Chapter 7: Phenomena

Phenomena: Scientists dissolved different substances in water and then measured the [H+] and [OH−] concentrations in each solution. What patterns do you notice about the substances?

<table>
<thead>
<tr>
<th>Substance</th>
<th>Amount of substance dissolved in 1 L of water</th>
<th>[H+]</th>
<th>[OH−]</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl</td>
<td>1.0 mol</td>
<td>1.0 M</td>
<td>1.0×10−14 M</td>
</tr>
<tr>
<td>KNO₃</td>
<td>1.0 mol</td>
<td>1.0×10−14 M</td>
<td>1.0 M</td>
</tr>
<tr>
<td>H₂CO₃</td>
<td>1.0 mol</td>
<td>1.0×10−14 M</td>
<td>1.0×10−14 M</td>
</tr>
<tr>
<td>HBr</td>
<td>1.0 mol</td>
<td>1.0 M</td>
<td>1.0×10−14 M</td>
</tr>
<tr>
<td>HOCl</td>
<td>1.0 mol</td>
<td>1.0×10−14 M</td>
<td>1.0×10−14 M</td>
</tr>
<tr>
<td>CH₃NH₂</td>
<td>1.0 mol</td>
<td>1.0×10−14 M</td>
<td>1.0×10−14 M</td>
</tr>
<tr>
<td>NH₃</td>
<td>1.0 mol</td>
<td>1.0×10−14 M</td>
<td>1.0×10−14 M</td>
</tr>
<tr>
<td>HNO₃</td>
<td>1.0 mol</td>
<td>1.0×10−14 M</td>
<td>1.0×10−14 M</td>
</tr>
<tr>
<td>C₅H₅N</td>
<td>1.0 mol</td>
<td>1.0×10−14 M</td>
<td>1.0×10−14 M</td>
</tr>
<tr>
<td>H₂O</td>
<td>N/A</td>
<td>1.0×10−7 M</td>
<td>1.0×10−7 M</td>
</tr>
</tbody>
</table>

Chapter 7: Acids and Bases

Acids and Bases

**Acid**
- Sour taste (lemon citric acid)
- Dissolve many metals \((\text{acid(aq)} + \text{metal(s)} \rightarrow \text{salt(aq)} + \text{H}_2(g))\)
- Turn litmus paper red

**Base**
- Bitter taste (unsweetened baker’s chocolate)
- Slippery feel (cleaning products)
- Turn litmus paper blue

Arhenius (1884)

- **Acid**: A compound that forms hydrogen ions \((H^+)\) in water.
  - **Examples**:
    - HCl(aq) acid
    - CH₄(aq) not an acid because it does not release \((H^+)\) ions in solution

- **Base**: A compound that forms hydroxide ions \((OH−)\) in water.
  - **Examples**:
    - NaOH(aq) base
    - NH₃ base because \(\text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightarrow \text{NH}_4\text{aq} + \text{OH}-(aq)\)

Bronsted-Lowry (1923)

- **Acid**: A proton donor.
- **Base**: A proton acceptor.

**Deprotonation**: The loss of a proton from a Bronsted-Lowry acid

**Note**: First deprotonation is the loss of the first H, the second deprotonation is the loss of a second H, and the third deprotonation is the loss of a third H.

**Amphoteric**: A substance that can act as an acid or base

**Example**: H₂O

**Conjugate Acid Base Pair**: Two substances that are related to each other by the transfer of one proton

Acid \(\text{donates a proton} \rightarrow \text{Conjugate Base}\)

Base \(\text{accepts a proton} \rightarrow \text{Conjugate Acid}\)
Chapter 7: Acids and Bases

Student Question

Which of the following represent conjugate acid-base pairs? For those pairs that are not conjugates, write the correct conjugate acid or base for each species in the pair.

a) \( \text{H}_2\text{SO}_4 \) and \( \text{SO}_4^{2-} \)
b) \( \text{H}_2\text{PO}_4^- \) and \( \text{HPO}_4^{2-} \)
c) \( \text{HClO}_4 \) and \( \text{Cl}^- \)
d) \( \text{NH}_4^+ \) and \( \text{NH}_2^- \)

Strength of Acids/Bases

- **Strong Acid or Base**: An acid/base that completely ionizes in solution.
- **Weak Acid or Base**: An acid/base that does not completely ionize in solution.

