Sections 17.3 – 17.6
Acid-Base Equilibria

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Acid-Base Equilibria

In these sections…

a. Relative acid-base strength
b. Determining Ka and Kb experimentally
c. Estimating pH of solutions
d. Acid-Base Properties of Salts
e. Molecular control of acid-base strength

Acid-Base Equilibria

Bronsted Acid: H^+ (proton) donor
Bronsted Base: H^+ acceptor

Acid-Base reactions: H^+ transfer reaction

Conjugate Acid-Base Pairs:

acid	*conjugate base*
HF	F^-
NH_4^+	NH_3

Strong vs. Weak Acids

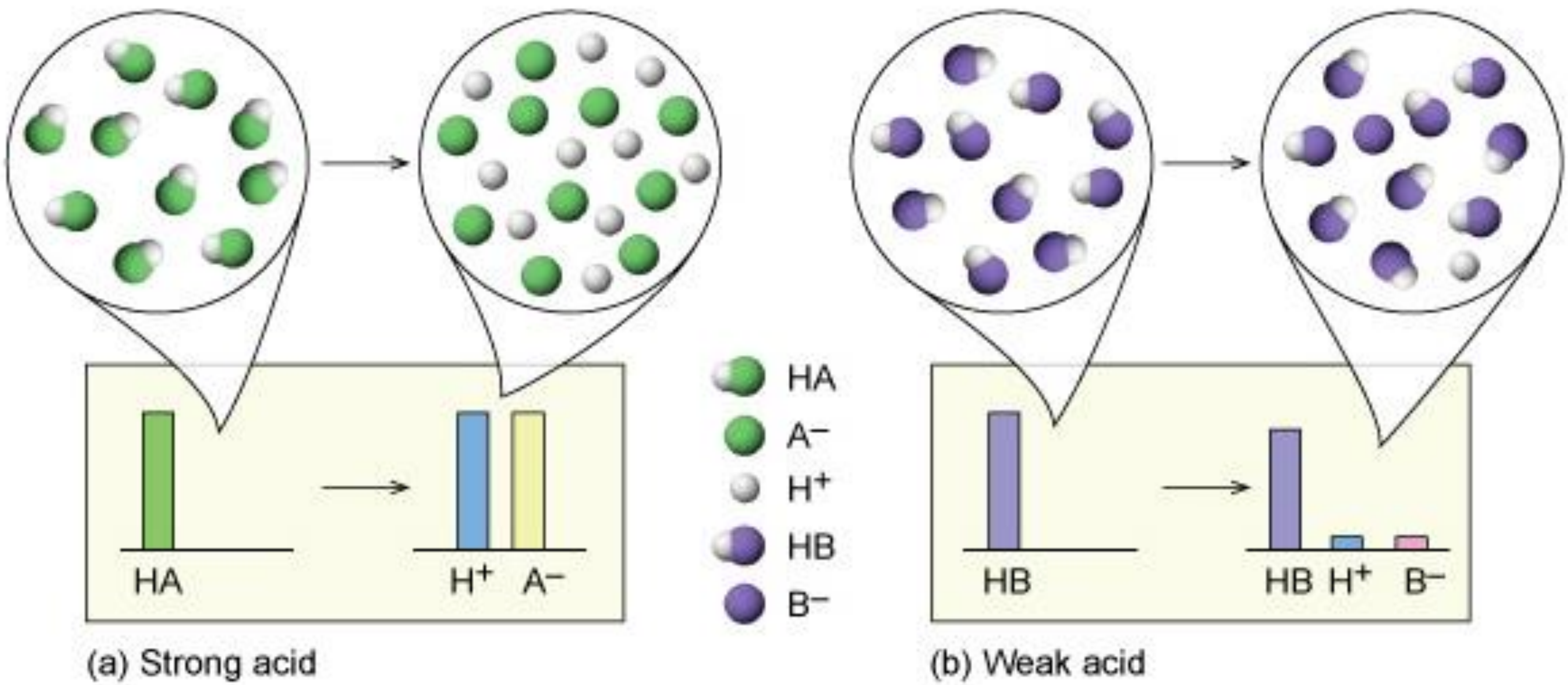

Figure 16.3.1: Molecular view of (a) strong and (b) weak acids

Weak Acid-Base Strength Varies Greatly Depending on the Equilibrium Constant

Acid Equilibria in Water

$$HA + H_2O \rightleftharpoons H_3O^+ + A^-$$

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

Base Equilibria in Water

$$B + H_2O \rightleftharpoons OH^- + HB^+$$

$$K_b = \frac{[OH^-][HB^+]}{[B]}$$

K_a and K_b Values

Name of Acid	Acid	K_a	Name of Base	Base	K_b
Sulfuric acid	H_2SO_4	large	hydrogen sulfate ion	HSO_4^-	very small
Hydrochloric acid	HCl	large	chloride ion	Cl^-	very small
Nitric acid	HNO_3	large	nitrate ion	NO_3^-	very small
Hydronium ion	H_3O^+	1.0	water	H_2O	1.0×10^{-14}
Hydrogen sulfate ion	HSO_4^-	1.2×10^{-2}	sulfate ion	SO_4^{2-}	8.3×10^{-13}
Phosphoric acid	H_3PO_4	7.5×10^{-3}	dihydrogen phosphate ion	$H_2PO_4^-$	1.3×10^{-12}
