

10.2: Acid and Base Strength

Learning Objectives

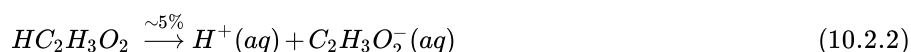
- Define a strong and a weak acid and base.
- Recognize an acid or a base as strong or weak.

Strong and Weak Acids

Except for their names and formulas, so far we have treated all acids as equals, especially in a chemical reaction. However, acids can be very different in a very important way. Consider HCl(aq) . When HCl is dissolved in H_2O , it completely **dissociates** (separates) into $\text{H}^+(\text{aq})$ and $\text{Cl}^-(\text{aq})$ ions; all the HCl molecules become ions:



Any acid that dissociates 100% into ions is called a **strong acid**. If it does not dissociate 100%, it is a **weak acid**. $\text{HC}_2\text{H}_3\text{O}_2$ is an example of a weak acid:



Because this reaction does not go 100% to completion, it is more appropriate to write it as a **reversible reaction**:



As it turns out, there are very few strong acids, which are given in Table 10.2.1. If an acid is not listed here, it is a weak acid. It may be 1% ionized or 99% ionized, but it is still classified as a weak acid.

Any acid that dissociates 100% into ions is called a strong acid. If it does not dissociate 100%, it is a weak acid.

Figure 10.2.1: Some of the common strong acids and bases are listed here.

Strong Acids		Strong Bases	
HClO_4	perchloric acid	LiOH	lithium hydroxide
HCl	hydrochloric acid	NaOH	sodium hydroxide
HBr	hydrobromic acid	KOH	potassium hydroxide
HI	hydroiodic acid	Ca(OH)_2	calcium hydroxide
HNO_3	nitric acid	Sr(OH)_2	strontium hydroxide
H_2SO_4	sulfuric acid	Ba(OH)_2	barium hydroxide

Strong and Weak Bases

The issue is similar with bases: a **strong base** is a base that is 100% ionized in solution. If it is less than 100% ionized in solution, it is a **weak base**. There are very few strong bases (Table 10.2.1); any base not listed is a weak base. All strong bases are OH^- compounds. So a base based on some other mechanism, such as NH_3 (which does not contain OH^- ions as part of its formula), will be a weak base.

✓ Example 10.2.1: Identifying Strong and Weak Acids and Bases

Identify each acid or base as strong or weak.

- HCl
- Mg(OH)_2
- $\text{C}_5\text{H}_5\text{N}$

Solution

- Because HCl is listed in Table 10.2.1, it is a strong acid.
- Because $\text{Mg}(\text{OH})_2$ is listed in Table 10.2.1, it is a strong base.
- The nitrogen in $\text{C}_5\text{H}_5\text{N}$ would act as a proton acceptor and therefore can be considered a base, but because it does not contain an OH compound, it cannot be considered a strong base; it is a weak base.

? Exercise 10.2.1

Identify each acid or base as strong or weak.

- RbOH
- HNO_2

Answer

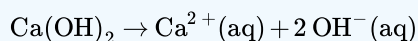
- strong base
- weak acid

✓ Example 10.2.2: Characterizing Base Ionization

Write the balanced chemical equation for the dissociation of $\text{Ca}(\text{OH})_2$ and indicate whether it proceeds 100% to products or not.

Solution

This is an ionic compound of Ca^{2+} ions and OH^- ions. When an ionic compound dissolves, it separates into its constituent ions:



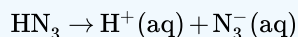
Because $\text{Ca}(\text{OH})_2$ is listed in Table 10.2.1, this reaction proceeds 100% to products.

? Exercise 10.2.2

Write the balanced chemical equation for the dissociation of hydrazoic acid (HN_3) and indicate whether it proceeds 100% to products or not.

Answer a

The reaction is as follows:

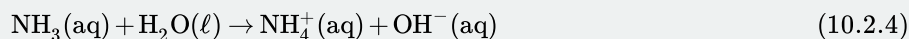


It does not proceed 100% to products because hydrazoic acid is not a strong acid.

📌 Looking Closer: 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 hydrochloric acid [$\text{HCl}(\text{aq})$]. Vinegar has already been 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 ammonia (NH_3), which is found in numerous cleaning products. As we mentioned previously, ammonia is a base because it increases the hydroxide ion concentration by reacting with water:



Many soaps are also slightly basic because they contain compounds that act as Brønsted-Lowry bases, accepting protons from water and forming excess hydroxide ions. This is one reason that soap solutions are slippery.

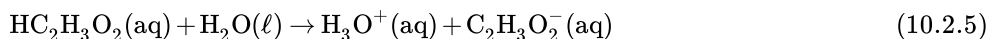


Figure 10.2.1: (left) Bottles of alkaline drain cleaners containing sodium hydroxide can dissolve greases and hair. (right) Chemical burns caused by sodium hydroxide solution photographed 44 hours after exposure. Figures used with permission from Wikipedia.

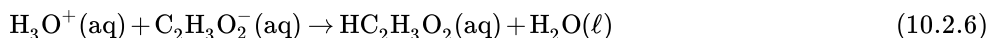
Perhaps the most dangerous household chemical is the lye-based drain cleaner. Lye is a common name for sodium hydroxide, although it is also used as a synonym for potassium hydroxide. Lye is an extremely caustic chemical that can react with grease, hair, food particles, and other substances that may build up and form a clog in a pipe. Unfortunately, lye can also attack 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 use peroxide compounds to react on the materials in the clog and clear the drain.

