Acid and Bases

Chemistry 30

Physical Properties

Acids	Bases
Corrosive when concentrated	Corrosive when concentrated
Have a sour taste	Have a bitter taste
Often have a sharp odour	

Chemical Properties

Acids	Bases
React with bases to produce water and a salt	React with acids to form water and a salt
React with some metals to produce hydrogen gas and a salt	React with fats and oil (may feel slippery due to reaction with body oils)
React with carbonates to produce water, carbon dioxide and a salt	Less reactive than acids, but can be more dangerous

Indicators

- **Indicator**: substance used to identify an acid or base
- Some just identify acid or base, others will tell how acidic or basic substance is

Acidity of Solutions

- Recall: aqueous solutions can be made from dissolving a substance in water
- If aqueous solution contains equal hydroxide and hydrogen ions, it is neutral
- More hydroxide means the solution is basic
- More hydrogen means the solution is acidic

Water is Neutral

- Water is neutral
- Produces equal hydrogen and hydroxide ions

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

- For one litre of water at room temperature:

$[H_2O]$ = 55 mol/L

$[H^+] = [OH^-] = 10^{-7}$ mol/L

Arrhenius Model

States that:
- Acids contain hydrogen, ionize to make hydrogen ions in solutions
- Bases contain hydroxide, ionize to make hydroxide ions in solutions

Arrhenius Model Examples

When hydrogen chloride gas is dissolves in water, it produces hydrogen ions (and is therefore an acid):

$$HCl\ (g) \rightarrow H^+\ (aq) + Cl^-\ (aq)$$

Potassium hydroxide is a base, since it produces hydroxide ions:

$$KOH\ (s) \rightarrow K^+\ (aq) + OH^-\ (aq)$$

Limits of the Arrhenius Model

- Suitable for describing most acids, but does not apply to many bases
- For example, ammonia (NH_3) is a common base, but it does not contain hydroxide

Brønsted-Lowry Model

- Acids are hydrogen ion (proton) **donors**
- Bases are hydrogen ion (proton) **acceptors**

- To identify acid versus base in a reaction, identify which is losing H^+ and which is gaining

Conjugate Acids and Bases

- **Conjugate base**: resulting compound after acid loses H^+
- **Conjugate acid**: resulting compound after base gains H^+

acid + base ⇌ conjugate base + conjugate acid

$$HA + B \rightleftharpoons A^- + HB^+$$

Indicates what acid and base would be in reverse reaction, if it were to occur (i.e. when none of the species are strong acids or bases)

Example 1: Conjugate Acids and Bases

Identify the conjugate acid-base pairs.

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

Example 2: Conjugate Acids and Bases

Identify the conjugate acid-base pairs.

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

Amphoteric Substances

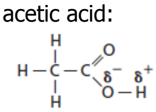
- **Amphoteric**: substances that can act as either an acid or a base
- Example: water, HCO_3^-

$HCO_3^- (aq) + H_3O^+ (aq) \rightarrow H_2CO_3 (aq) + H_2O (l)$

$HCO_3^- (aq) + OH^- (aq) \rightarrow CO_3^{2-} (aq) + H_2O (l)$

Identifying Available Protons

- Only available hydrogen ions to lose are from polar bonds.
- Process is called ionization – breaking a polar bond to form two ions
- For example, in acetic acid:



Three H-C bonds cannot be broken, but O-H can

Monoprotic and Polyprotic Acids

- **Monoprotic** acids: one available hydrogen
  - e.g. HF, $HClO_4$, HCH_3COO
- **Polyprotic** acids: more than one (usually two or three) available hydrogen ions
  - e.g. H_2SO_4, H_3PO_4
  - Go through steps to donate all of their hydrogens
  - More difficult for ionization to occur with each step

Example: Ionization of Phosphoric Acid

Step 1

$H_3PO_4 (aq) \rightleftharpoons H_2PO_4^- (aq) + H^+ (aq) \quad K_a = 7.1 \times 10^{-3}$

Step 2

$H_2PO_4^- (aq) + \rightleftharpoons HPO_4^{2-} (aq) + H^+ (aq) \quad K_a = 6.3 \times 10^{-8}$

Step 3

$HPO_4^{2-} (aq) \rightleftharpoons PO_4^{3-} (aq) + H^+ (aq) \quad K_a = 4.5 \times 10^{-13}$

Strength of Acids and Bases

- **Strength** of an acid or base: extent to which it dissolves in solution
- Basically, strength is an indicator of how soluble the compound is.

