CHEM 115
Stoichiometry

Lecture 6
Prof. Sevian

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Announcements

- FSGs are Tuesdays 3:20-4:20 and Wednesdays 11:00-12:00 in S-1-89
- Check out “Student opportunities” link on course website - will be updated over the course of the semester with more opportunities for summer internships and scholarships as I receive information
- If you haven’t taken the 55-minute first term chemistry pre-test, please see me after class to schedule a time to take it by tomorrow…worth 10 points on your grade for the course

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Agenda

- Balancing chemical equations
  - When the units are ions
  - When the units are individual atoms
- Stoichiometry calculations
  - Figuring out what the problem is asking
  - Doing the calculations

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What we have learned so far

- Moles are a counting group
- Mass and moles are two different measures of the quantity of matter
  - Mass is what you measure in the lab (use a scale or mass balance)
  - Moles are a count of how many particles (can't be measured directly)
  - The two are connected because each particle has a mass which depends on what the particle is made of
- There are lots of ways to torture chemistry students with using mass to moles conversions
  - What is the molar mass of a compound?
  - How many moles are in a particular mass of compound? (and vice versa)
  - What is the % composition by mass of the different elements in a particular compound?
  - What is the empirical formula of a compound that has a particular set of % composition (by mass) of elements?
  - What is the molecular formula if you know empirical formula and molar mass?
  - Combinations of the above

This was Clicker question #5 from Lecture 5, but instead we will go over it as an example

What kind of problem is this - what strategy would you use?

> Serotonin is a compound that conducts nerve impulses in the brain. It contains 68.2 mass percent C, 6.86 mass percent H, 15.9 mass percent N, and the rest O. Its molar mass is 176 g/mol. Determine its molecular formula.

A. Take the ratio of 68.2 : 6.86 : 15.9 : whatever part O, convert to whole numbers to get molecular formula
B. Divide each percentage (as grams) by 176 to get moles, then take ratio
C. Assume 100 g so %'s are grams, convert to moles, then take ratio of moles
D. Assume 1 mol, calculate mass of each element in 179 g, then convert those masses to number of moles to get ratio of moles

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Chemical Equations

- Represent a chemical change of matter
- Reactants (starting materials) on left
- Products (ending materials) on right

$$\text{Reactants} \rightarrow \text{Products}$$

- What goes in must come out, just connected (bonded) differently

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Doing stoichiometry involves…

- Balancing chemical equations to determine how many moles go in and come out
  1. First determine what species to balance
  2. Then balance the species on both sides (either ions or atoms)
     a) Accounting method
     b) Pictures method
- Figuring out how much mass goes in and/or comes out
  - Information given
  - Information sought

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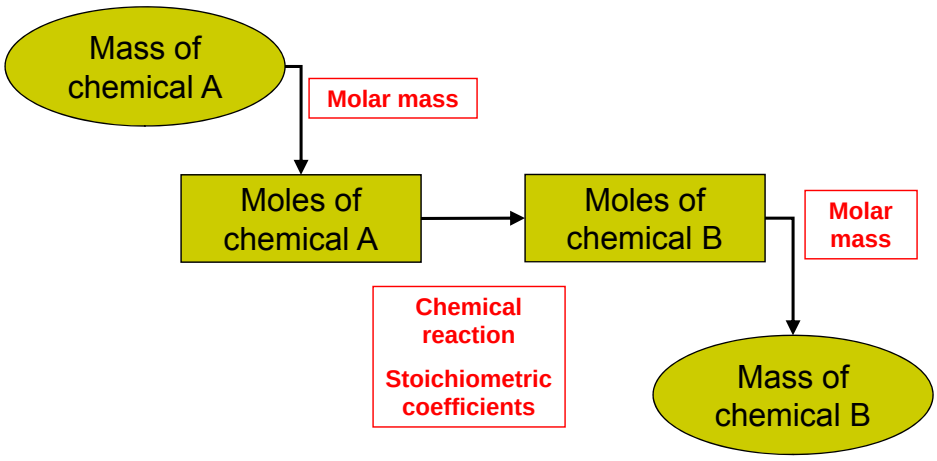
General Strategy for Simple Stoichiometry Problems



