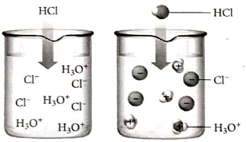
Relative Strength of Acids and Bases: All about the Ionization!

Strong acid or base: K >> 1

- 100% ionized in water (completely dissociates)
  - $[H_3O^+]$ = [strong acid]
  - $[OH^-]$ = [strong base]
- Strong electrolytes (conduct electricity in solution)

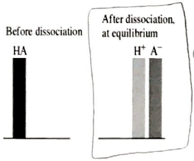
A Strong Acid

When HCl dissolves in water, it ionizes completely.



Single arrow indicates complete ionization.

$$HCl(aq) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$$



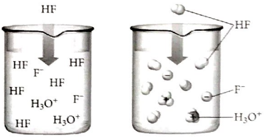
100% (ALL) dissociates! (ionized)

Weak acid or base: K << 1

- Much less than 100% ionized in water (< 1%)
  - $[H_3O^+]$ << [weak acid]
  - $[OH^-]$ << [weak base]
- Weak electrolytes (few ions in sol'n)
- Vast majority of acids/bases are weak!

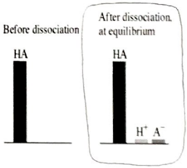
A Weak Acid

When HF dissolves in water, only a fraction of the molecules ionize.



Equilibrium arrow indicates partial ionization.

$$HF(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + F^-(aq)$$



mostly NOT ionized

K_a and K_b: Equilibrium Expressions for Acids and Bases

Given the dissociation of the generic acid, HA:

$$HA(aq) + H_2O(l) \leftrightharpoons A^-(aq) + H_3O^+(aq)$$

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

Given the dissociation of the generic base, B:

$$B(aq) + H_2O(l) \leftrightharpoons BH^+(aq) + OH^-(aq)$$

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

Memorize the following: (for reals - you MUST know these!)

1. Strong acids:
    a. Hydrohalic acids: **HCl, HBr, HI** (note: HF is NOT a strong acid! The H – F bond is too strong.)
    b. Nitric acid: **HNO_3**
    c. Sulfuric acid: **H_2SO_4**
    d. Perchloric acid: **$HClO_4$**
2. Strong bases:
    a. **Group IA and IIA metal hydroxides** (i.e. LiOH, NaOH, $Ca(OH)_2$, etc)
    b. Solubility plays a huge role
        i. Very soluble = very strong
        ii. $Be(OH)_2$ and $Mg(OH)_2$ are very poorly soluble, limiting their effectiveness; however, the small amount of these bases which dissolves will ionize 100%, so they can be considered strong bases.

Tricks to Remember the Strong Acids

1. **BriCl-SO-NO-ClO** (Pronounced "Brickle-So-No-Clo; all long "oh" sounds)
2. By song! ☺

The Song Acid Song!

(sung with the melody from You Are My Sunshine)

All ~~my~~ the strong acids,
They share the same fate -
To 100% dissociate!
They will never
Get back together,
All ~~those~~ their H's are gone forever.

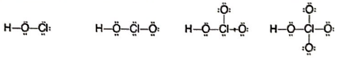
There's hydrochloric,
And hydrobromic,
And hydroiodic just says *hi*!
Then there's perchloric,
Of course sulfuric,
And then nitric by the by.

Oxyacid Trends: The more oxygen atoms present, the stronger the acid WITHIN that group.

→ Why?

- The H^+ being donated is bonded to an oxygen atom.
- The oxygen atoms are highly electronegative and are pulling the bonded pair of electrons AWAY from the site where the H^+ is bonded:
  - More oxygen atoms = greater bond polarity
  - Greater bond polarity = greater + charge density around H
  - Greater positive charge density around H = easier (less energy to remove) H
  - Easier to remove H = stronger acid!

Hypochlorous	Chlorous	Chloric	Perchloric



$K_a = 3.0 \times 10^{-8}$	$K_a = 1.1 \times 10^{-2}$	K_a = large	K_a = VERY large

Increasing Acid Strength →

Acid Ionization Constant (K_a): the equilibrium constant for the dissociation of an acid in water

Larger K_a = Stronger acid!

