9.1: Acid and Base Strength

Learning Outcomes

- Define weak acids and bases.
- Write an equation representing the behavior of a weak acid.
- Explain differences between strong and weak acids and strong and weak bases.
- List the 6 strong acids.
- Calculate pK_a and p$K_b$values.
- Rank acids in order of strength based on their K_a and p$K_a$values.
- Rank bases in order of strength based on their K_b and p$K_b$values.

So far, we have primarily been defining acids by their ability to donate an H^+ ion and bases by their ability to accept an H^+ ion. However, acids and bases vary in their relative ability to undergo these processes. Which was mentioned when we talked about weak electrolytes.

In general, acids can be classified as strong or weak based on the extent to which they produce H_3O^+ when dissolved in water. For a generic acid, we can write the following equilibrium reaction:

$$\mathrm{HA}\,(aq) + \mathrm{H_2O}\,(l) \rightleftharpoons \mathrm{H_3O^+}\,(aq) + \mathrm{A^-}\,(aq) \tag{9.1.1}$$

Using the usual shorthand notation, this equation can also be written as follows:

$$\mathrm{HA}\,(aq) \rightleftharpoons \mathrm{H^+}\,(aq) + \mathrm{A^-}\,(aq) \tag{9.1.2}$$

This type of equilibrium, in which a proton is being transferred to water, is often indicated by writing the equilibrium constant as K_a. The relative position of this equilibrium for a given acid determines whether it will be considered strong or weak. When dissolved in water, a **strong acid** will completely transfer its proton to the solvent. In terms of the equilibrium above, the products will be heavily favored $(K_a \gg 1)$. In fact, the products are so heavily favored that the reverse reaction is often not even considered, and the proton transfer is written as unidirectional. For example, the strong acid HCl can dissociated in water according to the following reaction:

$$\mathrm{HCl}\,(aq) + \mathrm{H_2O}\,(l) \rightarrow \mathrm{H_3O^+}\,(aq) + \mathrm{Cl^-}\,(aq) \tag{9.1.3}$$

which is sometimes written as

$$\mathrm{HCl}\,(aq) \rightarrow \mathrm{H^+}\,(aq) + \mathrm{Cl^-}\,(aq) \tag{9.1.4}$$

to simplify the equation by eliminating the water in the equation because the "*aq*" indicates that water is present. At equilibrium, essentially no intact HCl molecules are still present in solution.

In contrast, the equilibrium for a **weak acid** favors the reactants. A particularly common type of weak acid is an organic molecule that contains a carboxyl group $COOH$. For example, acetic acid (the acidic component of vinegar) has the formula CH_3COOH. Its dissociation equation can be written as follows:

$$\mathrm{CH_3COOH}\,(aq) + \mathrm{H_2O}\,(l) \rightleftharpoons \mathrm{H_3O^+}\,(aq) + \mathrm{CH_3COO^-}\,(aq) \tag{9.1.5}$$

sometimes written as $\mathrm{CH_3COOH}\,(aq) \rightleftharpoons \mathrm{H^+}\,(aq) + \mathrm{CH_3COO^-}\,(aq)$. Because we are dealing with a weak acid, K_a for this equilibrium is much less than 1. At equilibrium, most of the acetic acid molecules are still intact, and only a small percentage have transferred their protons to the solvent. The K_a values for some weak acids are listed in the table below. All weak acids are not equally

Table 9.1.1

Acid Name	Structure	K_a
hydrofluoric acid	H−F	7.1×10^{-4}
nitrous acid	O=N−O−H	4.5×10^{-4}
formic acid	HCOOH	1.7×10^{-4}

Acid Name	Structure	K_a
acetic acid	CH_3COOH	1.8×10^{-5}
hydrocyanic acid	$H-CN$	4.9×10^{-10}

The nature of pK_a is also used to indicate the strength of an acid. pK_a is determined much like pH by taking the negative logarithm of K_a. As with pH, it is used to make values easier to manage. As an acid's strength increases, its K_a value increases and its pK_a value decreases as shown in the table above. Most acids that you will encounter in general chemistry courses are weak acids. There are six common strong acids (see table below). If you recognize these six then you can assume any other acids are weak.

Acids

- Hydrochloric acid, HCl
- Hydrobromic acid, HBr
- Hydroiodic acid, HI
- Perchloric acid, $HClO_4$
- Nitric acid, HNO_3
- Sulfuric acid, H_2SO_4

Strong vs. Weak Bases

Analogous to the acid dissociation reaction from the previous section, we can write the reaction between a generic base and water as follows:

$$B\,(aq) + H_2O\,(l) \rightleftharpoons BH^+\,(aq) + OH^-\,(aq) \tag{9.1.6}$$

The equilibrium constant for a reaction in which a base is deprotonating water (taking water's hydrogen atom) is often given the symbol K_b. Strong bases and weak bases can then be defined based on the position of this equilibrium. A **weak base** would have a very small K_b value (much less than 1), indicating that most molecules of the base do *not* remove a proton from water. Conversely, a **strong base** would have a K_b value greater than or equal to 1.

Nitrogen-containing compounds are a common type of weak base. The lone pair on the nitrogen atom can accept a proton from water as follows:

$$NH_3\,(aq) + H_2O\,(l) \rightleftharpoons NH_4^+\,(aq) + OH^-\,(aq) \tag{9.1.7}$$

The equilibrium constant for this reaction is quite low, so most of the NH_3 molecules will not remove a proton from water. K_b and pK_b values for a few weak bases are listed in the table below.

Table 9.1.3

Base	K_b
ethylamine $(CH_3CH_2NH_2)$	5.6×10^{-4}
methylamine (CH_3NH_2)	4.4×10^{-4}
ammonia (NH_3)	1.8×10^{-5}

The only strong bases that are commonly used in general chemistry courses are ionic compounds composed of metal cations and hydroxide anions, such as $NaOH$, KOH, or $Ba(OH)_2$.

Contributors and Attributions

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