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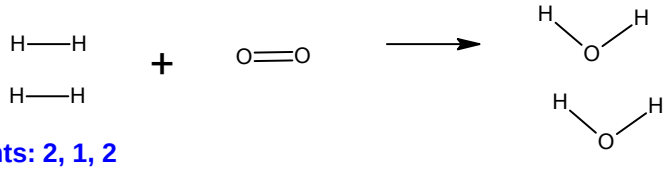
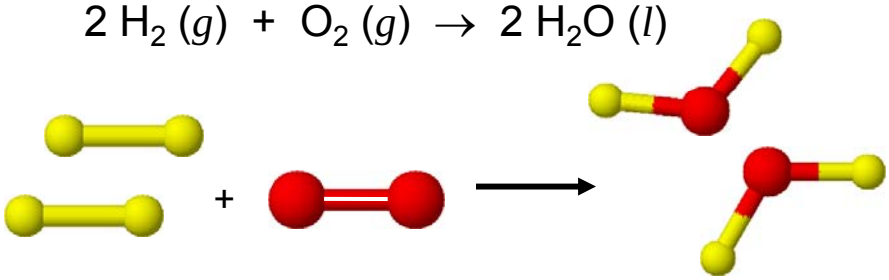
Balancing the Chemical Equation for the Formation of Water

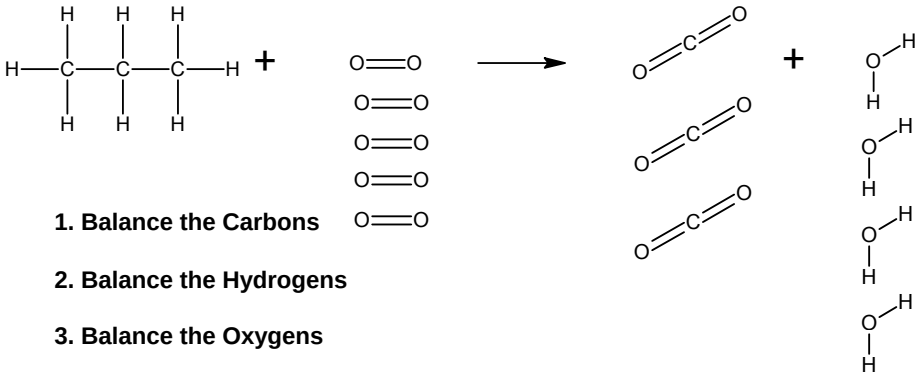


Coefficients: 2, 1, 2

$$2\ H_2\ (g)\ +\ O_2\ (g)\ \rightarrow\ 2\ H_2O\ (l)$$



Balancing the Chemical Equation for the Combustion of Propane



1. Balance the Carbons

2. Balance the Hydrogens

3. Balance the Oxygens

4. Is it balanced?

Balanced chemical equation:

$C_3H_8\ +\ 5\ O_2\ \rightarrow\ 3\ CO_2\ +\ 4\ H_2O$

Combustion Reactions in General

- Flame-producing reaction of a chemical with oxygen to produce oxides

  $4\ Fe\ (s) + 3\ O_2\ (g) \rightarrow 2\ Fe_2O_3\ (s)$

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

- Hydrocarbons (C and H) burn to produce CO_2 and H_2O (the oxides of C and H), if enough oxygen is present

  $CH_4\ (g) + 2\ O_2\ (g) \rightarrow CO_2\ (g) + 2\ H_2O\ (l)$

  $2\ C_2H_6\ (g) + 7\ O_2\ (g) \rightarrow 4\ CO_2\ (g) + 6\ H_2O\ (l)$

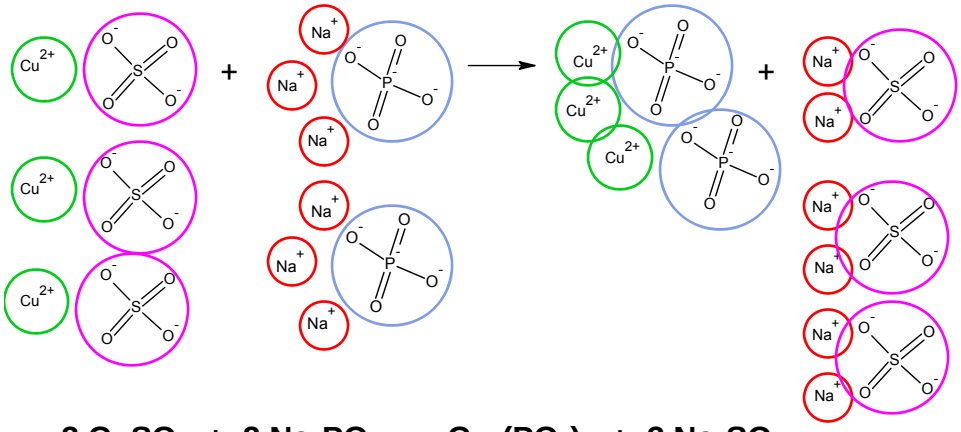
- Organic compounds (containing C, H, N and O) burn to produce CO_2, H_2O and N_2, if enough oxygen is present