Hexaaquairon(III) ion	$Fe(H_2O)_6^{3+}$	6.3×10^{-3}	pentaaquahydroxoiron(III) ion	$Fe(H_2O)_5OH^{2+}$	1.6×10^{-12}
Hydrofluoric acid	HF	7.4×10^{-4}	fluoride ion	F^-	1.4×10^{-11}
Formic acid	HCO_2H	1.8×10^{-4}	formate ion	HCO_2^-	5.6×10^{-11}
Benzoic acid	$C_6H_5CO_2H$	6.3×10^{-5}	benzoate ion	$C_6H_5CO_2^-$	1.6×10^{-10}
Acetic acid	CH_3CO_2H	1.8×10^{-5}	acetate ion	$CH_3CO_2^-$	5.6×10^{-10}
Hexaaquaaluminum ion	$Al(H_2O)_6^{3+}$	7.9×10^{-6}	pentaaquahydroxoaluminum ion	$Al(H_2O)_5OH^{2+}$	1.3×10^{-9}
Carbonic acid	H_2CO_3	4.2×10^{-7}	hydrogen carbonate ion	HCO_3^-	2.4×10^{-8}
Hydrogen sulfide	H_2S	1×10^{-7}	hydrogen sulfide ion	HS^-	1×10^{-7}
Dihydrogen phosphate ion	$H_2PO_4^-$	6.2×10^{-8}	hydrogen phosphate ion	HPO_4^{2-}	1.6×10^{-7}
Hypochlorous acid	$HClO$	3.5×10^{-8}	hypochlorite ion	ClO^-	2.9×10^{-7}
Ammonium ion	NH_4^+	5.6×10^{-10}	ammonia	NH_3	1.8×10^{-5}
Hydrocyanic acid	HCN	4.0×10^{-10}	cyanide ion	CN^-	2.5×10^{-5}
Hexaaquairon(II) ion	$Fe(H_2O)_6^{2+}$	3.2×10^{-10}	pentaaquahydroxoiron(II) ion	$Fe(H_2O)_5OH^+$	3.1×10^{-5}
Hydrogen carbonate ion	HCO_3^-	4.8×10^{-11}	carbonate ion	CO_3^{2-}	2.1×10^{-4}
Hydrogen phosphate ion	HPO_4^{2-}	3.6×10^{-13}	phosphate ion	PO_4^{3-}	2.8×10^{-2}
Water	H_2O	1.0×10^{-14}	hydroxide ion	OH^-	1.0
Hydrogen sulfide ion	HS^-	1×10^{-19}	sulfide ion	S^{2-}	1×10^{5}

Strong Acids: HCl, HBr, HI, HNO_3, H_2SO_4, $HClO_4$
Strong Bases: $NaOH$, KOH, $Ca(OH)_2$, $Ba(OH)_2$

Trends in relative acid/base strength for conjugate pairs.

