Chapter 8.1
The Nature of Acids and Bases

Learning Goals: I will be able to …

1. **explain** the Arrhenius and Bronsted-Lowry theories of acids and bases
2. **identify** acid ionization constant, K_a, and write the expression for it

Acid-Base Theories

The "Boyz"

Arrhenius Theory of Acids

- Acid: molecular substances that breaks-ups in aqueous solution into H^+ and anions
- H^+ (“hydrogen ions” or “protons”)
- H^+ gives acids its protons
- Example: $HCl_{(g)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$

Common Acids

Name	Formula	Acid Strength	Common Uses/Notes
Sulfuric acid	H_2SO_4	Strong	Battery acid; extremely corrosive
Nitric acid	HNO_3	Strong	Manufacture of fertilizers, explosives
Hydrochloric acid	HCl	Strong	Cleaning of metals, bricks; removing scale from boilers
Phosphoric acid	H_3PO_4	Moderate	Manufacture of fertilizers; acidulant for foods
Hydrogen sulfate ion	HSO_4^-	Moderate	Toilet bowl cleaners
Lactic acid	$CH_3CHOHCOOH$	Weak	Acidulant for soda pop, foods
Acetic acid	CH_3COOH	Weak	Vinegar; acidulant
Carbonic acid	H_2CO_3	Weak	Unstable; formed in aqueous CO_2
Boric acid	H_3BO_3	Very weak	Antiseptic eye wash
Hydrocyanic acid	HCN	Very weak	None; extremely toxic

Arrhenius Theory of Bases

- Base: releases OH^- ions in aqueous solution
- OH^- (hydroxide ions)
- OH^- gives bases their properties
- Example: $NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$

Common Bases

Name	Formula	Classification	Common Uses/Notes
Sodium hydroxide	$NaOH$	Strong	Acid neutralization; soap making; dehorning calves
Potassium hydroxide	KOH	Strong	Making liquid soaps; absorbing CO_2
Lithium hydroxide	$LiOH$	Strong	Alkaline storage batteries
Calcium hydroxide	$Ca(OH)_2$	Strong*	Mortar, plaster, cement; water purification
Magnesium hydroxide	$Mg(OH)_2$	Strong*	Antacid, laxative
Ammonia	NH_3	Weak	Fertilizer, household cleansers

* Although these bases are classified as strong, they are not very soluble. Calcium hydroxide is only slightly soluble in water, and magnesium hydroxide is practically insoluble.

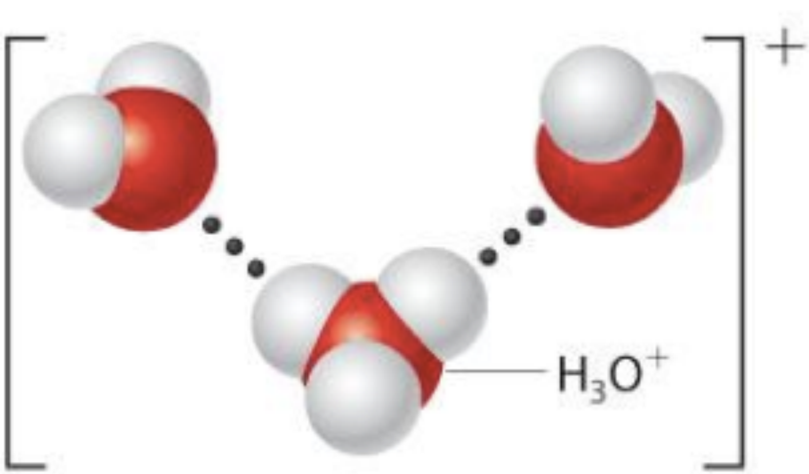
Limitations of Arrhenius Theory

- H^+ does not exist in solution
- More likely to find H^+ attached to H_2O (hydrated)
  - H_3O^+
- Some bases, like ammonia, do not fit this definition, the solution is basic, but the compound does not dissociate, forming hydroxide ion
  - $NH_{3(g)} + H_2O_{(l)} \rightarrow NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$
- Limited to the solvent water, but acid-base reactions can occur in other solvents

The Hydronium Ion, $H_3O^+_{(aq)}$

Many acid-base reactions occur in water.

- Acids such as $HCl_{(aq)}$ break apart in water
- The proton, H^+, covalently bonds to water molecules forming the hydronium ion, $H_3O^+_{(aq)}$
- $H_3O^+_{(aq)}$ is indicated using the shorter form $\mathbf{H^+_{(aq)}}$
- Ionization occurs – process in which a changed particle (ion) is formed



When acids like HCl dissociate in water, the hydronium ion, $H_3O^+(aq)$, forms. This ion bonds with surrounding water molecules.

