CHEM 103
Acid-Base Reactions

Lecture Notes
March 2, 2006
Prof. Sevian

1

Chem 103

Please sit with your groups today.

We will be doing a group problem at the end of class.

2

Agenda

- Recap: Complete vs. net ionic reactions
- Acids and bases
- pH scale
- Weak vs. strong
- Neutralization
- How metal carbonates react with acids

Writing Net Ionic Equations

1. Start with the balanced reaction, written with phases
2. Identify ions in aqueous solution, ionic solids that precipitate, and any molecules on both sides of the arrow
3. Cross out any spectator ions
4. What’s left is the net ionic equation

Spectator Ions are Vehicles

$$2\ NaI\ (aq) + HgCl_2\ (aq) \rightarrow HgI_2\ (s) + 2\ NaCl\ (aq)$$

~~two Na^+ ions (*aq*)~~ | two I^- ions (*aq*) | one Hg^{2+} ion (*aq*) | ~~two Cl^- ions (*aq*)~~ | one unit of HgI_2 ppt (*s*) | ~~two Na^+ ions (*aq*)~~ | ~~two Cl^- ions (*aq*)~~

$$2\ NH_4I\ (aq) + Hg(NO_3)_2\ (aq) \rightarrow HgI_2\ (s) + 2\ NH_4NO_3\ (aq)$$

~~two NH_4^+ ions (*aq*)~~ | two I^- ions (*aq*) | one Hg^{2+} ion (*aq*) | ~~two NO_3^- ions (*aq*)~~ | one unit of HgI_2 ppt (*s*) | ~~two NH_4^+ ions (*aq*)~~ | ~~two NO_3^- ions (*aq*)~~

Net reaction: two $\mathbf{I^-}$ ions + one $\mathbf{Hg^{2+}}$ ion → one unit of $\mathbf{HgI_2}$ ppt

$$2\ I^-\ (aq) + Hg^{2+}\ (aq) \rightarrow HgI_2\ (s)$$

You Try It

Write the Net Ionic Equation

Cadmium nitrate + sodium sulfide

cadmium nitrate + sodium sulfide → cadmium sulfide + sodium nitrate

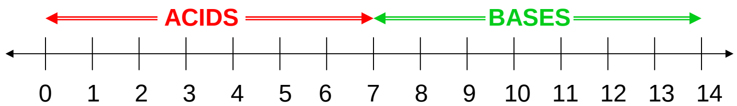
$$Cd(NO_3)_2\ (aq) + Na_2S\ (aq) \rightarrow CdS\ (s) + 2\ NaNO_3\ (aq)$$

Net reaction:

6

Acid-Base Rxns
Macroscopic View

- **pH scale is used to identify acids and bases, and indicate their level of strength**



- **A chemical "indicator" can also indicate the pH** (indicator compound undergoes chemical transformation based on pH of solution, different configurations of indicator compound are different colors)
- **Reaction between an acid and a base produces a solution with pH somewhere in between**
- **Resulting solution tastes salty (do not do this in lab)**
- **Some examples**
  - Acids, bases, and what happens when you mix them?

8

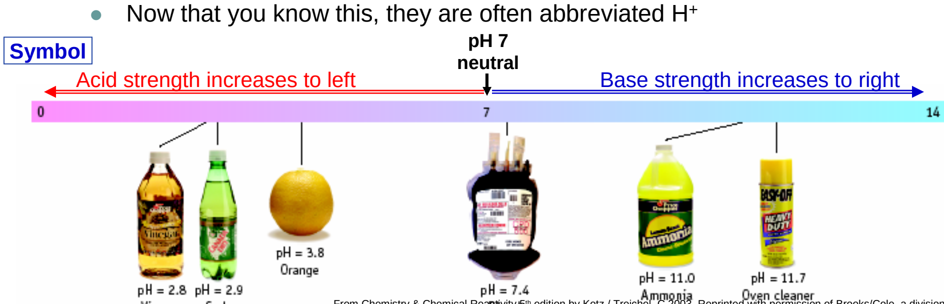
What is the pH scale?