K_a and K_b Values					
Name of Acid	**Acid**	**K_a**	**Name of Base**	**Base**	**K_b**
Sulfuric acid	H_2SO_4	large	hydrogen sulfate ion	HSO_4^-	very small
Hydrochloric acid	HCl	large	chloride ion	Cl^-	very small
Nitric acid	HNO_3	large	nitrate ion	NO_3^-	very small
Hydronium ion	H_3O^+	1.0	water	H_2O	1.0×10^{-14}
Hydrogen sulfate ion	HSO_4^-	1.2×10^{-2}	sulfate ion	SO_4^{2-}	8.3×10^{-13}
Phosphoric acid	H_3PO_4	7.5×10^{-3}	dihydrogen phosphate ion	$H_2PO_4^-$	1.3×10^{-12}
Hexaaquairon(III) ion	$Fe(H_2O)_6^{3+}$	6.3×10^{-3}	pentaaquahydroxoiron(III) ion	$Fe(H_2O)_5OH^{2+}$	1.6×10^{-12}
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Formic acid	HCO_2H	1.8×10^{-4}	formate ion	HCO_2^-	5.6×10^{-11}
Benzoic acid	$C_6H_5CO_2H$	6.3×10^{-5}	benzoate ion	$C_6H_5CO_2^-$	1.6×10^{-10}
Acetic acid	CH_3CO_2H	1.8×10^{-5}	acetate ion	$CH_3CO_2^-$	5.6×10^{-10}
Hexaaqualuminum ion	$Al(H_2O)_6^{3+}$	7.9×10^{-6}	pentaaquahydroxoaluminum ion	$Al(H_2O)_5OH^{2+}$	1.3×10^{-9}
Carbonic acid	H_2CO_3	4.2×10^{-7}	hydrogen carbonate ion	HCO_3^-	2.4×10^{-8}
Hydrogen sulfide	H_2S	1×10^{-7}	hydrogen sulfide ion	HS^-	1×10^{-7}
Dihydrogen phosphate ion	$H_2PO_4^-$	6.2×10^{-8}	hydrogen phosphate ion	HPO_4^{2-}	1.6×10^{-7}
Hypochlorous acid	$HClO$	3.5×10^{-8}	hypochlorite ion	ClO^-	2.9×10^{-7}
Ammonium ion	NH_4^+	5.6×10^{-10}	ammonia	NH_3	1.8×10^{-5}
Hydrocyanic acid	HCN	4.0×10^{-10}	cyanide ion	CN^-	2.5×10^{-5}
Hexaaquairon(II) ion	$Fe(H_2O)_6^{2+}$	3.2×10^{-10}	pentaaquahydroxoiron(II) ion	$Fe(H_2O)_5OH^+$	3.1×10^{-5}
Hydrogen carbonate ion	HCO_3^-	4.8×10^{-11}	carbonate ion	CO_3^{2-}	2.1×10^{-4}
Hydrogen phosphate ion	HPO_4^{2-}	3.6×10^{-13}	phosphate ion	PO_4^{3-}	2.8×10^{-2}
Water	H_2O	1.0×10^{-14}	hydroxide ion	OH^-	1.0
Hydrogen sulfide ion	HS^-	1×10^{-19}	sulfide ion	S^{2-}	1×10^{5}

Strong Acids: HCl, HBr, HI, HNO_3, H_2SO_4, $HClO_4$
Strong Bases: $NaOH$, KOH, $Ca(OH)_2$, $Ba(OH)_2$

Relationship Between K_a and K_b for an Acid-Base Conjugate Pair

$K_a \times K_b = 1.0 \times 10^{-14}$

Ammonia is a base with $K_b = 1.8 \times 10^{-5}$. What is the conjugate acid, and what is its K_a value?