**Strong Acids**

- \( \text{HCl} \)
- \( \text{HNO}_3 \)
- \( \text{HBr} \)
- \( \text{HClO}_4 \)
- \( \text{HI} \)
- \( \text{HClO}_3 \)
- \( \text{HBrO}_3 \)
- \( \text{HBrO}_4 \)
- \( \text{H}_2\text{SO}_4 \)
- \( \text{HIO}_4 \)

**Strong Bases**

- \( \text{LiOH} \)
- \( \text{Sr(OH)}_2 \)
- \( \text{NaOH} \)
- \( \text{Ca(OH)}_2 \)
- \( \text{KOH} \)
- \( \text{Ba(OH)}_2 \)
- \( \text{RbOH} \)
- \( \text{Mg(OH)}_2 \)

**Name**

<table>
<thead>
<tr>
<th>Formula</th>
<th>( K_a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Sulfate Ion</td>
<td>( 1.2 \times 10^-2 )</td>
</tr>
<tr>
<td>Chlorous Acid</td>
<td>( 1.2 \times 10^-2 )</td>
</tr>
<tr>
<td>Monochloracetic Acid</td>
<td>( 1.35 \times 10^-3 )</td>
</tr>
<tr>
<td>Hydrofluoric Acid</td>
<td>( 7.2 \times 10^-4 )</td>
</tr>
<tr>
<td>Nitrous Acid</td>
<td>( 4.0 \times 10^-4 )</td>
</tr>
<tr>
<td>Acetic Acid</td>
<td>( 1.8 \times 10^-5 )</td>
</tr>
<tr>
<td>Hydrated Aluminium(Ill) ion</td>
<td>( 1.4 \times 10^-5 )</td>
</tr>
<tr>
<td>Hypochlorous Acid</td>
<td>( 3.5 \times 10^-8 )</td>
</tr>
<tr>
<td>Hydrocyanic Acid</td>
<td>( 6.2 \times 10^-10 )</td>
</tr>
<tr>
<td>Ammonium ion</td>
<td>( 5.6 \times 10^-10 )</td>
</tr>
<tr>
<td>Phenol</td>
<td>( 1.6 \times 10^-10 )</td>
</tr>
</tbody>
</table>

**Name**

<table>
<thead>
<tr>
<th>Formula</th>
<th>( K_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>( 1.8 \times 10^-5 )</td>
</tr>
<tr>
<td>Methylamine</td>
<td>( 4.38 \times 10^-4 )</td>
</tr>
<tr>
<td>Ethylamine</td>
<td>( 5.6 \times 10^-4 )</td>
</tr>
<tr>
<td>Aniline</td>
<td>( 3.8 \times 10^-10 )</td>
</tr>
<tr>
<td>Pyridine</td>
<td>( 1.7 \times 10^-9 )</td>
</tr>
</tbody>
</table>

Note: A strong acid is defined as an acid that has a \( K_a \) larger than 1. Not all strong acids have the same \( K_a \). For example, the \( K_a \) of \( \text{H}_2\text{SO}_4 \) is \( 9.2 \times 10^8 \), whereas the \( K_a \) of \( \text{HCl} \) is \( 1 \times 10^6 \). Therefore, \( \text{H}_2\text{SO}_4 \) is one of the weakest strong acids.

**Is there a relationship between \( K_a \) and \( K_b \)?**

- **General Weak Acid Equilibrium Equation**
  \( \text{HA(aq)} \rightleftharpoons \text{H}^+(aq) + \text{A}^-(aq) \)
  \( K_a = \frac{[\text{H}^+] [\text{A}^-]}{[\text{HA}]} \)

- **General Weak Base Equilibrium Equation**
  \( \text{B(aq)} + \text{H}_2\text{O}(l) \rightleftharpoons \text{BH}^+(aq) + \text{OH}^-(aq) \)
  \( K_b = \frac{[\text{BH}^+] [\text{OH}^-]}{[\text{B}]} \)

- **Water Equilibrium Equation**
  \( \text{H}_2\text{O}(l) \rightleftharpoons \text{H}^+(aq) + \text{OH}^-(aq) \)
  \( K_w = \frac{[\text{H}^+] [\text{OH}^-]}{[\text{H}_2\text{O}]} = 1.0 \times 10^{-14} \)

Note: \( K_w \) is known as the ion product constant.
**Chapter 7: Acids and Bases**

### pH/pOH Scale

- How do you tell if a solution is acidic, basic, or neutral?
  - $[H^+] = [OH^-]$: neutral
  - $[H^+] > [OH^-]$: acidic
  - $[H^+] < [OH^-]$: basic

- Are the $[H^+]$ and $[OH^-]$ related?
  - $K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$
  - For neutral solutions: $[H^+] = [OH^-] = 1.0 \times 10^{-7}$
  - $[H^+] > 1.0 \times 10^{-7}$ and $[OH^-] < 1.0 \times 10^{-7}$: acidic
  - $[H^+] < 1.0 \times 10^{-7}$ and $[OH^-] > 1.0 \times 10^{-7}$: basic

- How do you calculate $pH$?
  - $pH = -\log[H^+]$
  - $pH = 7$: neutral
  - $pH < 7$: acidic
  - $pH > 7$: basic

### pH/pOH of Strong Acids/Bases

**Student Question**

Calculate the $pH$ of 0.25 M $Ba(OH)_2$.

- a) 0.60
- b) 13.10
- c) 13.40
- d) 13.70
- e) None of the above

### pH/pOH of Weak Acids/Bases

**Student Question**

What is the $pH$ of a 0.18 M monoprotic acid solution whose conjugate base has a $K_b = 2.8 \times 10^{-8}$?