Chemical Equilibrium in Weak Acids and Bases

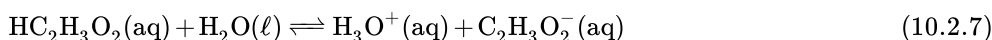
Ionization of weak acids or bases are reversible reactions, which means the forward and reverse reactions occur and eventually reach equilibrium. For example, the ionization of the weak acid $\text{HC}_2\text{H}_3\text{O}_2(\text{aq})$ is as follows:



The reverse process also begins to occur:



Eventually, there is a balance between the two opposing processes, and no additional change occurs. The chemical reaction is better represented at this point with a double arrow:



The \rightleftharpoons implies that both the forward and reverse reactions are occurring, and their effects cancel each other out. A process at this point is considered to be at **chemical equilibrium** (or equilibrium). It is important to note that the processes do not stop. They balance out each other so that there is no further net change; that is, chemical equilibrium is a *dynamic equilibrium*.

✓ Example 10.2.3: Partial Ionization

Write the equilibrium chemical equation for the partial ionization of each weak acid or base.

- $\text{HNO}_2(\text{aq})$
- $\text{C}_5\text{H}_5\text{N}(\text{aq})$

Solution

- $\text{HNO}_2(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{NO}_2^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$
- $\text{C}_5\text{H}_5\text{N}(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{C}_5\text{H}_5\text{NH}^+(\text{aq}) + \text{OH}^-(\text{aq})$

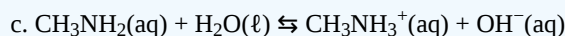
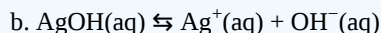
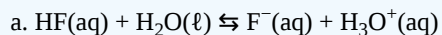
? Exercise 10.2.3

Write the equilibrium chemical equation for the partial ionization of each weak acid or base.

- $\text{HF}_{(\text{aq})}$
- $\text{AgOH}_{(\text{aq})}$

c. $\text{CH}_3\text{NH}_2(\text{aq})$

Answer



Strengths of Conjugate Acid and Base Pairs

The extent to which an acid, HA, donates protons to water molecules depends on the strength of the conjugate base, A^- , of the acid. If A^- is a strong base, any protons that are donated to water molecules are recaptured by A^- . Thus there is relatively little A^- and H_3O^+ in solution, and the acid, HA, is weak. If A^- is a weak base, water binds the protons more strongly, and the solution contains primarily A^- and H_3O^+ —the acid is strong. Strong acids form very weak conjugate bases, and weak acids form stronger conjugate bases (Figure 10.2.2).

The first six acids in Figure 10.2.2 are the most common strong acids. These acids are completely dissociated in aqueous solution. The conjugate bases of these acids are weaker bases than water. When one of these acids dissolves in water, their protons are completely transferred to water, the stronger base.

Those acids that lie between the hydronium ion and water in Figure 10.2.2 form conjugate bases that can compete with water for possession of a proton. Both hydronium ions and non-ionized acid molecules are present in equilibrium in a solution of one of these acids. Compounds that are weaker acids than water (those found below water in the column of acids) in Figure 10.2.2 exhibit no observable acidic behavior when dissolved in water. Their conjugate bases are stronger than the hydroxide ion, and if any conjugate base were formed, it would react with water to re-form the acid.

Acid			Base		
Increasing acid strength ↑	perchloric acid	HClO_4	Do not undergo base ionization in water	ClO_4^-	perchlorate ion
	sulfuric acid	H_2SO_4		HSO_4^-	hydrogen sulfate ion
	hydrogen iodide	HI		I^-	iodide ion
	hydrogen bromide	HBr		Br^-	bromide ion
	hydrogen chloride	HCl		Cl^-	chloride ion
	nitric acid	HNO_3		NO_3^-	nitrate ion
	hydronium ion	H_3O^+		H_2O	water
	hydrogen sulfate ion	HSO_4^-		SO_4^{2-}	sulfate ion
	phosphoric acid	H_3PO_4		H_2PO_4^-	dihydrogen phosphate ion
	hydrogen fluoride	HF		F^-	fluoride ion
	nitrous acid	HNO_2		NO_2^-	nitrite ion
	acetic acid	$\text{CH}_3\text{CO}_2\text{H}$		CH_3CO_2^-	acetate ion
	carbonic acid	H_2CO_3		HCO_3^-	hydrogen carbonate ion
	hydrogen sulfide	H_2S		HS^-	hydrogen sulfide ion
	ammonium ion	NH_4^+		HN_3	ammonia
	hydrogen cyanide	HCN		CN^-	cyanide ion
	hydrogen carbonate ion	HCO_3^-		CO_3^{2-}	carbonate ion
	water	H_2O		OH^-	hydroxide ion
	hydrogen sulfide ion	HS^-	Undergo complete base ionization in water	S^{2-}	sulfide ion
	ethanol	$\text{C}_2\text{H}_5\text{OH}$		$\text{C}_2\text{H}_5\text{O}^-$	ethoxide ion
	ammonia	NH_3		NH_2^-	amide ion
	hydrogen	H_2		H^-	hydride ion
	methane	CH_4		CH_3^-	methide ion

Figure 10.2.2: The chart shows the relative strengths of conjugate acid-base pairs.

The extent to which a base forms hydroxide ion in aqueous solution depends on the strength of the base relative to that of the hydroxide ion, as shown in the last column in Figure 10.2.2. A strong base, such as one of those lying below hydroxide ion, accepts protons from water to yield 100% of the conjugate acid and hydroxide ion. Those bases lying between water and hydroxide ion accept protons from water, but a mixture of the hydroxide ion and the base results. Bases that are weaker than water (those that lie above water in the column of bases) show no observable basic behavior in aqueous solution.

Key Takeaways

- Strong acids and bases are 100% ionized in aqueous solution.
- Weak acids and bases are less than 100% ionized in aqueous solution.

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