Strong Acids and Bases

- Dissolves **100%** in solution (very soluble)
- In solution, all of the non-water particles are **ions**
- Six strong acids:
  - Hydrochloric acid HCl
  - Nitric acid HNO_3
  - Sulfuric acid H_2SO_4
  - Hydrobromic acid HBr
  - Hydroiodic acid HI
  - Perchloric acid $HClO_4$

Strong Acids and Bases

Eight **common** strong bases:

$LiOH$, $NaOH$, KOH, $RbOH$, $CsOH$, $Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$

- Strong acids/bases have **highly polar bonds** – easily broken apart by water
- Strong acids/bases are considered to not have conjugates (no reverse reaction)

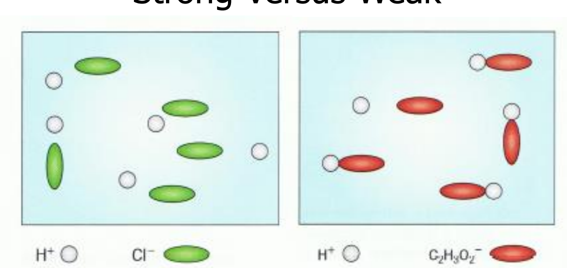
Weak Acids and Bases

- Ionize **less than 50%** in solution
- Solutions have an equilibrium between the compound (as a neutral molecule) and its ions

Weak Acids and Bases

- Almost non-polar bonds (do not dissolve easily in water)
- Note that strength is a scale - not all acids/bases that are not strong are weak
- Temperature and concentration can also affect the level of dissociation of any substance being dissolved in water

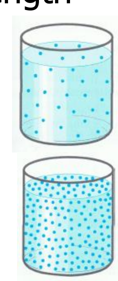
Strong Versus Weak



Concentration Versus Strength

A **dilute** solution has a small amount of acid or base particles (either ions or molecules) per unit volume of solution.

A **concentrated** solution has a large amount of acid or base particles per unit volume.

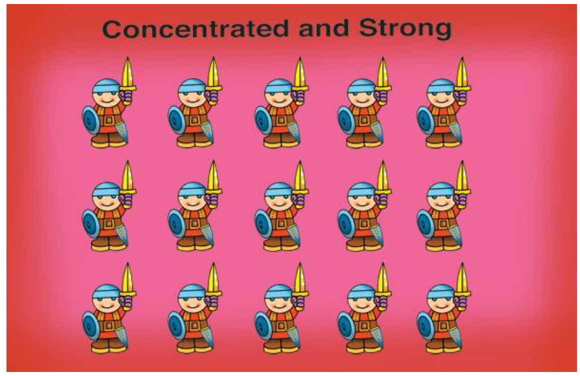


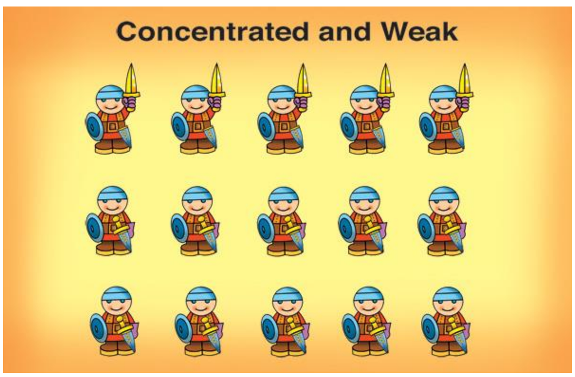
The strength of an acid or base does not affect its ability to be concentrated or dilute.

