Acids and Bases

Acid/Base Definitions

- Arrhenius Model
  - Acids produce hydrogen ions in aqueous solutions
  - Bases produce hydroxide ions in aqueous solutions
- Bronsted-Lowry Model
  - Acids are proton donors
  - Bases are proton acceptors
- Lewis Acid Model
  - Acids are electron pair acceptors
  - Bases are electron pair donors

Problems with Arrhenius Theory

- It does not explain why molecular substances, such as NH_3, dissolve in water to form basic solutions, even though they do not contain OH^- ions.
- It does not explain how some ionic compounds, such as Na_2CO_3 or Na_2O, dissolve in water to form basic solutions, even though they do not contain OH^- ions.
- It does not explain why molecular substances, such as CO_2, dissolve in water to form acidic solutions, even though they do not contain H^+ ions.
- It does not explain acid–base reactions that take place outside aqueous solution.

Brønsted–Lowry Acid–Base Theory

- It defines acids and bases based on what happens in a reaction.
- Any reaction involving H^+ (proton) that transfers from one molecule to another is an acid–base reaction, regardless of whether it occurs in aqueous solution or if there is OH^- present.
- All reactions that fit the Arrhenius definition also fit the Brønsted–Lowry definition.

Brønsted–Lowry Theory

- The acid is an H^+ donor.
- The base is an H^+ acceptor.
  - Base structure must contain an atom with an unshared pair of electrons.
- In a Brønsted–Lowry acid–base reaction, the acid molecule donates an H^+ to the base molecule.

$$\text{H–A} + \text{:B} \Leftrightarrow \text{:A}^- + \text{H–B}^+$$

Brønsted–Lowry Acids

- Brønsted–Lowry acids are H^+ donors.
  - Any material that has H can potentially be a Brønsted–Lowry acid.
  - Because of the molecular structure, often one H in the molecule is easier to transfer than others.
- When HCl dissolves in water, the HCl is the acid because HCl transfers an H^+ to H_2O, forming H_3O^+ ions.
  - Water acts as base, accepting H^+.

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

Acid. **base**

Amphoteric Substances

- **Amphoteric substances** can act as either an acid or a base because they have both a transferable H and an atom with lone pair electrons.

- Water acts as base, accepting H^+ from HCl.

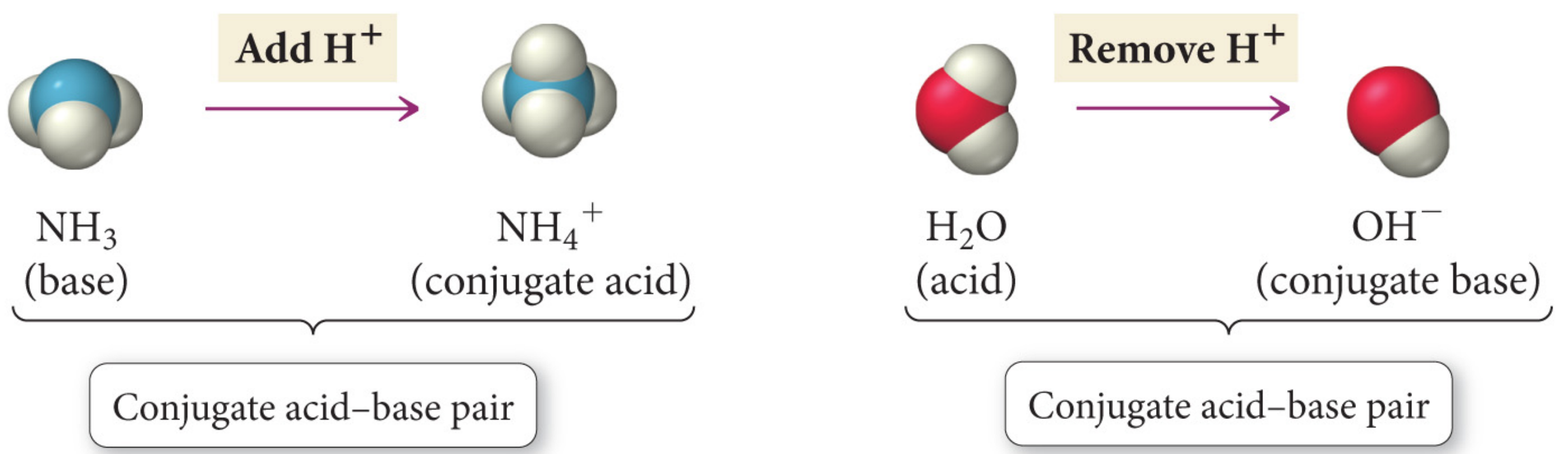
$$HCl(aq) + H_2O(l) \rightarrow Cl^-(aq) + H_3O^+(aq)$$

