8 • Ionic Reactions in Solution
Driving Forces for Metathesis Reactions
(1 of 12)

During a double replacement or metathesis reaction, two new combinations of ions are produced. We identify four reasons why these NEW combinations are more stable than the original combos.

- a **precipitate** forms
  memorize your solubility rules
- a **gas** forms which leaves the system
  memorize the list of gases that form
- a **weak electrolyte** forms
  memorize the strong acid list so you will recognize weak acids, also H_2O and NH_4OH
- a **complex ion** forms
  learn the structure of complex ions and common ligands

---

8 • Ionic Reactions in Solution
Precipitates as a Driving Force
The Solubility Rules
(2 of 12)

Always Always Soluble compounds with alkali metal ions (Li^+, Na^+, K^+, Cs^+, Rb^+), NH_4^+, NO_3^-, $C_2H_3O_2^-$, ClO_3^- & ClO_4^-

Usually Soluble
Cl^-, Br^-, I^- [except “AP/H”... Ag^+, Pb^{2+}, Hg_2^{2+}]
SO_4^{2-} [except “CBS”: Ca^{2+}, Ba^{2+}, Sr^{2+} & “PBS”: Pb^{2+}]

Usually NOT Soluble
O^{2-}, OH^- [except alkali and “CBS” Ca^{2+}, Ba^{2+}, Sr^{2+}]

Never Soluble
CO_3^{2-}, SO_3^{2-}, S^{2-}, PO_4^{3-} [except NH_4^+ & alkali]

NOTE: some of these insoluble compounds WILL dissolve in acid solutions because of gas formation... useful idea!

---

8 • Ionic Reactions in Solution
Weak Electrolyte Formation as a Driving Force
Weak Acids and other Weak Electrolytes
Neutralization Reactions
(3 of 12)

Weak electrolytes are substances that break up into ions only a LITTLE in solution... therefore, the two ions are MOSTLY in a combined state... not likely to re-form the reactants.

H_2O, weak acids, NH_4OH

Memorize the 8 strong acids so you can recognize a weak acid when you see one...

HCl, HBr, HI, HNO_3, H_2SO_4, $HClO_3$, $HClO_4$, HIO_4

Acids (forming H^+ ions) and bases (forming OH^- ions) combine to form a salt (an ionic compound) and H_2O... the very weak electrolyte. Neutralization of the acid and base occur because the H^+ & OH^- ions are “tied up” as H_2O.

---

8 • Ionic Reactions in Solution
Gas Formation as a Driving Force
Gases That Commonly Form
(4 of 12)

If you see the following substances formed during metathesis, realize that they will breakup into gases and **leave the system** (preventing re-formation of the reactants).

Watch For…	**It Turns Into…**
H_2CO_3	$\rightarrow CO_2(g) + H_2O$
H_2SO_3	$\rightarrow SO_2(g) + H_2O$
H_2S	$\rightarrow H_2S(g)$ [rotten egg smell]
NH_4OH	$\rightarrow NH_3(g) + H_2O$
$2\ HNO_2$	$\rightarrow NO(g) + NO_2(g) + H_2O$

NOTE: these compounds are formed from acids with carbonates, sulfites, sulfides, nitrites, and bases with ammonium compounds.

8 • Ionic Reactions in Solution
Preparation of Salts
(5 of 12)

If you want to make the ionic compound, **XY**, you mix
A**Y** + **X**B to make **XY** + AB
Either **XY** or AB need to <u>drive</u> the reaction (ppt, gas, etc.)

You may need to do this in **two** steps... make a carbonate (or sulfite, sulfide, hydroxide or oxide) of the cation (+ ion) you need and then react it with an acid that has the proper anion.

The Practical Side:
Keep in mind how you could recover the product you want... could you filter the product mixture? Do you want what is in the filter paper or what is in the filtrate? If you need the filtrate, you need to be careful not to have excess ions in it.

---

8 • Ionic Reactions in Solution
Comparing Driving Forces
(6 of 12)

Gas formation is a very strong driving force... even compounds that exist as insoluble solids will react (slowly) to form gases because gases leave the system and CANNOT re-form reactants.

$$CaCO_3(s) + 2HCl \rightarrow CO_2(g) + H_2O + Ca^{2+} + 2\ Cl^-$$

The tendency to **form H_2O** is very strong. Insoluble oxides will react with acids.

$$ZnO(s) + 2HCl \rightarrow Zn^{2+} + 2Cl^- + H_2O$$

Sometimes, one insoluble solid can change into another even **MORE insoluble solid**... but you need more than the solubility rules to predict this (you need K_{sp}'s).

$$AgCl(s) + Br^- \rightarrow AgBr(s) + Cl^-$$

---

8 • Ionic Reactions in Solution
More Concentration Units
Weight Percent, ppm, and ppb
(7 of 12)

Percent means "parts per 100"

96% means $\frac{96}{100}$, that is, 96 out of every 100.

