A bit more about molecular, ionic, and net ionic equations

- molecular equations: Represent all substances (even ionic substances) as if they were molecules. Include spectator ions, and do not show charges on ions. Traditional chemical equations.

- ionic equations: Show all free ions - including spectators - in a chemical reaction. Molecules and WEAK electrolytes are shown as molecules. STRONG electrolytes (like HCl) are shown as ions. Ions that are part of undissolved ionic compounds are shown as molecules.

- NET ionic equation: An ionic equation that leaves out spectator ions. Intended to show only things that actually change in a reaction.

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow \underline{AgCl(s)} + Na^+(aq) + NO_3^-(aq)\ *$$

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

* You can get from the complete ionic equation to the net ionic equation by crossing out the spectator ions on both sides.

"Undissolved ionic compounds":

How can I tell if an ionic compound dissolves in water?

- consult experimental data: "solubility rules"!

A few of the "rules"...

- Compounds that contain a Group IA cation (or ammonium) are soluble
- Nitrates and acetates are soluble
- Carbonates, phosphates, and hydroxides tend to be insoluble

See p 129 9th edition (10th ed: p131)

... or see the web site for a solubility chart.

$Fe(OH)_3$

#8 - hydroxides generally insoluble, except Group IA, ammonium, calcium strontium, barium

Conclusion: iron(III) hydroxide is insoluble.

$Ca(C_2H_3O_2)_2$

#2 - acetates are soluble, no common exceptions.

Conclusion: calcium acetate is soluble.

AgI

#3 - Iodides usually dissolve, exceptions are silver, mercury, lead

Conclusion: silver(I) iodide is INSOLUBLE

$BaCO_3$

#5 - Most carbonates are insoluble

Conclusion - barium carbonate is insoluble.

Exchange Chemistry

- Three kinds of exchange chemistry.

1. PRECIPITATION ← Formation of IONIC SOLID

2. ACID/BASE or NEUTRALIZATION

3. GAS FORMATION (formation of unstable molecules)

   SOME (but not all) reactions that form gases are examples of exchange chemistry.

Formation of MOLECULES!

Just because you mix together two ionic compounds does NOT mean that a reaction will occur. You need a DRIVING FORCE for a reaction.

PRECIPITATION REACTIONS

- driving force is the formation of an insoluble ionic compound.

$$3MgCl_2(aq) + 2Na_3PO_4(aq) \rightarrow 6NaCl(aq) + Mg_3(PO_4)_2(s)$$

ions: Mg^{2+} Cl^- Na^+ PO_4^{3-}

Mg^{2+} PO_4^{3-}

The formation of SOLID magnesium phosphate drives this reaction!

When you're trying to complete a precipitation reaction:

1 Write the IONS that form when the reactants are dissolved.

2 Make NEW compounds by pairing up cations with anions. Don't forget that the positive and negative charges must balance each other out!

3 Use the solubility rules to determine the PHASE of each new compound - solid or aqueous.

4 Balance the overall equation.

$MgCl_2(aq) + NaC_2H_3O_2(aq) \rightarrow$ NO REACTION!*

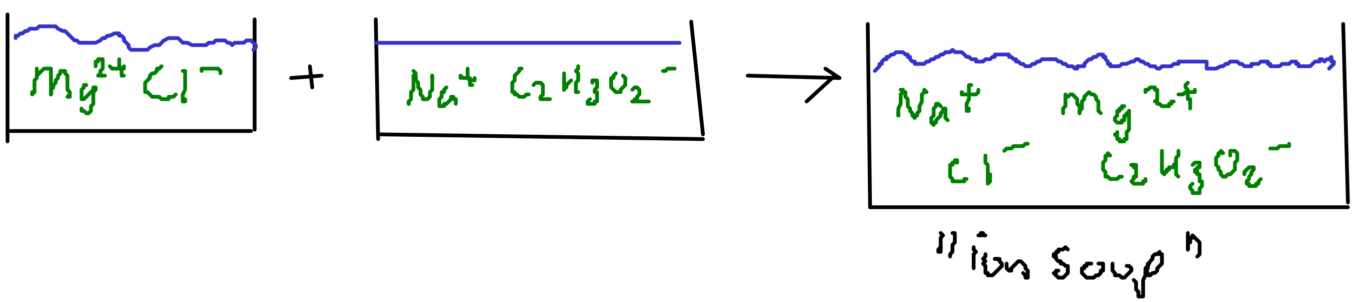
ions: Mg^{2+} Cl^- Na^+ $C_2H_3O_2^-$

"exchange"

$Mg(C_2H_3O_2)_2$ ... dissolves in water

$NaCl$ ... dissolves in water

So, no solid forms here. All possible combinations of these four ions result in compounds that dissolve readily in water.



NO CHANGE, therefore NO DRIVING FORCE, and NO REACTION

*We will learn about other driving forces than the formation of solid, but these driving forces do not apply to this reaction

ACID/BASE REACTIONS (also called NEUTRALIZATION REACTIONS)

- There are several stable molecules that may be formed in double replacement reactions, but the most common is WATER!