  $2\ C_8H_{14}N_4O_2\ (s) + 21\ O_2\ (g) \rightarrow 16\ CO_2\ (g) + 14\ H_2O\ (l) + 4\ N_2\ (g)$

When the balancing units are ions, not atoms

Another reason why it's important to know how to name chemicals: so you can identify the ions to balance reactions that involve ions

$$CuSO_4 + Na_3PO_4 \rightarrow Cu_3(PO_4)_2 + Na_2SO_4$$



$$3\ CuSO_4 + 2\ Na_3PO_4 \rightarrow Cu_3(PO_4)_2 + 3\ Na_2SO_4$$

Balancing chemical equations
Step 1: What species to balance?

- The important question is: What are the smallest units (species) that both go in and come out?
  - If the chemical reaction involves only ions, chances are you should balance ions instead of atoms
  - If there are ionic compounds involved, knowing how to name them will assist greatly in balancing, because the names are the ions
- Practice: what species should be balanced?
  - $C_5H_{10} + O_2 \rightarrow CO_2 + H_2O$
  - $CaSO_4 + AgNO_3 \rightarrow Ag_2SO_4 + Ca(NO_3)_2$
  - $Mg + O_2 \rightarrow MgO$
  - $Al + CuSO_4 \rightarrow Al_2(SO_4)_3 + Cu$

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Balancing chemical equations
Step 2: The balancing act

- Two methods
  1. Accounting method
  2. Pictures method
- Both methods work
- Whichever one you use just depends on your mathematical inclination
- Method 2 is more time consuming

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Accounting method of balancing

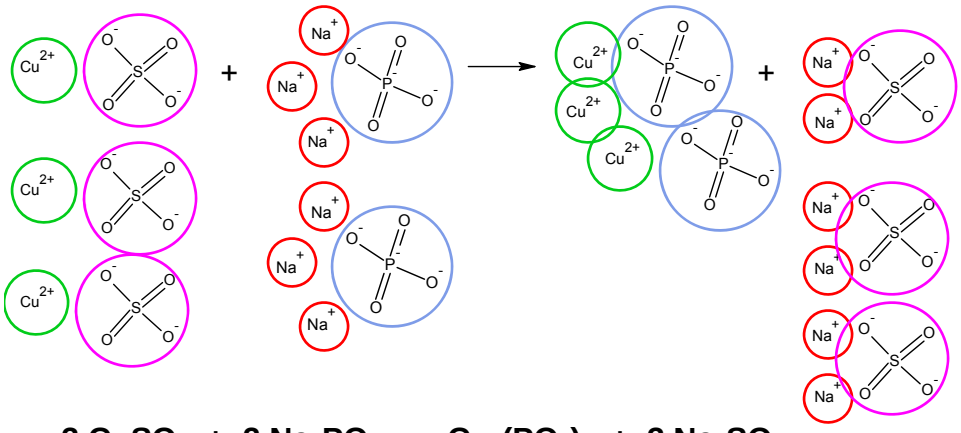
$$C_5H_{10} + O_2 \rightarrow CO_2 + H_2O$$

- Balancing units are C, H and O
- Balance the O's last, since they are present in two different products
- 5 C in → 5 C must come out, so CO_2 has coefficient 5
- 10 H in → 10 H must come out, so H_2O has coefficient 5
- Now, 5 CO_2 + 5 H_2O produced means (10 + 5) or 15 O's come out, so 15 O must go in
- The only way to get 15 O to go in is to have the coefficient of O_2 be 7.5
- So far, we have C_5H_{10} + 7.5 O_2 → 5 CO_2 + 5 H_2O
- Double all the coefficients to get