Macro Provides information about whether a material (aqueous solution) is acid or base, and how strong it is

Particle Actually measures hydronium ion (H^+ or H_3O^+) concentration

- Hydrogen ions (H^+) do not actually exist in solution
- Instead, H^+ ions attach to water molecules and form H_3O^+ ions
- H_3O^+ ions are called <u>hydronium</u> ions
- Now that you know this, they are often abbreviated H^+

Symbol



From Chemistry & Chemical Reactivity 5th edition by Kotz / Treichel. C 2003. Reprinted with permission of Brooks/Cole, a division of Thomson Learning: www.thomsonrights.com. Fax 800-730-2215.

Macroscopic View
Acids vs. Bases

Acids
- Taste sour
- Sharp odor
- Corrosive
- Most foods are acidic
- Solution conducts electricity

Bases
- Taste bitter
- Feel slippery
- Caustic
- Most cleaners are basic
- Solution conducts electricity

When acid and base solutions are mixed in stoichiometrically equal quantities, the pH moves toward being neutral, and the resulting solution tastes salty. Reaction is called NEUTRALIZATION.

Acid + Base → Salt + Water

Particle Level View
Acids vs. Bases

Acids
- When a chemical that is an acid is added to water, it increases the H^+ concentration in the solution
- Registers less than 7 on pH scale because $[H^+]$ is greater than neutral water, which is 1.0×10^{-7} *mol/L*

Bases
- When a chemical that is a base is added to water, it increases the OH^- concentration in the solution
- Registers more than 7 on pH scale because $[OH^-]$ is greater than neutral water, which is 1.0×10^{-7} *mol/L*

Why is Water So Special?

Water itself breaks into ions:

$$H_2O \rightarrow H^+ + OH^-$$

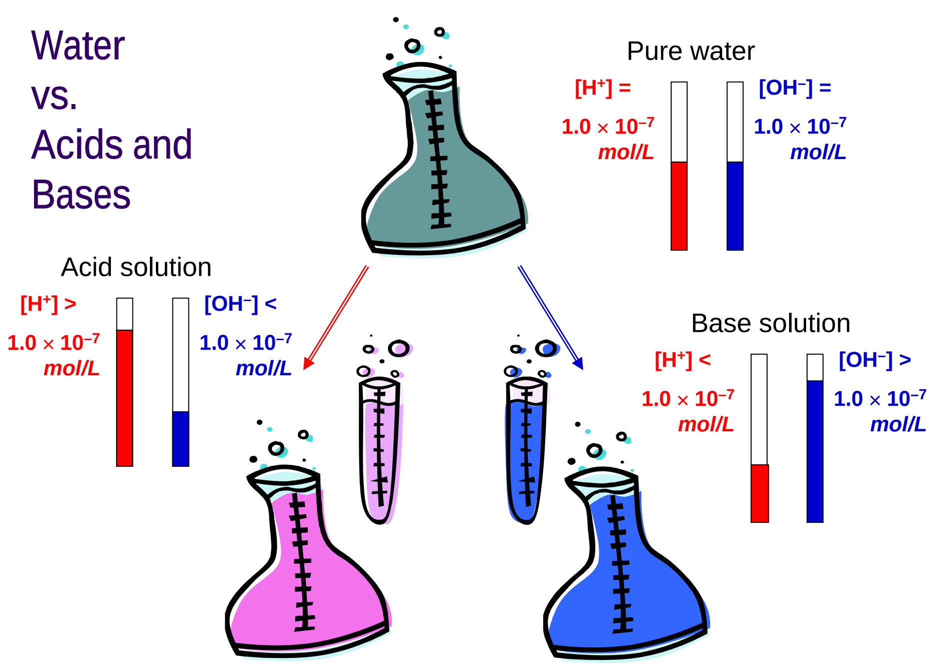
In a sample of pure water, equal quantities of these ions are present:

$$[H^+] = [OH^-] = 1.0 \times 10^{-7} \text{ mol/L}$$

But when you add an acid or base to water, the balance changes.

12

Water vs. Acids and Bases



Symbolic Representation

How Can You Recognize an Acid?

