LIMITING REACTANT CALCULATIONS

- To find the limiting reactant, calculate how much product would be produced from ALL given reactants. Whichever produces the SMALLEST amouht of product is the limiting reactant, and the smallest anount of product is the actual amount of product produced.

Example: 56.08 12.01 64.10 <- Formula weights

$$CaO(s) + 3C(s) \xrightarrow{\Delta} CaC_2(s) + CO(g)$$

If you start with 100. g of each reactant, how much calcium carbide would be produced?

① 56.08 g CaO = mol CaO ② mol CaO = mol CaC_2 ③ 64.10 g CaC_2 = mol CaC_2

$$100.\,g\,CaO \times \frac{mol\,CaO}{56.08\,g\,CaO} \times \frac{mol\,CaC_2}{mol\,CaO} \times \frac{64.10\,g\,CaC_2}{mol\,CaC_2} = 114\,g\,CaC_2$$

① 12.01 g C = mol C ② 3 mol C = mol CaC_2 ③ 64.10 g CaC_2 = mol CaC_2

$$100.\,g\,C \times \frac{mol\,C}{12.01\,g\,C} \times \frac{mol\,CaC_2}{3\,mol\,C} \times \frac{64.10\,g\,CaC_2}{mol\,CaC_2} = 178\,g\,CaC_2$$

This reaction should produce 114 grams of calcium carbide. At that point, all of the CaO will have been consumed, and the reaction will have to stop. We can say that CaO is LIMITING, and C is present IN EXCESS.

PERCENT YIELD

- Chemical reactions do not always go to completion! Things may happen that prevent the conversion of reactants to the desired/expected product!

(1) SIDE REACTIONS:

$$C + O_2 \longrightarrow CO_2$$

This reaction occurs when there is a large amount of oxygen available

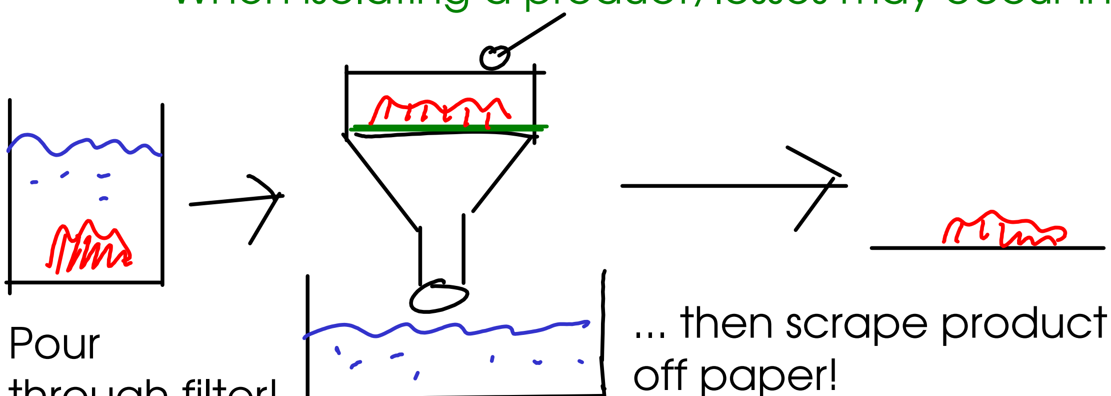
$$2C + O_2 \longrightarrow 2CO$$

... while this reaction is more favorable in low-oxygen environments!

... so in a low-oxygen environment, you may produce less carbon dioxide than expected!

(2) TRANSFER AND OTHER LOSSES

- When isolating a product, losses may occur in the process. Example: filtering



Pour through filter!

... then scrape product off paper!

During each step of this process, some amount of product loss will occur!

(3) EQUILIBRIUM

- Reactions may reach an equilbrium between prodcuts and reactants. We'll talk more about this in CHM 111. The net results is that the reaction will appear to stop before all reactants have been consumed!

- All of these factors cause a chemical reaction to produce LESS product than calculated. For many reactions, this difference isn't significant. But for others, we need to report the PERCENT YIELD.

$$\text{PERCENT YIELD} = \frac{\text{ACTUAL YIELD}}{\text{THEORETICAL YIELD}} \times 100\%$$

ACTUAL YIELD: Determined EXPERIMENTALLY!

THEORETICAL YIELD: Calculated based on the limiting reactant. (The chemical calculations you've done up to now have been theoretical yields!)

... the percent yield of a reaction can never be greater than 100% due to conservation of mass! If you determine that a percent yield is greater than 100%, then you've made a mistake somewhere - either in a calculation or in the experiment itself!

78.114 g/mol — 123.111 g/mol <- Formula weights

22.4 g — 31.6 g ACTUAL

$$C_6H_6 + HNO_3 \longrightarrow C_6H_5NO_2 + H_2O$$

benzene — nitric acid — nitrobenzene

22.4 grams of benzene are reacted with excess nitric acid. If 31.6 grams of nitrobenzene are collected from the reaction, what is the percent yield?

To get the percent yield, we'll need to CALCULATE the theoretical yield of nitrobenzene based on the 22.4 grams benzene we started with. Then compare to the given ACTUAL YIELD (31.6 g) of nitrobenzene.