Determining the K_a Value Experimentally

Measure pH for a solution of known concentration.
pH → $[H_3O^+]$ → x in an ICE table → all [ ]'s → K_a

What is the value of K_a for an acid, HA, for which a 0.240 M solution has a pH of 3.28?

Determining K_b:

A 0.300 M solution of a weak base has a pH of 9.20. What is K_b?

Estimating the pH when [HA] and K_a are known

Set up ICE Table → $x = [H_3O^+]$ → pH

What is the pH of a 0.150 M solution of HF?

Estimate when $[HA]_o > 100 \times K_a$

What is the pH of a 0.150 M solution of HCN?

Estimating pH of weak base solutions

What is the pH of a 0.150 M solution of NH_3?

Acid-Base Properties of Salts

Look at acid-base properties of each ion.

Ions that are conjugates from strong acids or strong bases are pH neutral.
Anions that are conjugates of weak acids are usually weak bases.

K_a and K_b Values

Name of Acid	Acid	K_a	Name of Base	Base	K_b
Sulfuric acid	H_2SO_4	large	hydrogen sulfate ion	HSO_4^-	very small
Hydrochloric acid	HCl	large	chloride ion	Cl^-	very small
Nitric acid	HNO_3	large	nitrate ion	NO_3^-	very small
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Carbonic acid	H_2CO_3	4.2×10^{-7}	hydrogen carbonate ion	HCO_3^-	2.4×10^{-8}
Hydrogen sulfide	H_2S	1×10^{-7}	hydrogen sulfide ion	HS^-	1×10^{-7}
Dihydrogen phosphate ion	$H_2PO_4^-$	6.2×10^{-8}	hydrogen phosphate ion	HPO_4^{2-}	1.6×10^{-7}
Hypochlorous acid	$HClO$	3.5×10^{-8}	hypochlorite ion	ClO^-	2.9×10^{-7}
Ammonium ion	NH_4^+	5.6×10^{-10}	ammonia	NH_3	1.8×10^{-5}
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Hydrogen carbonate ion	HCO_3^-	4.8×10^{-11}	carbonate ion	CO_3^{2-}	2.1×10^{-4}
Hydrogen phosphate ion	HPO_4^{2-}	3.6×10^{-13}	phosphate ion	PO_4^{3-}	2.8×10^{-2}
Water	H_2O	1.0×10^{-14}	hydroxide ion	OH^-	1.0
Hydrogen sulfide ion	HS^-	1×10^{-19}	sulfide ion	S^{2-}	1×10^{5}

Strong Acids: HCl, HBr, HI, H_2SO_4, HNO_3, $HClO_4$
Strong Bases: $NaOH$, KOH, $Ca(OH)_2$, $Ba(OH)_2$

Examples:

$NaCN$

KNO_3

NH_4Cl

$NaHCO_2$

Na_2CO_3

$KHSO_4$

NH_4CN

Molecular Structure and Acid Strength

1. H-A Bond Strength and Acid Strength

As bond strength increases, acid strength decreases.

Table 16.4 Bond Energies and K_a values for the H—X acids

H—X	Bond Energy	K_a
H—F	569 kJ/mol	$\sim 7 \times 10^{-4}$
H—Cl	431 kJ/mol	$\sim 10^{7}$
H—Br	368 kJ/mol	$\sim 10^{9}$
H—I	297 kJ/mol	$\sim 10^{10}$

The order of acid strength for this series

HF << HCl < HBr < HI

2. H-A, Electronegativity of A and Acid Strength

As electronegativity increases, acid strength increases.