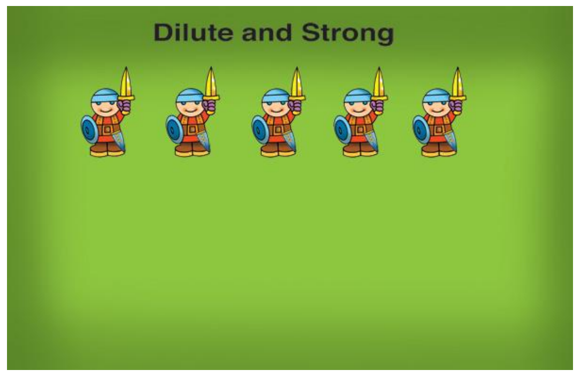
Concentration Versus Strength

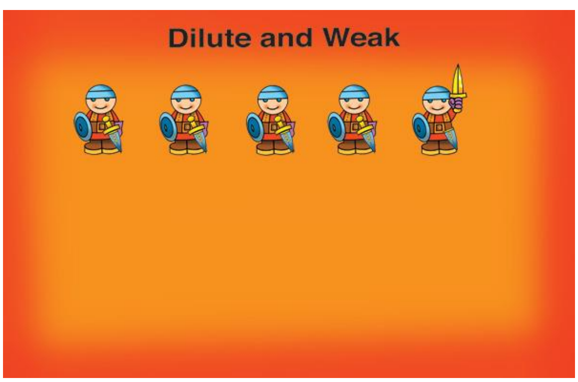
In the next four pictures, consider any soldiers to be particles.

Soldiers with their swords up are **ions**. Soldiers with their swords holstered are **molecules**.









Acid Ionization Equations

Strong acids **ionize** completely:

$$HA \rightarrow H^+ + A^-$$

Weak acids ionize partially, so they are in equilibrium:

$$HA \rightleftharpoons H^+ + A^-$$

Example: Ionization Equations

Write a balanced equation for the ionization of hydrochloric acid:

Write the balance equation for the ionization of carbonic acid:

Base Dissociation/Ionization Equations

Strong bases dissociate completely:

$$BOH \rightarrow B^+ + OH^-$$

Weak bases ionize partially, so they are in equilibrium. A weak base need to be combined with **water**, to produce hydroxide ions:

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

Example: Ionization/Dissociation Equations

Write a balanced equation for the dissociation of sodium hydroxide:

Write a balanced equation for the dissociation of methylamine:

Ionization Constants

- K_a and K_b are acid and base **ionization constants**
- Similar to K_{sp} – determine how much an acid/base will ionize in solution
- Higher values mean the acid or base is stronger

Example: K_a

Put these in order from strongest to weakest:

Formic acid	1.8×10^{-4}
Hydrocyanic acid	6.2×10^{-10}
Citric acid	3.2×10^{-7}
Boric acid	5.9×10^{-10}
Benzoic acid	6.4×10^{-5}

Ionization Constants

- Just like K_{eq} K_a and K_b have equilibrium expressions
- For example, for acetic acid:

$$K_a = \frac{[H^+][CH_3COO^-]}{[CH_3COOH]} = 1.8 \times 10^{-5}$$

- For polyprotic acids, there is a ionization constant for each ionization

Things to Calculate with K_a/K_b

- $[H^+]$ and $[OH^-]$ – determine if something is an acid or base, how acidic/basic
- pH and pOH – determine how acidic/basic

Example 1: Calculations Strong Acids or Bases

Calculate $[H^+]$ in a 2.00 L solution of hydrogen chloride in which 3.65 g of HCl is dissolved. K_a for HCl is very large.

Example 2: K_a for Weak Acids

An acetic acid ($HC_2H_3O_2$) solution is 0.25 mol/L. Given that K_a for acetic acid is 1.8×10^{-5}, find $[H^+]$.