① $78.114\,g\ C_6H_6 = mol\ C_6H_6$ ② $mol\ C_6H_6 = mol\ C_6H_5NO_2$

③ $123.111\,g\ C_6H_5NO_2 = mol\ C_6H_5NO_2$

$$22.4\,g\ C_6H_6 \times \frac{mol\ C_6H_6}{78.114\,g\ C_6H_6} \times \frac{mol\ C_6H_5NO_2}{mol\ C_6H_6} \times \frac{123.111\,g\ C_6H_5NO_2}{mol\ C_6H_5NO_2} = 35.3\,g\ C_6H_5NO_2$$

$$\%\ yield = \frac{actual}{theoretical} \times 100 = \frac{31.6\,g}{35.3\,g} \times 100 = \boxed{89.5\%}$$

Electrolytes and Ionic Theory

- electrolytes: substances that dissolve in water to form charge-carrying solutions

* Electrolytes form ions in solution - (ions that are mobile are able to carry charge!). These IONS can interact with one another and undergo certain kinds of chemistry!

IONIC THEORY

- the idea that certain compounds DISSOCIATE in water to form free IONS

Strong vs weak?

- If an electrolyte COMPLETELY IONIZES in water, it's said to be STRONG

- If an electrolyte only PARTIALLY IONIZES in water, it's said to be WEAK

- Both kinds of electrolyte undergo similar kinds of chemistry.

What kinds of compounds are electrolytes?

MOLECULAR COMPOUNDS

- Most molecular compounds are NONELECTROLYTES - they don't ionize in water

-ACIDS and BASES will ionize in water. Most of these are WEAK ELECTROLYTES, but there are a few STRONG ACIDS and STRONG BASES.

$$C_{12}H_{22}O_{11}(s) \xrightarrow{H_2O} C_{12}H_{22}O_{11}(aq)$$ ... nonelectroiyte

$$HC_2H_3O_2(l) \xrightarrow{H_2O} H^+(aq) + C_2H_3O_2^-(aq)$$

... acetic acid (electrolyte)

IONIC COMPOUNDS

- SOLUBLE ionic compounds are STRONG ELECTROLYTES - they completely ionize in water.

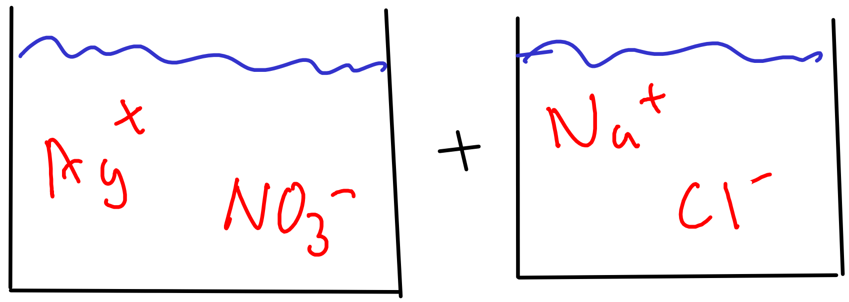
- Not all ionic compounds are water soluble, however!

$$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(aq)$$

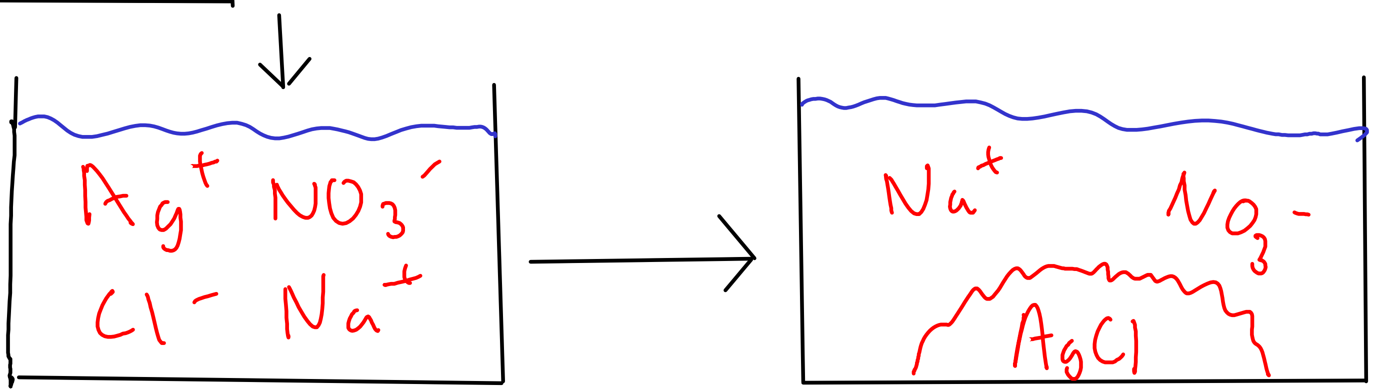
- What good is ionic theory?