Weight Percent (w/w) means $\frac{96g}{100g}$… (w/v) means $\frac{96g}{100mL}$

ppm means "parts per million"

96 ppm means $\frac{96}{1\ 000\ 000}$, 96 out of every 1 million.

ppb means "parts per billion"

96 ppb means $\frac{96}{1\ 000\ 000\ 000}$, 96 out of every BILLION!

---

8 • Ionic Reactions in Solution
Chemical Analyses
Precipitations, Combustions, and Titrations
(8 of 12)

Real chemistry often deals with testing what is in a particular reaction mixture, environmental sample, etc. Stoichiometry is used to analyze the compositions.

- You can **precipitate** an ion you are interested in, **filter** the precipitate and then determine from its mass the amount of compound in the original sample.
- You can **burn** a sample and collect the combustion products (CO_2 & H_2O) to determine the amount of C and H in the original sample.
- You can carefully measure the **volumes** of solutions used during a titration. The endpoint must have some sort of indicator to allow you to recognize when the correct amounts of reactants have been added.

8 • Ionic Reactions in Solution
Titration Terminology
Acid-Base and Redox Titrations
(9 of 12)

A **titration** is a **volumetric analysis** because you carefully measure the volume of **titrant**, dispensing it from a **buret**. When you have added just enough titrant to completely react with the sample, you have reached the endpoint. This is usually apparent because of the color change of some indicator molecule (such as phenolphthalein). The endpoint can also be tracked because of changes in pH or changes in voltage due to the amount of some ion.

Acid-Base & Redox titrations follow the formula: $V\cdot\underline{N}=V\cdot\underline{N}$ where the $\underline{N}$ indicates $[H^+]$ or $[OH^-]$ in acid-base titrations and $[\text{Oxidizer}]\cdot e^-$ gained or $[\text{Reducer}]\cdot e^-$ lost in redox titrations.

---

8 • Ionic Reactions in Solution
Three Most Common Oxidizing Agents
and what they turn into
(10 of 12)

purple permanganate ion

acid solution $MnO_4^- + 8H^+\ \ 5e^- \rightarrow Mn^{2+} + 4H_2O$
Mn^{2+} ion is colorless

neutral/basic $MnO_4^- + 2H_2O + 3e^- \rightarrow MnO_2(s) + 4OH^-$
$MnO_2(s)$ is a black solid

yellow chromate / orange dichromate ion depends on $[H^+]$

$$2CrO_4^{2-} + 2H^+ \rightleftarrows Cr_2O_7^{2-} + H_2O$$

acid solution $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

slightly basic $CrO_4^{2-} + 4\,H_2O + 3e^- \rightarrow Cr(OH)_3 + 5OH^-$
$Cr(OH)_3$ is a solid

very basic $CrO_4^{2-} + 2H_2O + 3e^- \rightarrow CrO_2^- + 4OH^-$

---

8 • Ionic Reactions in Solution
Common Reducing Agents
and what they turn into
(11 of 12)

Tin(II) (a gentle reducing agent)

$$Sn^{2+} \rightarrow Sn^{4+} + 2\,e^-$$

Sulfites and Bisulfites

acidic solution: $HSO^{3-} + H_2O \rightarrow SO_4^{2-} + 3H^+ + 2e^-$

basic solution: $SO_3^{2-} + 2OH^- \rightarrow SO_4^{2-} + H_2O + 2e^-$

Thiosulfate ion (also called “hypo” in photography)

strong oxidizer: $S_2O_3^{2-} + 5H_2O \rightarrow 2SO_4^{2-} + 10H^+ + 8e^-$

half-reaction w/I_2: $2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2e^-$

complete: $I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$

excess I^-: $I_2 + I^- \rightarrow I_3^-$

$$I_2 + \text{starch} \rightleftarrows \text{starch}\bullet I_2 \text{ complex (blue-black)}$$

---

8 • Ionic Reactions in Solution
Equivalents, Equivalent Weights, and Normality
(an old-fashioned, but useful idea)
(12 of 12)

equivalents = H^+, OH^-, or electrons gained or lost
n = # of equivalents in the balanced chemical equation
example: $I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$ n = 2
equivalent weight = molar mass ÷ n
…mass of a chemical that provides 1 mole of equivalents.

Normality, $\underline{N}$, $= n\cdot\underline{M}, = \dfrac{\text{moles equivalents}}{\text{Liter solution}}$

This idea is useful in acid-base and redox titrations because it takes into account the differences of acids and bases or oxidizers and reducers. This concept allows the use of the simple formula: $V\cdot\underline{N} = V\cdot\underline{N}$