- Water acts as acid, donating H^+ to NH_3.

$$NH_3(aq) + H_2O(l) \Leftrightarrow NH_4^+(aq) + OH^-(aq)$$

Conjugate Acid–Base Pairs

- In a Brønsted-–Lowry acid–base reaction,
  - the original base becomes an acid in the reverse reaction.
  - the original acid becomes a base in the reverse process.
- Each reactant and the product it becomes is called a **conjugate pair**.



Conjugate Pairs

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Base	Acid	Conjugate acid	Conjugate base

A base accepts a proton and becomes a conjugate acid.

An acid donates a proton and becomes a conjugate base.

Acid Dissociation

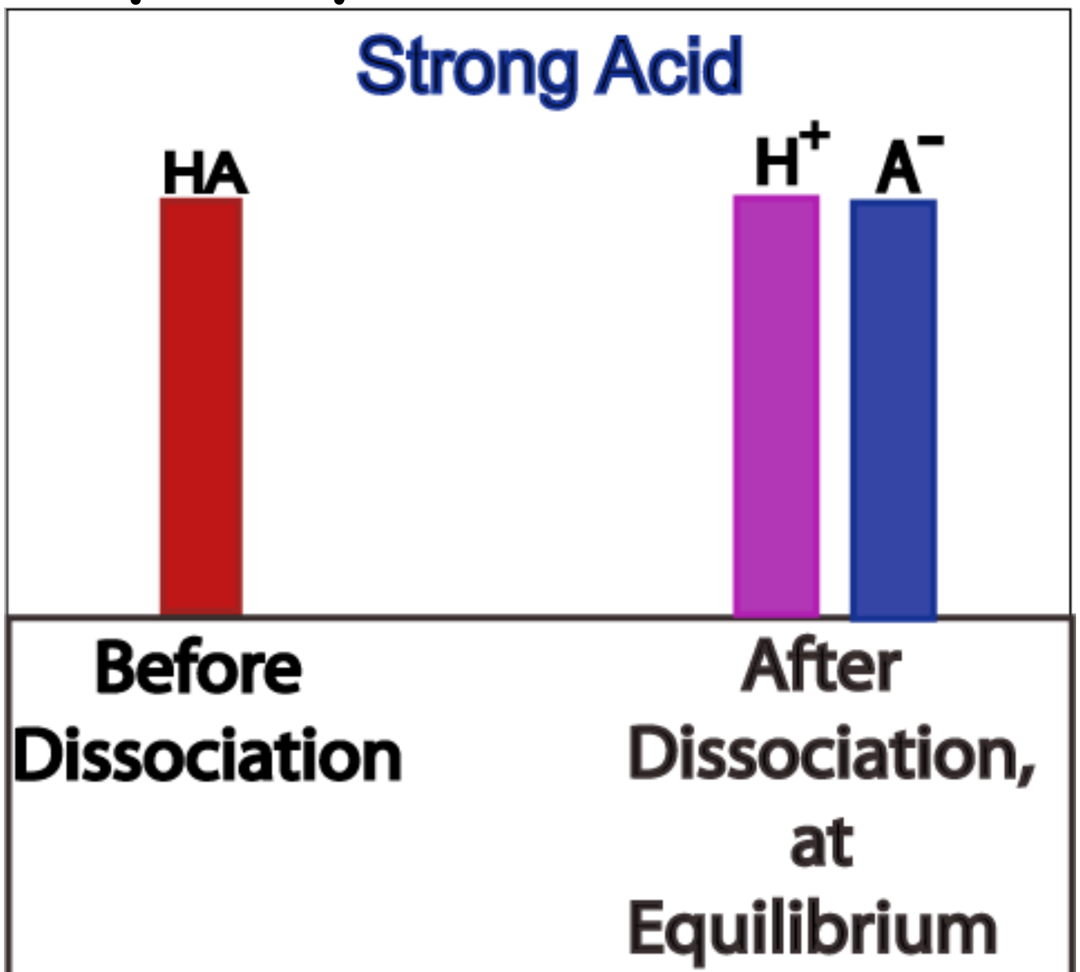
HA	→	H^+	+	A^-
Acid		Proton		Conjugate base