- a) 3.22
- b) 2.85
- c) 3.90
- d) 4.70
- e) None of the above

### Acid/Base Properties of Salts

**Student Question**

Is $NH_4C_2H_3O_2$:

- a) Acid
- b) Base
- c) Neutral
- d) More information needed

### Acid Rain

- $pH$ of water ~7
- $pH$ of unpolluted rain ~5.7
- $pH$ of rain in industrial areas has been recorded at ~2.4
Chapter 7: Acids and Bases

Acid Rain

What are the natural causes of acids in rain?

**Source** | **Causes**
---|---
CO₂ | Decomposition/Respiration/Fires
NO | Electrical Discharge
SO₂ | Volcanic Gases

What are the man made causes of acids in rain?

**Source** | **Causes**
---|---
CO₂ | Fossil Fuel Combustion/Fires
NO | High Temperature Air Combustion
SO₂ | Fossil Fuel Combustion

CO₂ (produced from the combustion of C or C₅H₄)

- C(s) + O₂(g) → CO₂(g)
- CH₄(g) + 2O₂(g) → CO₂(g) + 2H₂O(g)
- CO₂(g) + H₂O(l) → H₂CO₃(aq)

NO (formed from N at high temperatures)

- N₂(g) + O₂(g) → 2NO(g)
- 2NO(g) + O₂(g) → 2NO₂(g)
- 3NO₂(g) + H₂O(l) → 2HNO₃(aq) + NO(g)

Note: The majority of the NO emissions come from automobiles.

SO₂ (formed from the combustion of S)

- S(s) + O₂(g) → SO₂(g)
- 2SO₂(g) + O₂(g) → 2SO₃(g)
- SO₃(g) + H₂O(l) → H₂SO₄(aq)

Note: Why are we more worried about controlling SO₂ and NO emissions for acid rain?

Note: The majority of all SO₂ emissions come from the production of electricity.

Three Way Catalytic converters (1981)

- 2NO(g) + O₂(g) → 2NO₂(g)

SO₂

- Scrubbers (in the 1990s)
- (limestone slurries are put into the smoke stacks)
- CaCO₃(s) + H₂SO₄(aq) → CaSO₄(aq) + H₂O(l) + CO₂(g)

Note: Acid rain level have dropped 65% since 1976.

Take Away From Chapter 7

**Big Idea:** A Bronsted-Lowery acid is a proton donor and a Bronsted-Lowery base is a proton acceptor. After an acid/base loses/gains its proton it becomes a conjugate base/acid. An equilibrium problem must be set up to solve for the pH of a weak acid or base.

**Acids and Bases**

- Know the different acid/base definitions.
  - Arrhenius: Acid: Forms H⁺ in water, Base: Forms OH⁻ in water
  - Bronsted-Lowery: Acid: Proton donor, Base: Proton acceptor

**Conjugate Acids/Bases**

- Be able to recognize conjugate acid base pairs.
- Pairs that differ by 1 hydrogen atom (H₂PO₄⁻ and H₃PO₄).

**Strength of Acids/Bases**

- Memorize the strong acids and bases. (24, 23, 24)
- Strong Acids: HCl, HBr, HI, HNO₃, HBrO₃, HBrO₄, HIO₃, HIO₄, HClO₄, and H₂SO₄ (1st deprotonation)
- Strong Bases: LiOH, NaOH, KOH, RbOH, CsOH, Sr(OH)₂, Ca(OH)₂, Ba(OH)₂, and Mg(OH)₂
- Know the relationship between [H⁺] and [OH⁻]: [H⁺][OH⁻] = 1.0×10⁻¹⁴

- Be able to change between Kₐ and Kₐ values.
- Know that the stronger the acid/base the weaker the conjugate acid/base. (31)
- Be able to order acids/bases in increasing strength using Kₐ and/or Kₐ values (27, 28, 29, 30, 69, 70)
Take Away From Chapter 7

- **pH/pOH Scale** (74, 75)
  - Be able to calculate the pH of a solution.
    - pH = \(-\log[H^+]\)
  - Be able to calculate the pOH of a solution.
    - pOH = \(-\log[OH^-]\)
  - Be able to convert between pH and pOH
    - \(pH = -pOH\)

- **pH/pOH of Strong Acids/Bases**
  - Be able to calculate the pH and pOH of strong acids and strong bases.

- **pH/pOH of Weak Acids/Bases** (79)
  - Be able to identify the major species in solution.
  - Be able to calculate the pH and pOH of weak acids and bases (ICE table).
  - Be able to calculate the water solubility of a substance given the pH of a saturated solution.

- **Acid/ Base Properties of Salts** (101, 103, 105, 109, 131)
  - Be able to determine if a salt is acidic, basic, or neutral.
  - Be able to calculate the pH of a salt with only one acid anion or cation.

- **Acid Rain**

Numbers correspond to end of chapter questions.