Bronsted and Lowry

Johannes Brønsted
Copenhagen
(Denmark)

Thomas Lowry
London (England)

Bronsted-Lowry Theory of Acids

- Acid: proton (H^+) donor

$$HCl + NH_3 \rightarrow NH_4^+ + Cl^-$$

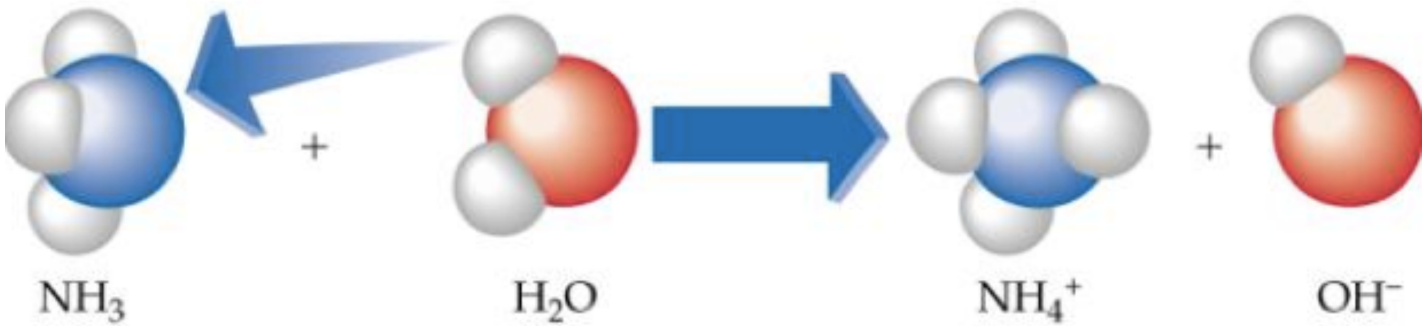
- HCl donates a H^+ to NH_3
  - H^+ does not exist by itself

Bronsted-Lowry Theory of Bases

- Bases: accept a proton

$$H_2O + NH_3 \rightarrow NH_4^+ + OH^-$$

- NH_3 accepts a H^+ from H_2O



- A Bronsted-Lowry acid must have a H in its formula (like an Arrhenius acid)
- Any negative ion can be a Bronsted-Lowry base

For an acid-base reaction:

- There must be a transfer of a proton
- A substance can behave as an acid, if another substance behaves as a base
- i.e. there is a proton donor (acid) and a proton acceptor (base)

$$HCl_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$$

acid	base	conjugate acid	conjugate base

Conjugate acid-base pair

- The two molecules or ions related by transfer of a proton from one to the other (**conjugate** means "linked together")

Example: $HCl_{(aq)}$ and $H_2O_{(l)}$

- HCl donates the proton and H_2O receives the proton

Conjugate base of an acid

- The particle remaining when the proton is removed from the acid
- $HCl_{(aq)}$ is acid
- Remove proton → $Cl^{-}_{(aq)}$ is conjugate base

Conjugate acid of a base

- The particle produced when a base receives a proton
- $H_2O_{(l)}$ is a base
- Add proton → $H_3O^+_{(aq)}$ is conjugate acid

Practice

Identify the conjugate acid-base pair:

a) $H_2SO_4 + H_2O \rightarrow HSO_4^- + H_3O^+$

b) $HCl + NH_3 \rightarrow Cl^- + NH_4^+$

c) $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$

Comparing the Arrhenius and Bronsted-Lowry Theory

Theory	Arrhenius	Brønsted-Lowry
Acid	any substance that dissociates to form H+ in aqueous solution	any substance that provides a proton to another substance (or any substance from which a proton may be removed)
Base	any substance that dissociates to form OH- in aqueous solution	any substance that receives a proton from an acid (or any substance that removes a proton from an acid)
Example	$HCl_{(aq)} \rightarrow H^{+}_{(aq)} + Cl^{-}_{(aq)}$	$HCl_{(aq)} + H_2O_{(l)} \rightarrow H_3O^{+}_{(aq)} + Cl^{-}_{(aq)}$