  2 C_5H_{10} + 15 O_2 → 10 CO_2 + 10 H_2O

Pictures method of balancing

$$CuSO_4 + Na_3PO_4 \rightarrow Cu_3(PO_4)_2 + Na_2SO_4$$



$$3\ CuSO_4 + 2\ Na_3PO_4 \rightarrow Cu_3(PO_4)_2 + 3\ Na_2SO_4$$

Stoichiometry

- "Counting atoms"
- Quantitative part of chemistry
- Foundation is conservation of matter
- Must use balanced chemical equations
- Reaction coefficients (also called stoichiometric coefficients) tell you how many units of a chemical are required, compared to units of other chemicals in the reaction
- We can't measure units in the laboratory (we measure mass, volume, *etc.*) – this is why it is important to know how to convert between lab measurements and moles

- Usually, units means moles

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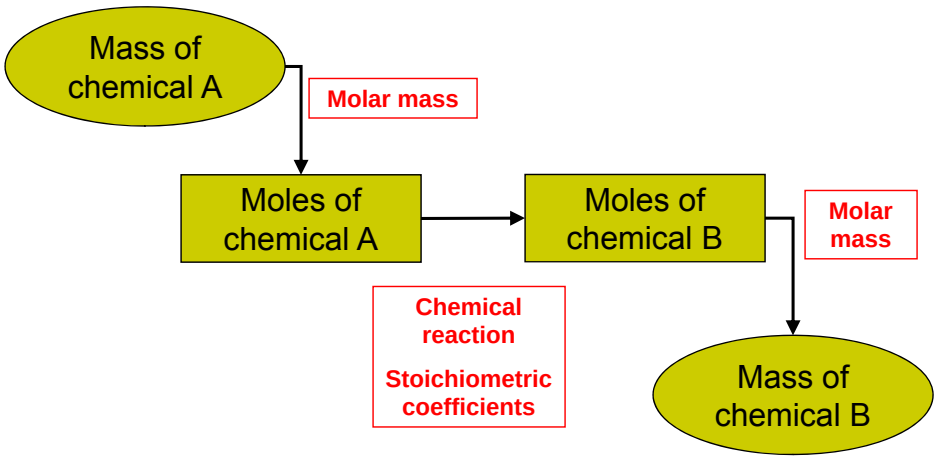
General Strategy for Simple Stoichiometry Problems



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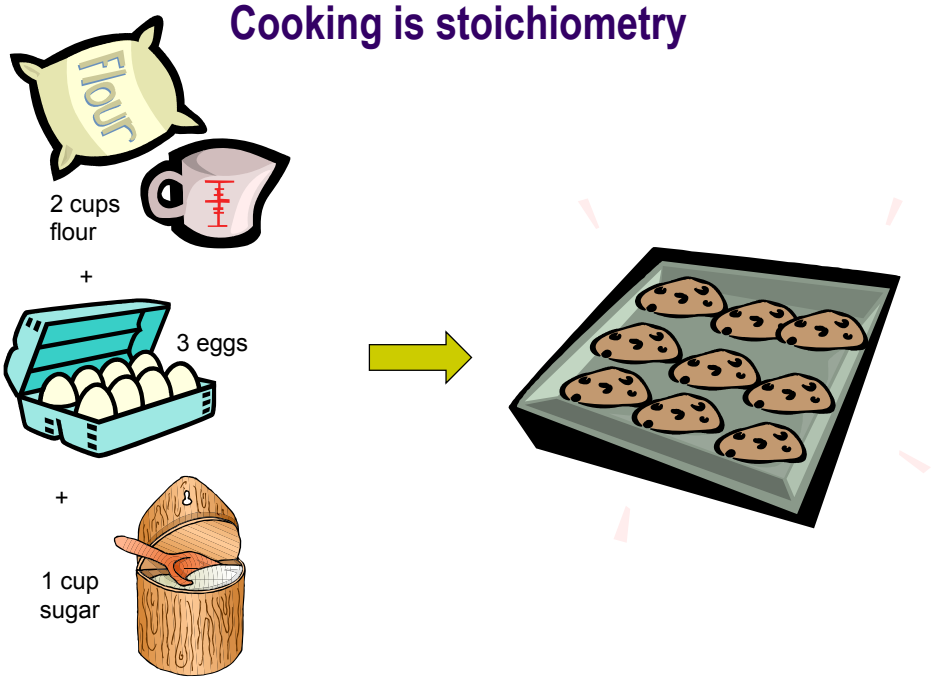
Cooking is stoichiometry



Extending the idea

- Let's say the recipe makes 24 cookies
- What if you wanted to make 48 cookies?
- What if you wanted to make 12 cookies?
- What if you wanted to make 1.20 cookies?
- How many cookies could you make if you only had 2 eggs instead of 3 (and enough of everything else)?