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

Alternately, H^+ may be written in its hydrated form, H_3O^+ (hydronium ion)

Dissociation of Strong Acids

Strong acids are assumed to dissociate completely in solution.



Large K_a or small K_a?

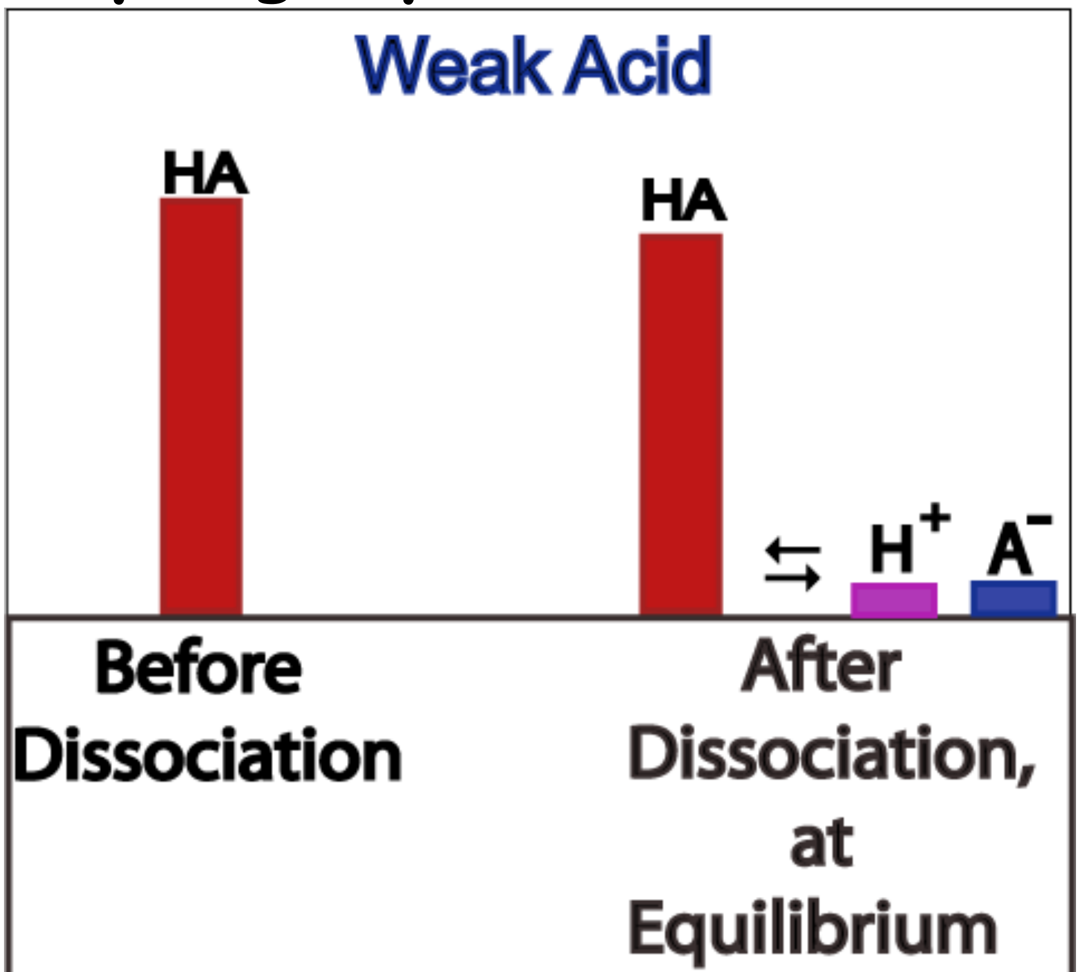
Reactant favored or product favored?