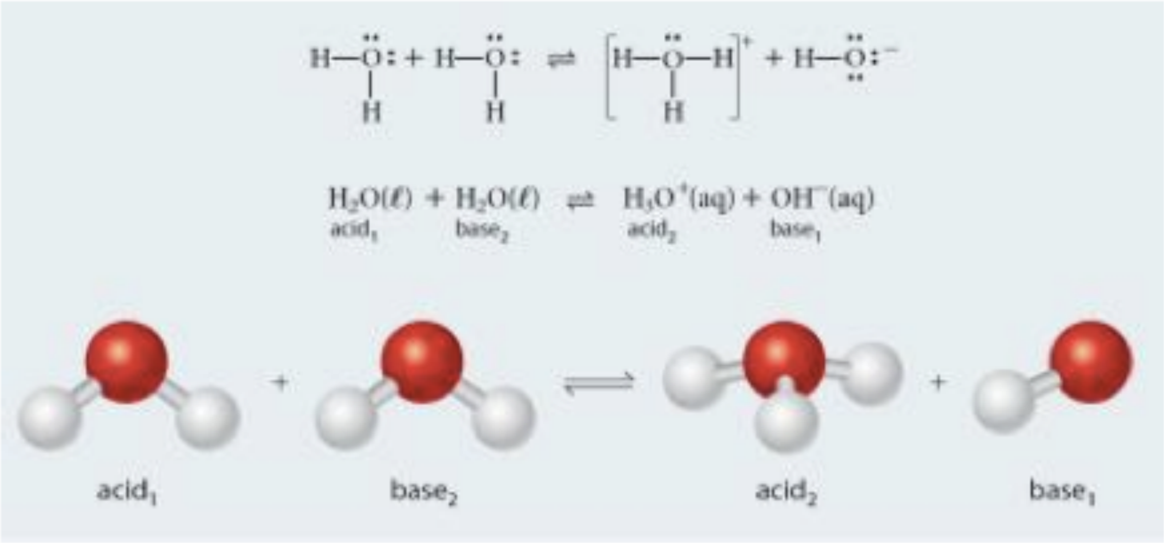
Both an Acid and a Base: Amphiprotic Substances

- Water molecules are **amphiprotic** – acting as an acid or a base.

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

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

Water undergoes autoionization and can act as both a Brønsted-Lowry acid or a Brønste-Lowry base.



The Acid Ionization Constant, K_a

- The **acid ionization constant, K_a,** is used for reactions in which an acid $HA_{(aq)}$, reacts with water to form a conjugate base, $A^-_{(aq)}$.

$$HA_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + A^-_{(aq)}$$

$$K = \frac{[H_3O^+_{(aq)}][A^-_{(aq)}]}{[H_2O_{(l)}][HA_{(aq)}]}$$

$$K_a = \frac{[H_3O^+_{(aq)}][A^-_{(aq)}]}{[HA_{(aq)}]}$$

Table 1 Some Acid Ionization Constants

Acid	Acid ionization constant, K_a
hydrocyanic, $HCN(aq)$	6.2×10^{-10}
benzoic, $HC_6H_5CO_2(aq)$	6.3×10^{-5}
propanoic, $HC_3H_5O_2(aq)$	1.3×10^{-5}
ethanoic (acetic), $HC_2H_3O_2(aq)$	1.8×10^{-5}
hydrofluoric, $HF(aq)$	6.6×10^{-4}
nitrous, $HNO_2(aq)$	4.6×10^{-4}
methanoic (formic), $HCHO_2(aq)$	1.8×10^{-4}

Practice

Write the acid ionization constant equation for the equilibrium reaction:

a) $HNO_{2(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + NO_2^-{}_{(aq)}$

b) $HC_2H_3O_{2(aq)} \rightleftharpoons H^+_{(aq)} + C_2H_3O_2^-{}_{(aq)}$

Did You Learn?

- According to the Arrhenius theory, in aqueous solution an acid produces hydrogen ions, H^+, and a base produces hydroxide ions, OH^-.
- According to the Bronsted-Lowry theory, an acid is a hydrogen ion (proton) donor and a base is a hydrogen ion acceptor.
- When an acid, HA, reacts with water, the water acts as a base and forms a conjugate acid, H_3O^+. The acid forms a conjugate base, A^-, according to the equation
  - $HA_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + A^-_{(aq)}$
- The acid equilibrium constant, K_a, is represented by

$K_a = \frac{[H_3O^+_{(aq)}][A^-_{(aq)}]}{[HA_{(aq)}]}$ which may be simplified as $K_a = \frac{[H^+_{(aq)}][A^-_{(aq)}]}{[HA_{(aq)}]}$

HOMEWORK

Required Reading:

p. 488 – 494

(remember to supplement your notes!)

Questions:

P. 492 #1, 2

P. 493 #1bc

P.494 #1-8