- Size of K_a depends on strength of attraction between A^- and H^+
  - Stronger attraction between A^- and H^+ = weaker acid (↓ K_a)
  - Weaker attraction between A^- and H^+ = stronger acid (↑ K_a)

Strong acid: $K_a >> 1$
Weak acid: $K_a << 1$

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

Base Ionization Constant (K_b): the equilibrium constant for the reaction of a base with water

Larger K_b = Stronger base!

- Size of K_b depends on strength of attraction between B and H^+
  - Stronger attraction between B and H^+ = stronger base (↑ K_b)

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

Equilibrium and Brønsted-Lowry

In general, Brønsted-Lowry acid-base reactions are equilibrium systems meaning that both the forward and reverse reactions occur.

- The extent of the reaction depends on the relative Strength of the acids and bases involved, and the value of their equilibrium constants (K_a and K_b).
  a. The **stronger** an acid is, the Weaker its conjugate base.
  b. The Stronger a base is, the **weaker** its conjugate acid.

Let's look at an example to see why!

Example 1: Strong Acid $HCl + H_2O \rightarrow Cl^- + H_3O^+$ K >> 1, products are favored!

A B CB CA

But if you reverse the reaction and look at the strength of the conjugate base of HCl, Cl^-:

$Cl^- + H_3O \rightleftharpoons HCl + H_2O$ K << 1, reactants are favored! No products.

B A CA CB

➔ Cl^- is a Weak base, because it really does NOT want to accept that H^+!

Important Notes:

- The **favored direction of the reaction** is the one in which the Weaker acid/base are produced.
- The Stronger acid and base will always be on the Same side of the equation (which means the Weaker acid and base will also always be on the same side of the equation.)

Example 1: K >> 1

$HClO_{4(aq)} + H_2O_{(l)} \leftrightharpoons H_3O^+_{(aq)} + ClO_4^-{}_{(aq)}$

A B CA CB

Favored: products (K>1)

Stronger acid: $HClO_4$ Weaker acid: H_3O^+

Stronger base: H_2O Weaker base: ClO_4^-

Example 2: K = 1.76 x 10^{-5}

$CH_3COOH_{(aq)} + H_2O_{(l)} \leftrightharpoons CH_3COO^-{}_{(aq)} + H_3O^+_{(aq)}$

A B CB CA

Favored: reactants (K<1)

Stronger acid: H_3O^+ Weaker acid: CH_3COOH

Stronger base: CH_3COO^- Weaker base: H_2O

Consider the following acids and their K_a values.

Acid	K_a	Conjugate Base?
$HC_2H_3O_2$	1.8 x 10^{-5}	$C_2H_3O_2^-$
HOCN	3.5 x 10^{-4}	OCN^-
HF	6.8 x 10^{-4}	F^-

1. Rank these acids in order of increasing strength: $HC_2H_3O_2$, HOCN, HF
2. Rank the *conjugate bases* of the acids in order of increasing strength: F^-, OCN^-, $C_2H_3O_2^-$

Using K_a's to determine K_{eq} for a given reaction: You can compare the K_a values of two acids to determine if a given acid/base reaction is reactant or product favored!

Example: $HC_2H_3O_2 + HCO_3^- \leftrightharpoons C_2H_3O_2^- + H_2CO_3$

K_a of $HC_2H_3O_2 = 1.8 \times 10^{-5}$ ⇒ stronger acid

K_a of $H_2CO_3 = 4.3 \times 10^{-7}$

1. What are the **two** conjugate acid-base pairs in this reaction? $HC_2H_3O_2$ and $C_2H_3O_2^-$, HCO_3^- and H_2CO_3
2. Which acid is stronger, $HC_2H_3O_2$ or H_2CO_3? $HC_2H_3O_2$
3. Is the example reaction reactant or product favored? product-favored!
4. Is the K value of this reaction less than 1, equal to 1, or greater than 1? $K > 1$