Sometimes true

Always true

- Name of chemical is “--- acid”
  - Hydrochloric acid: **HCl**
  - Sulfuric acid: $\mathbf{H_2SO_4}$
  - Nitrous acid: $\mathbf{HNO_2}$
  - But there are acids that aren’t named acid
- Chemical formula has a “releasable” H in it
  - All the above
  - Substances containing carboxy groups such as acetic acid, $\mathbf{CH_3COOH}$, and benzoic acid, $\mathbf{C_6H_5CH_3COOH}$
  - But acid anhydrides also form acidic solutions
- When the chemical is added to water, it forms a compound that is able to break apart into an H^+ ion and something else

14

Strong vs. Weak Acids

- Strong acids (pH 1 to 4) are strong electrolytes
  - Only a few common acids are strong

    $\mathbf{HCl, HBr, HI, HNO_3, H_2SO_4, HClO_4}$ (*memorize these*)
  - A few other less common acids are strong (you do not need to memorize these)

    e.g., $\mathbf{HClO_3, HBrO_3}$ and some others
- Weak acids (pH 5-7) are weak electrolytes
  - It is safe to assume that all other acids are weak

    Most common weak acids:

    $\mathbf{HF, HNO_2, HClO_2, HSO_3, CH_3COOH}$

15

Another Way to Form Acids

Acid anhydrides

- Nonmetal oxides
- When dissolved in water, react with water to form acid solution
- No change in oxidation number* of the nonmetal
- Examples:

  $SO_3 + H_2O \rightarrow H_2SO_4$

  $SO_2 + H_2O \rightarrow H_2SO_3$

  $N_2O_5 + H_2O \rightarrow 2\ HNO_3$

  $P_2O_5 + 3\ H_2O \rightarrow 2\ H_3PO_4$

*We will study oxidation numbers soon…

16

Symbolic Representation

How Can You Recognize a Base?

- Chemical formula contains hydroxide ion (OH^-)
  - Sodium hydroxide: $\mathbf{NaOH}$
  - Calcium hydroxide: $\mathbf{Ca(OH)_2}$
  - Aluminum hydroxide: $\mathbf{Al(OH)_3}$
  - Beware chemical formulas that look like they contain hydroxide ion. Organic alcohol group (-OH) is same atoms, but doesn't ionize to form $\mathbf{OH^-}$ ions.

    methanol $\mathbf{CH_3OH}$, ethanol $\mathbf{CH_3CH_2OH}$, phenol $\mathbf{C_6H_5OH}$
- Substance reacts with water to form hydroxide ions
  - Ammonia: $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$
  - Other amines (chemicals with $-NH_2$ functional group)

17

Strong vs. Weak Bases

- Strong bases (pH 11 to 14) are strong electrolytes
  - All bases containing the hydroxide ion (OH^-) are strong

    Most common strong bases:

    NaOH, KOH, LiOH, $Ca(OH)_2$, $Mg(OH)_2$
- Weak bases (pH 7-10) are weak electrolytes
  - Bases that do not contain the hydroxide ion (OH^-) are weak

    Most common weak bases:

    NH_3, CH_3NH_2, $C_6H_5NH_2$
- Organic alcohols are not bases
  - Organic molecules that contain an alcohol functional group (-OH) do not ionize to form hydroxide ions

18

What does pH mean?

- Tells you the hydronium ion concentration (H^+ ion)
- Concentration symbol is […], so hydronium ion concentration is abbreviated as $[H^+]$
- Concentration is measured in molarity, which is moles of solute per liter of solution, or *mol/L*, or *M*
- Concentration of H^+ ions in pure water is $[H^+]$ = 0.00000010 mol/L, or 1.0×10^{-7} *M*
- Too difficult to work with such small numbers, invent pH scale
- pH defined to equal –log $[H^+]$

19

Review of Powers of 10 Math

- All numbers can be written as powers of 10. Most important to remember where the decimal point is. (Key: is it a big or small number? If big then exponent is positive. If small, then exponent is negative.)

  $10{,}000 = 10^4$
  $100 = 10^2$
  $10 = 10^1$
  $1 = 10^0$
  $0.1 = 10^{-1}$
  $0.001 = 10^{-3}$
  $0.000001 = 10^{-6}$

- When multiplying two powers of 10, add the exponents. When dividing, subtract the exponents.