Dissociation Constants: Strong Acids

Acid	Formula	Conjugate Base	K_a
Perchloric	$HClO_4$	ClO_4^-	Very large
Hydriodic	HI	I^-	Very large
Hydrobromic	HBr	Br^-	Very large
Hydrochloric	HCl	Cl^-	Very large
Nitric	HNO_3	NO_3^-	Very large
Sulfuric	H_2SO_4	HSO_4^-	Very large
Hydronium ion	H_3O^+	H_2O	1.0

Dissociation of Weak Acids

Weak acids are assumed to dissociate only slightly (less than 5%) in solution.



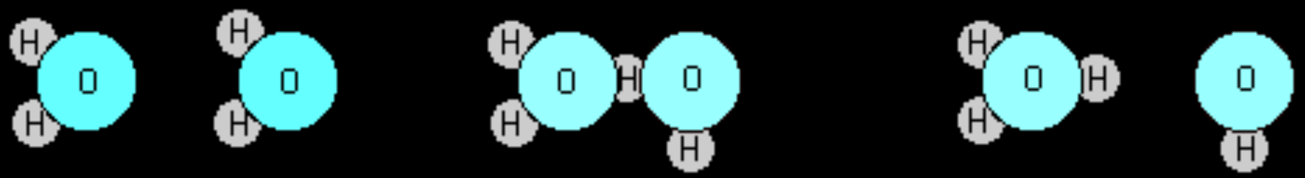
Large K_a or small K_a?

Reactant favored or product favored?

Dissociation Constants: Weak Acids

Acid	Formula	Conjugate Base	K_a
Iodic	HIO_3	IO_3^-	1.7×10^{-1}
Oxalic	$H_2C_2O_4$	$HC_2O_4^-$	5.9×10^{-2}
Sulfurous	H_2SO_3	HSO_3^-	1.5×10^{-2}
Phosphoric	H_3PO_4	$H_2PO_4^-$	7.5×10^{-3}
Citric	$H_3C_6H_5O_7$	$H_2C_6H_5O_7^-$	7.1×10^{-4}
Nitrous	HNO_2	NO_2^-	4.6×10^{-4}
Hydrofluoric	HF	F^-	3.5×10^{-4}
Formic	$HCOOH$	$HCOO^-$	1.8×10^{-4}
Benzoic	C_6H_5COOH	$C_6H_5COO^-$	6.5×10^{-5}
Acetic	CH_3COOH	CH_3COO^-	1.8×10^{-5}
Carbonic	H_2CO_3	HCO_3^-	4.3×10^{-7}
Hypochlorous	$HClO$	ClO^-	3.0×10^{-8}
Hydrocyanic	HCN	CN^-	4.9×10^{-10}