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Simple Stoichiometry

What mass of carbon dioxide gas is produced when 227 grams of propane (C_3H_8) combust completely?

Balanced chemical equation:

$$C_3H_8 + 5\,O_2 \rightarrow 3\,CO_2 + 4\,H_2O$$

1 mol C_3H_8 for every 3 mol CO_2

Start

$$227\text{ g } C_3H_8 \times \frac{1\text{ mol } C_3H_8}{44.09\text{ g } C_3H_8} \times \frac{3\text{ mol } CO_2}{1\text{ mol } C_3H_8} \times \frac{44.01\text{ g } CO_2}{1\text{ mol } CO_2} = 679.76\text{ g } CO_2$$

End

680. g CO_2

Types of Stoichiometry Problems

- Simple stoichiometry: Mass of one chemical (reactant or product) is specified. Find out mass of another chemical required or produced in the reaction (assuming just enough of each reactant is present). Must use a balanced chemical equation.
- Limiting reagent: Masses of two different reactants are specified. One of the reactants limits the reaction (it gets used up first). Figure out the maximum mass of a product that could be formed if all of the limiting reactant is used up. Must use a balanced chemical equation.
- Chemical analysis: Known and unknown chemicals or quantities given. Figure out unknown chemicals or quantities.

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Examples

1. Balance these chemical reactions
   a) $C_2H_2 + O_2 \rightarrow CO_2 + H_2O$
   b) calcium hydroxide + silver nitrate → silver hydroxide + calcium nitrate

2. When 2.06 g of nitrogen gas react with an excess of hydrogen gas, what mass of ammonia (NH_3) would be formed?

$$N_2 + 3\,H_2 \rightarrow 2\,NH_3$$

Balancing with first figuring out chemical formulas

calcium hydroxide + silver nitrate → silver hydroxide + calcium nitrate

- The problem is figuring out the chemical formulas
- calcium hydroxide
  - Made of Ca^{2+} ions and OH^- ions
  - Must be present in a 1:2 ratio to make $Ca(OH)_2$
- silver nitrate
  - Made of Ag^+ ions and NO_3^- ions
  - Must be present in a 1:1 ratio to make $AgNO_3$
- silver hydroxide
  - Made of Ag^+ ions and OH^- ions
  - Must be present in a 1:1 ratio to make AgOH
- calcium nitrate
  - Made of Ca^{2+} ions and NO_3^- ions
  - Must be present in a 1:2 ratio to make $Ca(NO_3)_2$

Mistakes I often see:

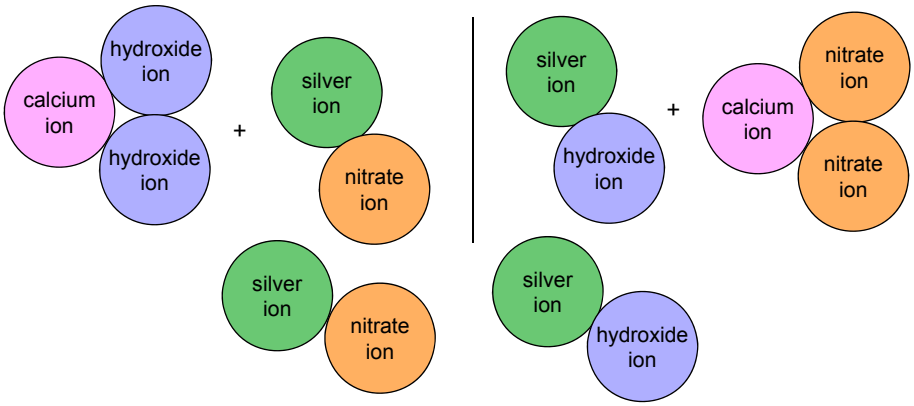
- Incorrect charges on ions
- Incorrect ratios
- Forgetting to write parentheses around polyatomic ions
- Leaving charges written on the ions in the formula