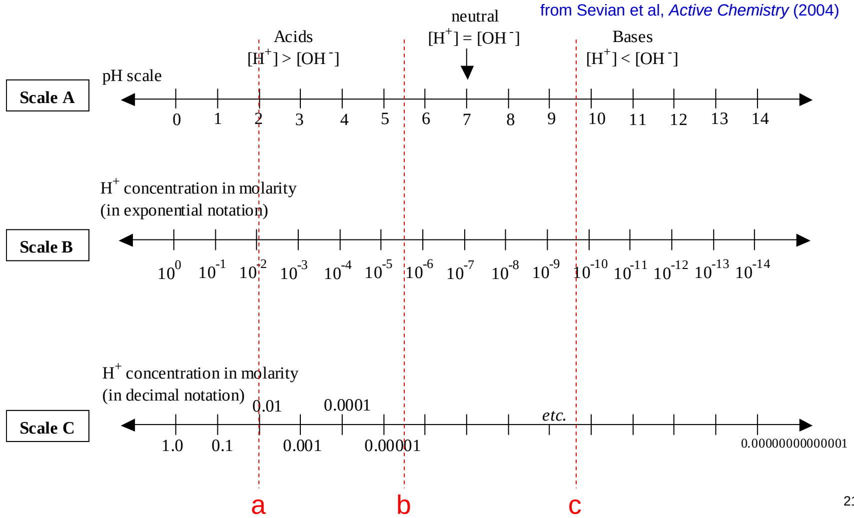
  $10^5 \times 10^{-2} = 10^{5+(-2)} = 10^3$
  $10^{-3} / 10^1 = 10^{(-3)-1} = 10^{-4}$

20

What does pH mean mathematically?

pH scale is a logarithmic scale

from Sevian et al, *Active Chemistry* (2004)



21

The pH scale, mathematically

- The logarithm (base 10) of a number is just the exponent of the power of 10 when you express the number as a power of 10

  log 100 = log 10^2 = 2

  log 0.00001 = log 10^{-5} = -5

- Numbers that are not integer powers of 10 can still be represented as powers of 10

  45.6 = 4.56 × 10^1 = $10^{1.659}$ = 1.659

  0.000000821 = 8.21 × 10^{-7} = $10^{-6.086}$ = -6.086

  (Note: sig figs of logarithms are only counted after the decimal point, because the integer comes from the exponent of 10)

- How to do this on your calculator

22

The pH scale, mathematically

- pH values range from 1 to 14
- pH = -log [H^+]
- Examples

  [H^+] = 0.00010 *M*, therefore pH = -log(0.0001) = 4.00

  [H^+] = 0.00000050 *M*, therefore pH = -log(0.00000050) = 6.301

  You try it:

  [H^+] = 0.0025 *M*, therefore pH = 2.60
- If you know the pH, you can get [H^+]

  [H^+] = antilog(-pH) or 10^{-pH}

  pH = 4.00, therefore [H^+] = antilog(-4.00) = 10^{-4} = 0.00010 *M*

  pH = 8.200, therefore [H^+] = antilog(-8.200) = $10^{-8.2}$ = 6.31 × 10^{-9} *M*

  You try it:

  pH = 2.3, therefore [H^+] = 5 × 10^{-3} *M*

23

What happens to pH when you mix acid and base solutions? Neutralization rxn

Acid + Base $\rightarrow$ Salt + Water

$(H^+)(anion^-) + (cation^+)(OH^-) \rightarrow (cation^+)(anion^-) + (H^+)(OH^-)$

This reaction occurs if the Base contains OH^- (in other words, only strong bases)

Strong acid + Strong base (strong acid ionizes nearly completely):

$HCl + NaOH \rightarrow NaCl + H_2O$

$H_2SO_4 + KOH \rightarrow KHSO_4 + H_2O$

Weak acid + Strong base (weak acid is mostly present as whole molecule):