- Double replacement reactions that form water are also called "neutralizations"

$$HA + BOH \longrightarrow H_2O + BA$$

acid base salt

"HOH" ionic compound

$H^+ A^-$ $B^+ OH^-$

* To make water (H_2O), you need a source of hydrogen ion (H^+) and hydroxide ion (OH^-)

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(\ell)$$

This is the NET IONIC EQUATION for many neutralizations

... assumes you're reacting STRONG acid with STRONG base!

ACIDS

- compounds that release hydrogen ion (H^+), when dissolved in water.

Properties of acids:

- Corrosive: React with most metals to give off hydrogen gas
- Cause chemical burns on contact
- Taste sour (like citrus - citric acid!)
- Changes litmus indicator to RED

BASES

- Substances that release hydroxide ion (OH^-) when dissolved in water

Properties of bases:

- Caustic: Attack and dissolve organic matter (think lye, which is NaOH)
- Cause skin/eye damage on contact
- Taste bitter
- changes litmus indicator to BLUE

Due to the dissolving action of base on your skin, bases will feel "slippery". The base ITSELF is not particularly slippery, but what's left of your skin IS!

ACID/BASE or NEUTRALIZATION reactions continued

- the driving force of these reactions is the formation of water molecules.

$$\underbrace{H^+(aq)}_{\text{From the acid}} + \underbrace{OH^-(aq)}_{\text{From the base}} \rightarrow H_2O(l)$$ Net ionic equation

$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow 2H_2O(l) + Na_2SO_4(aq)$$

ions: H^+ SO_4^{2-} Na^+ OH^-

- How can this reaction be detected?
    - pH detector (indicator paper, etc.)
    - do the products have similar chemical properties to the reactants?
    - release of heat!

... formation of water is usually accompanied by a release of heat

GAS FORMATION / OTHER MOLECULES

- There are a few other molecules that can be made with exchange-type chemistry.
- Most of these molecules are unstable and can break apart to form gases.

- Formation of a weak acid:
  - The formation of ANY weak acid in an exchange-type reaction can be a driving force.
  - Some weak acids are unstable and can break apart into gas molecules.

$$H_2CO_3(aq) \longrightarrow H_2O(\ell) + \boxed{CO_2(g)}$$

Gas bubbles can leave solution!

... but how would you form carbonic acid in an exchange-type reaction?

acid + carbonate CO_3^{2-}

OR

acid + bicarbonate HCO_3^-

$$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow 2H_2CO_3(aq) + Na_2SO_4(aq)$$

Ions: H^+ SO_4^{2-} Na^+ HCO_3^-

Formation of carbonic acid drives the reaction ... BUT ...

$$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow Na_2SO_4(aq) + \boxed{2H_2CO_3(aq)}$$

H^+ SO_4^{2-} Na^+ HCO_3^-

... but when we mix sulfuric acid and sodium bicarbonate, we observe BUBBLES. We need to write an equation that agrees with our observations. We know that carbonic acid decomposes, so we go ahead and put that into our equation.

$$H_2CO_3(aq) \longrightarrow H_2O(l) + CO_2(g)$$

$$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$$

Other molecules of interest:

H_2SO_3 : sulfurous acid - React an ACID with a SULFITE

$$H_2SO_3(aq) \rightarrow H_2O(l) + SO_2(g)$$

H_2S : hydrogen sulfide (gas) - React an ACID with a SULFIDE

$$H_2SO_4(aq) + Na_2S(aq) \rightarrow Na_2SO_4(aq) + H_2S(g)$$

A few more exchange examples:

*Transition metals DO NOT change their charge in exchange reactions!

$CaCl_2(aq) + 2AgNO_3(aq) \longrightarrow 2AgCl(s) + Ca(NO_3)_2(aq)$

$Ca^{2+}\ Cl^-\qquad Ag^+\ NO_3^-$

Formation of SOLID AgCl drives this precipitation reaction!

$H_3PO_4(aq) + 3NaOH(aq) \longrightarrow 3H_2O(l) + Na_3PO_4(aq)$

$H^+\ PO_4^{3-}\qquad Na^+\ OH^-$

This NEUTRALIZATION reaction is driven by the formation of WATER MOILECULES

$KCl(aq) + NaNO_3(aq) \longrightarrow \cancel{NaCl(aq) + KNO_3(aq)}$ NO REACTION

$K^+Cl^-\qquad Na^+\ NO_3^-$

Since there is no driving force (no solids and no molecules form), we conclude that there is NO REACTION.

$H_2SO_4(aq) + Na_2CO_3(aq) \longrightarrow Na_2SO_4(aq) + H_2CO_3(aq)$

$H^+\ SO_4^{2-}\qquad Na^+\ CO_3^{2-}$

$H_2CO_3 \rightarrow H_2O + CO_2$

$H_2SO_4(aq) + Na_2CO_3(aq) \longrightarrow Na_2SO_4(aq) + H_2O(l) + CO_2(g)$

Formation of CARBONIC ACID MOLECULES (which break apart into water moleclules and carbon dioxide molecules) drives this reaction

OXIDATION / REDUCTION CHEMISTRY

- Exchange reactions involve ions pairing up, but the ions themseves are not formed in exchange reactions. Exchanges start with pre-existing ions.