Self-Ionization of Water



$H_2O + H_2O \leftrightarrows H_3O^+ + OH^-$

At 25°, $[H_3O^+] = [OH^-] = 1 \times 10^{-7}$

<u>K_w is a constant at 25 °C:</u>

$$K_w = [H_3O^+][OH^-]$$

$$K_w = (1 \times 10^{-7})(1 \times 10^{-7}) = 1 \times 10^{-14}$$

Calculating pH, pOH

$$pH = -\log_{10}(H_3O^+)$$

$$pOH = -\log_{10}(OH^-)$$

Relationship between pH and pOH

$$pH + pOH = 14$$

Finding $[H_3O^+]$, $[OH^-]$ from pH, pOH

$$[H_3O^+] = 10^{-pH}$$

$$[OH^-] = 10^{-pOH}$$

pH and pOH Calculations

H^+ → OH^-: $[OH^-] = \dfrac{1 \times 10^{-14}}{[H^+]}$

OH^- → H^+: $[H^+] = \dfrac{1 \times 10^{-14}}{[OH^-]}$

H^+ → pH: $pH = -\log[H^+]$

pH → H^+: $[H^+] = 10^{-pH}$

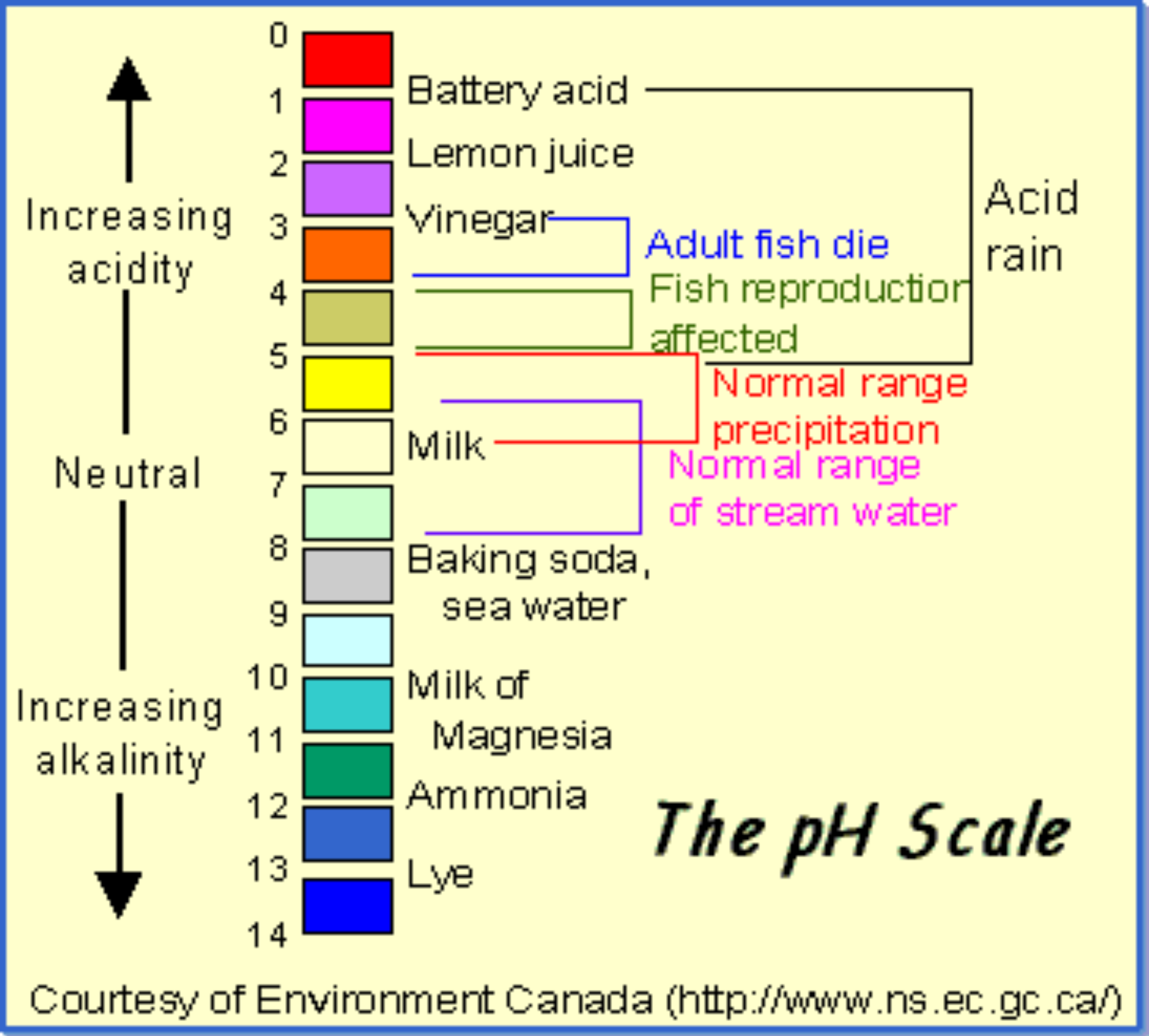
OH^- → pOH: $pOH = -\log[OH^-]$

pOH → OH^-: $[OH^-] = 10^{-pOH}$

pH → pOH: $pOH = 14 - pH$

pOH → pH: $pH = 14 - pOH$

pH Scale



0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Increasing acidity
Neutral
Increasing alkalinity
Battery acid
Lemon juice
Vinegar
Milk
Baking soda, sea water
Milk of Magnesia
Ammonia
Lye
Adult fish die
Fish reproduction affected
Normal range precipitation
Normal range of stream water
Acid rain
The pH Scale
Courtesy of Environment Canada (http://www.ns.ec.gc.ca/)