$HF + NaOH \rightarrow NaF + H_2O$

$CH_3COOH + KOH \rightarrow KCH_3COO + H_2O$

24

When a metal carbonate reacts with an acid: two-step process

1. $MgCO_3\ (s) + 2\ HCl\ (aq) \rightarrow MgCl_2\ (aq) + H_2CO_3\ (aq)$
   (exchange rxn)

2. $H_2CO_3\ (aq) \rightarrow H_2O\ (l) + CO_2\ (g)$
   (carbonic acid is unstable)

Sum reaction:

$MgCO_3\ (s) + 2\ HCl\ (aq) \rightarrow MgCl_2\ (aq) + H_2O\ (l) + CO_2\ (g)$

Net ionic equation:

$MgCO_3\ (s) + 2\ H^+\ (aq) \rightarrow Mg^{2+}\ (aq) + H_2O\ (l) + CO_2\ (g)$

25

Net Ionic Equations of Weak vs. Strong Acid + Strong Base Reactions Differ

Strong acid examples (acid ionizes nearly completely):

$HCl + NaOH \rightarrow NaCl + H_2O$

$H^+\ (\cancel{aq)\ +}\ Cl^-\ (\cancel{aq)\ +}\ Na^+\ (aq) + OH^-\ (\cancel{aq)\ \rightarrow}\ Na^+\ (\cancel{aq)\ +}\ Cl^-\ (aq) + H_2O\ (l)$

Net ionic equation: $H^+\ (aq) + OH^-\ (aq) \rightarrow H_2O\ (l)$

$H_2SO_4 + KOH \rightarrow KHSO_4 + H_2O$

$H^+\ (aq) + \cancel{HS}O_4^-\ (aq)\ \cancel{+\ K}^+\ (aq) + OH^-\ (aq)\ \cancel{\rightarrow}\ K^+\ (aq)\ \cancel{+\ H}SO_4^-\ (aq) + H_2O\ (l)$

Net ionic equation: $H^+\ (aq) + OH^-\ (aq) \rightarrow H_2O\ (l)$

26

Net Ionic Equations of Weak vs. Strong Acid + Strong Base Reactions Differ

Weak acid examples (acid is mostly present as whole molecule):

$HF + NaOH \rightarrow NaF + H_2O$

$HF\ (aq) + \cancel{Na^+}\ (aq) + OH^-\ (aq) \rightarrow \cancel{Na^+}\ (aq) + F^-\ (aq) + H_2O\ (l)$

Net ionic equation: $HF\ (aq) + OH^-\ (aq) \rightarrow F^-\ (aq) + H_2O\ (l)$

$CH_3COOH + KOH \rightarrow KCH_3COO + H_2O$

$CH_3COOH\ (aq) + \cancel{K^+}\ (aq) + OH^-\ (aq) \rightarrow \cancel{K^+}\ (aq) + CH_3COO^-\ (aq) + H_2O\ (l)$

Net ionic equation: $CH_3COOH\ (aq) + OH^-\ (aq) \rightarrow CH_3COO^-\ (aq) + H_2O\ (l)$

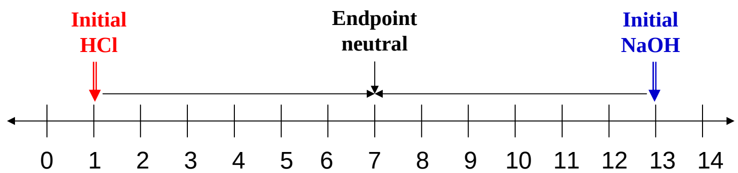
The difference between strong and weak acid-base reactions:
Strong acid present as ions, so it cancels out of net ionic equation.
Weak acid present as molecules, so doesn't cancel out of net ionic equation.

27

Neutralization: What happens to pH?

It approaches neutral pH

Ex 1: **HCl + NaOH → NaCl + H_2O** (strong acid + strong base)
(equal concentrations of **HCl** and **NaOH** mixed in equal molar quantities)



Ex 2: **CH_3COOH + KOH → KCH_3COO + H_2O** (weak acid + strong base)
(equal concentrations of **CH_3COOH** and **KOH** mixed in equal molar quantities)