... but the ions have to be produced somehow - through a chemistry that involves the transfer of electrons.

- oxidation / reduction chemistry ("redox" chemistry) involves transfer of electrons and can make ions.

$$2Al(s) + 3Br_2(l) \rightarrow 2AlBr_3(s)$$

Elemental, metallic aluminum. Uncharged!

Al^0

Aluminum cation

Al^{3+}

These are called "half-reactions"

$$Al \rightarrow Al^{3+} + \underbrace{3e^-}_{\text{electron}}$$

oxidation: loss of electrons

$$Br_2 + 2e^- \rightarrow 2Br^-$$

reduction: gain of electrons

- oxidation and reduction always occur together. In other words, we can't just make free electrons using oxidation without giving them somewhere to go.
- Many of the types of reactions that we learned about in previous courses are redox reactions!

- COMBINATIONS (often but not always redox)
- DECOMPOSITIONS (often redox)
- SINGLE REPLACEMENT (always redox)

$$Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$$

$$Cu \rightarrow Cu^{2+} + 2e^-$$ oxidation

$$2Ag^+ + 2e^- \rightarrow 2Ag(s)$$ reduction

net ionic $\rightarrow$ $Cu(s) + 2Ag^+(aq) \rightarrow Cu^{2+}(aq) + 2Ag(s)$

- COMBUSTION

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

$$2Mg(s) \rightarrow 2Mg^{2+} + 4e^-$$ oxidation

$$O_2(g) + 4e^- \rightarrow 2O^{2-}$$ reduction

A review of the reaction types we just mentioned:

(i) COMBINATION REACTIONS

- Reactions that involve two or more simple substances COMBINING to form a SINGLE product
- Often involve large energy changes. Sometimes violent!
- Form: $\boxed{A + B + \ldots \longrightarrow C}$

Example:

$$2\,Al(s) + 3\,Br_2(l) \longrightarrow 2\,AlBr_3(s)$$

2 DECOMPOSITION REACTIONS

- Reactions where a SINGLE REACTANT breaks apart into several products

- Form: $\boxed{A \longrightarrow B + C + \ldots}$

Example:

$$2\,H_2O_2(l) \longrightarrow 2\,H_2O(l) + O_2(g)$$

* This reaction is NOT a combustion reaction, even though O_2 is involved!

* Combustion reactions CONSUME O_2, while this reaction PRODUCES O_2

3 COMBUSTION REACTIONS

- Reactions of substances with MOLECULAR OXYGEN (O_2) to form OXIDES.
- Combustion forms an OXIDE of EACH ELEMENT in the burned substance!

- Form: $\boxed{AB + O_2 \longrightarrow AO + BO}$

* Combustion of hydrocarbons makes carbon dioxide and water, if enough oxygen is present. In low-oxygen environments, carbon monoxide is made instead!

Oxide: a compound containing OXYGEN and one other element!

Examples:

Oxides!

* $$C_3H_8(g) + 5O_2(g) \longrightarrow 4H_2O(g) + 3CO_2(g)$$

$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$$

This reaction can also be called a combination! Two reactants form a single product.

4 SINGLE REPLACEMENT REACTIONS

- Reactions where one element REPLACES another element in a compound.
- Can be predicted via an ACTIVITY SERIES (p151, 9th edition) (p153, 10th ed)
- Form: $\boxed{A + BC \longrightarrow AC + B}$ "A" and "B" are elements., often metals.
- Easy to spot, since there is an element "by itself" on each side of the equation.

Examples:

$$\overset{0}{Cu}(s) + 2\overset{+1}{Ag}NO_3(aq) \longrightarrow \overset{+2}{Cu}(NO_3)_2(aq) + 2\overset{0}{Ag}(s)$$

$$\overset{0}{Zn}(s) + \overset{+1}{H_2}SO_4(aq) \longrightarrow \overset{+2}{Zn}SO_4(aq) + \overset{0}{H_2}(g)$$

REDOX LANGUAGE

"oxidizer"

- "Oxidation" is loss of electrons, but an OXIDIZING AGENT is something that causes ANOTHER substance to lose electrons. An oxidizing agent is itself reduced during a redox reaction.

- "Reduction" is gain of electrons, but a REDUCING AGENT is something that causes ANOTHER substace to gain electrons. Reducing agents are themselves oxidized during a redox reaction.

$$2\overset{0}{Al}(s) + 3\overset{0}{Br_2}(l) \rightarrow 2\overset{+3}{Al}\overset{-1}{Br_3}(s)$$

Aluminum is OXIDIZED during this process. We say that metallic aluminum is a REDUCING AGENT!

Bromine is REDUCED during this process. We say that bromine is an OXIDIZING AGENT!

* Strong oxidizers (oxidizing agents) can cause spontaneous fires if placed into contact with combustibles (safety issue!).

* Reactive metals tend to be REDUCING AGENTS, while oxygen-rich ions like NITRATES tend to be OXIDIZING AGENTS. HALOGENS (Group VIIA) also tend to be OXIDIZING AGENTS

END OF CHAPTER 4 MATERIAL