- provides an easy-to-understand MECHANISM for certain kinds of chemical reactions.
  - "Exchange" reactions. (a.k.a "double replacement" reactions)

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



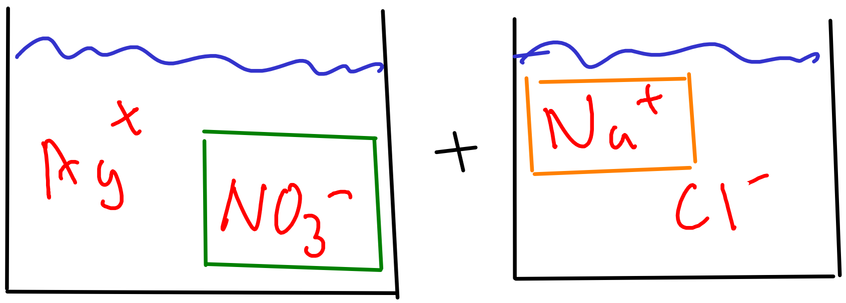
These free ions mix and can interact with each other!



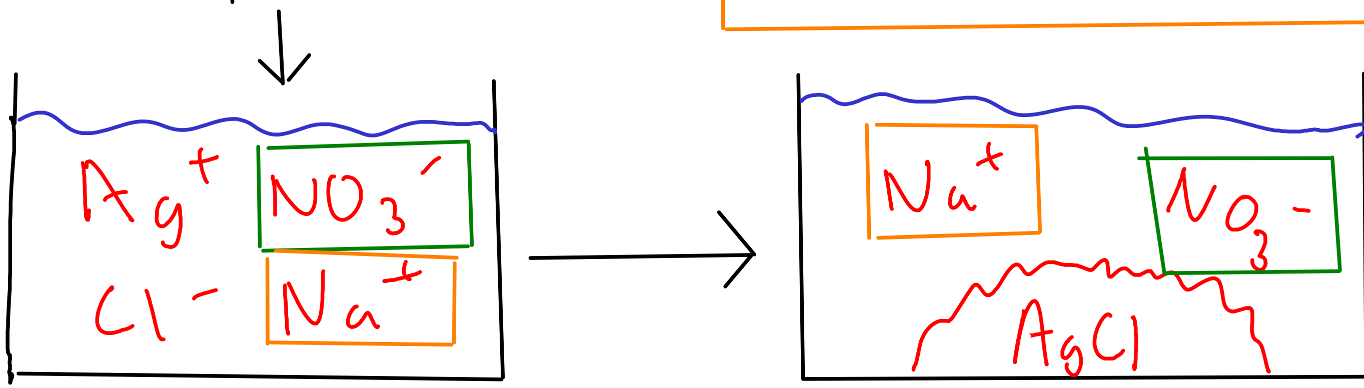
"ion soup"!

Insoluble AgCl falls out of solution as it is formed - "precipitation"

Looking a bit more closely...



The nitrate and sodium ions do not really participate in this reaction. They start and end in exactly the same state. We call them "SPECTATOR IONS".



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

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$ "Net ionic equation"

(The net ionic equation shows only ions and substances that change during the course of the reaction!)

- The net ionic equation tells us that any source of aqueous silver and chloride ions will exhibit this same chemistry, not just silver nitrate and sodium chloride!

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.

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

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

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

* 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 p129 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.

(2) and (3): 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-}

This reaction is driven by the formation of INSOLUBLE magnesium phosphate...

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!*

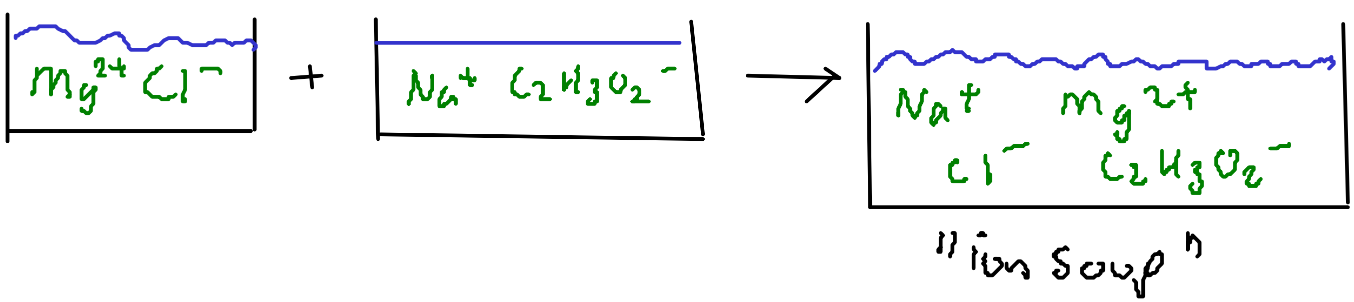
ions: Mg^{2+} Cl^- Na^+ $C_2H_3O_2^-$

"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"

$$HA + BOH \rightarrow H_2O + BA$$

acid (HA) base (BOH)

H_2O: "HOH"

BA: salt ← ionic compound

$H^+ \; A^- \qquad B^+ \; OH^-$

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

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

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.

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

Net ionic equation

From the acid ($H^+(aq)$) — From the base ($OH^-(aq)$)

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

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.

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

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^-

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

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

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

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

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

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