Then balance the equation

calcium hydroxide + silver nitrate → silver hydroxide + calcium nitrate

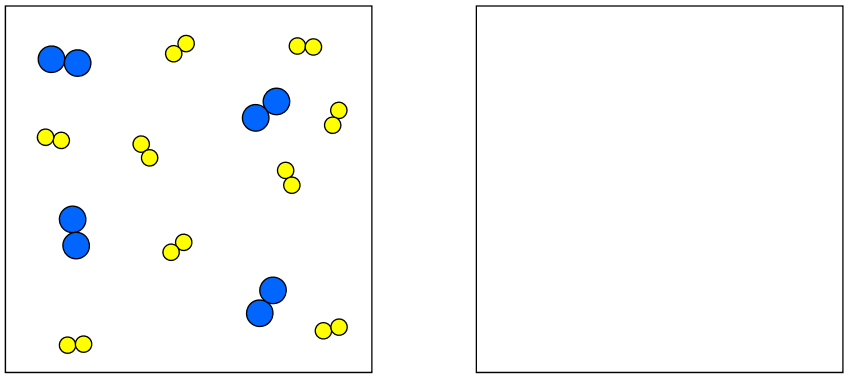
$$Ca(OH)_2 + AgNO_3 \rightarrow AgOH + Ca(NO_3)_2$$

Try balancing the names of the ions, if the subscripts are confusing



$$Ca(OH)_2 + 2\ AgNO_3 \rightarrow 2\ AgOH + Ca(NO_3)_2$$

The $N_2 + 3\ H_2 \rightarrow 2\ NH_3$ reaction

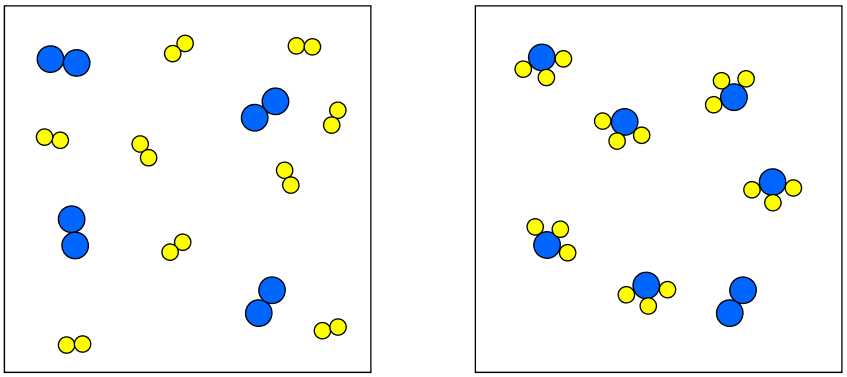


before after

Here is what an NH_3 molecule looks like: 
Draw the “after” picture.
Assume that all of the molecules that can react, do.

Let's look at the stoichiometry of

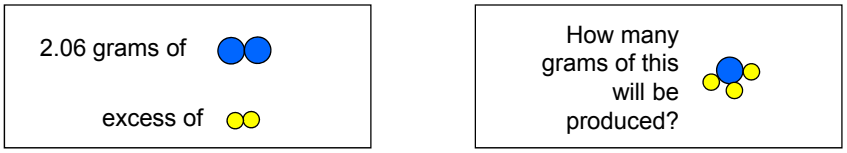
$$N_2 + 3\,H_2 \rightarrow 2\,NH_3$$



	N_2	H_2	NH_3
Before			
Change			
After			

Now let's look at the example problem

$$N_2 + 3\,H_2 \rightarrow 2\,NH_3$$



	N_2	H_2	NH_3
Before	2.06 g N_2 $2.06\,g\ N_2 \times \frac{1\,mol\ N_2}{28.02\,g\ N_2} = 0.0735\,mol\ N_2$	excess	none
Change	- 0.0735 mol N_2	*you could figure out how much if you wanted to*	$0.0735\,mol\ N_2 \times \frac{2\,mol\ NH_3}{1\,mol\ N_2} = 0.147\,mol\ NH_3$
After	none	some	$0.147\,mol\ NH_3 \times \frac{17.03\,g\ NH_3}{1\,mol\ NH_3} = 2.50\,g\ NH_3$

Conclusions about solving stoichiometry problems

- Mass is what is conserved
- Converting from how much of one chemical to how much of another requires knowing how many moles
- Figure out what is given and what you're looking for
  - Is the given information in mass or moles?
  - Is the answer sought in mass or moles?
  - Which reactant is limiting?
- For complicated problems, it helps to set up a "before-change-after" table…remember that quantities in this table must be in moles
- See website for another worked example

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