base reaction and identify the proton donor and proton acceptor.
4. Write the dissociation of nitric acid in water as a Brønsted-Lowry acid-base reaction and identify the proton donor and proton acceptor.



5. Pyridine (C_5H_5N) acts as a Brønsted-Lowry base in water. Write the hydrolysis reaction for pyridine and identify the Brønsted-Lowry acid and Brønsted-Lowry base.

6. The methoxide ion (CH_3O^-) acts as a Brønsted-Lowry base in water. Write the hydrolysis reaction for the methoxide ion and identify the Brønsted-Lowry acid and Brønsted-Lowry base.

7. Identify the Brønsted-Lowry acid and Brønsted-Lowry base in this chemical equation.

$$H_3PO_4 + OH^- \rightarrow H_2PO_4^- + H_2O$$

8. Identify the Brønsted-Lowry acid and Brønsted-Lowry base in this chemical equation.

$$H_2C_2O_4 + 2F^- \rightarrow 2HF + C_2O_4^{2-}$$

9. Predict the products of this reaction, assuming it undergoes a Brønsted-Lowry acid-base reaction.

$$HC_2H_3O_2 + C_5H_5N \rightarrow ?$$

10. Predict the products of this reaction, assuming it undergoes a Brønsted-Lowry acid-base reaction.

$$(C_2H_5)_3N + H_2O \rightarrow ?$$

11. What is the conjugate acid of H_2O ? of NH_3 ?

12. What is the conjugate acid of $H_2PO_4^-$? of NO_3^- ?

13. What is the conjugate base of HSO_4^- ? of H_2O ?



14. What is the conjugate base of H_3O^+ ? of H_2SO_4 ?

15. Identify the conjugate acid-base pairs in this reaction.



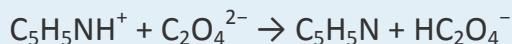
16. Identify the conjugate acid-base pairs in this reaction.



17. Identify the conjugate acid-base pairs in this reaction.



18. Identify the conjugate acid-base pairs in this reaction.



ANSWERS

1. A Brønsted-Lowry acid is a proton donor. It does not necessarily increase the H^+ concentration in water.

3. $\text{HBr} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Br}^-$; PD: HBr; PA: H_2O

5. $\text{C}_5\text{H}_5\text{N} + \text{H}_2\text{O} \rightarrow \text{C}_5\text{H}_5\text{NH}^+ + \text{OH}^-$; PD: H_2O ; PA: $\text{C}_5\text{H}_5\text{N}$

7. BL acid: H_3PO_4 ; BL base: OH^-

9. $\text{C}_2\text{H}_3\text{O}_2^-$ and $\text{C}_5\text{H}_5\text{NH}^+$

11. H_3O^+ ; NH_4^+



13. SO_4^{2-} ; OH^-

15. HSO_4^- and SO_4^{2-} ; PO_4^{3-} and HPO_4^{2-}

17. NH_3 and NH_2^- ; $\text{C}_6\text{H}_5\text{O}^-$ and $\text{C}_6\text{H}_5\text{OH}$