Example 3: K_b for Weak Bases

Calculate the hydroxide ion concentration in a 0.025 M solution of aniline, $C_6H_5NH_2$, a weak base with $K_b = 4.3\times10^{-10}$.

Self-Ionization of Water

- Recall: water is neutral because it produces equal H^+ and OH^- ions
- Ion product constant of water, K_w is given by:

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

- At room temperature (25°C), $[H^+] = [OH^-] = 10^{-7}$ mol/L
- K_w is 10^{-14}

Example: Calculating Concentration with K_w

In an aqueous solution, $[H^+] = 1.0 \times 10^{-13}$ M. What is $[OH^-]$ in the solution? Is the solution basic or acidic?

pH and pOH

- Use pH to simplify concentration values (often very small numbers)
- Logarithmic scale that indicates the concentration of hydrogen ions in a solution:

$$pH = -\log [H^+]$$

pH and pOH

- pH Ranges:
  - Acids $pH < 7$
  - Neutral $pH = 7$
  - Bases $pH > 7$
- Most pH values fall between 0 and 14, but can be beyond that range
- For a log scale:
  - A solution with pH of 3 is ten times more acidic than a solution with pH 4
  - A solution with pH 3 is a hundred times more than pH 5

pH and pOH

- pOH is the same idea as pH, except for hydroxide ion concentration

$$pOH = -\log [OH^-]$$

- All of the values are reversed from pH – low values of pOH are basic
- To convert between them:

$$pH + pOH = 14.00$$

pH to Concentration

To calculate the concentration from pH or pOH:

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

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

pH of Acids and Bases

1. Write dissociation equation
2. Determine $[H^+]$ or $[OH^-]$:
   1. Example for strong acids/bases:
      For 0.1 mol/L HCl, $[H^+] = 0.1$ mol/L
      For 0.1 mol/L $Ca(OH)_2$, $[OH^-] = 0.2$ mol/L
   2. For weak acids/bases, use K_a or K_b calculation
3. Calculate pH (if you have $[H^+]$) or pOH (if you have $[OH^-]$)

Example 1: pH and pOH

A solution has $[H^+] = 3.54 \times 10^{-4}$ mol/L.

a. What is the pH of the solution?
b. What is the pOH of the solution?
c. What is $[OH^-]$?

Example 2: pH and pOH

For a 0.15 mol/L solution of sulfuric acid, what is the pH of the solution?

Example 3: pH and pOH

For a 0.00675 mol/L solution of aniline, what is the pH of the solution?

Neutralization Reactions

- Specific type of double displacement reaction that occurs when a base reacts with an acid
- Produces water and an aqueous ionic compound (a salt)

Stoichiometry of Neutralization

Important formulas to remember:

$$n = CV$$

$$m = nM$$

You should also remember how to use mole ratios!

Assumptions…

- Only need to know how to do stoichiometric calculations for reactions with at least one strong acid or base
- Assume that the reaction goes to completion

Solving Neutralization Problems

1. Write and balance the equation
2. Identify and list all known and unknown variables
3. Determine the relationship of moles of acid to moles of base (mole ratio)
4. Use stoichiometry to solve

Example 1: Neutralization

How many moles of hydrochloric acid are needed to neutralize 0.50 mol of calcium hydroxide?

Example 2: Neutralization

What volume of 0.0947 M NaOH is needed to neutralize 21.4 mL of 0.106 M HCl?

Example 3: Neutralization

What is the pH of a solution of $Ca(OH)_2$ if 200.00 mL is needed to completely neutralize 100.00 mL of 0.350M H_3PO_4?

Titration

- Lab method used to determine the unknown concentration of a solution by reacting it with a known volume and concentration of another solution
- Did this for K_{sp} lab
- Example: determine concentration of an acid (specific volume) by titrating it with a base of known concentration

Titration

- Common lab procedures
- Used in many manufacturing processes, in environmental science and in the health field
- End point is either a specific concentration/pH (measured with a pH meter) or an indicator colour change

Titration