Στοιχειομετρία

Stoichiometry

It's hard to say in Greek, and it's hard to say in English too.

This is all about the math, and it's way cool.

It allows you to predict the future!

This is the Greek God Janus,

one who was said to look to the past and

to the future at the same time.

With that in mind, I thought he belonged here.

Stoichiometry BASICS

Stoichiometry is a big word and it does include some big (long) multistep problems, but really it is just an extension of what we have done before. When we learned of moles and the conversions between mass and moles, and moles and volume, or moles and particles, we would convert from unit to unit. With stoich (the shorter name) we start with the relationship between the parts of a balanced chemical equation, say the hydrogen and the oxygen in the synthesis of water. We can see in this balanced chemical equation several things. Make sure you grasp each of the sentences that follow this equation:

$$2H_2 + O_2 \rightarrow 2H_2O$$

This can mean

1. two molecules of hydrogen and one molecule of oxygen make two molecules of water
2. Two moles of hydrogen and one mole of oxygen make two moles of water

Since the second statement is just as true, and we've already learned of mole math conversions, using this relationship and some calculations, you could also see that

3. 4 g H_2 (*the molar mass of H_2 x2*) + 32g O_2 (*the molar mass of O_2*) = 36 g H_2O
4. 2 x 6.02 x 10^{23} molecules H_2 require 6.02 x 10^{23} molecules O_2 to form 2 x 6.02 x 10^{23} molecules H_2O

In fact since the ratio of moles here is 2Hydrogen:1Oxygen:2Water is set, and since we can covert moles to mass, particles, or volumes, we can do all sorts of tricks (mathematically) to this equation.

For instance, the hardest stoich problem might be this:

If you start with 34.7 Liters of hydrogen, how many molecules of water form?

Go slowly and follow how this could be easily solved with what you already know.

Step 1: convert the 34.7 Liters of hydrogen into moles of hydrogen

Step 2: Since the ratio of moles of Hydrogen to moles of Water (in this equation) is 2:2, we could use a simple ratio to determine how many moles of water will form.

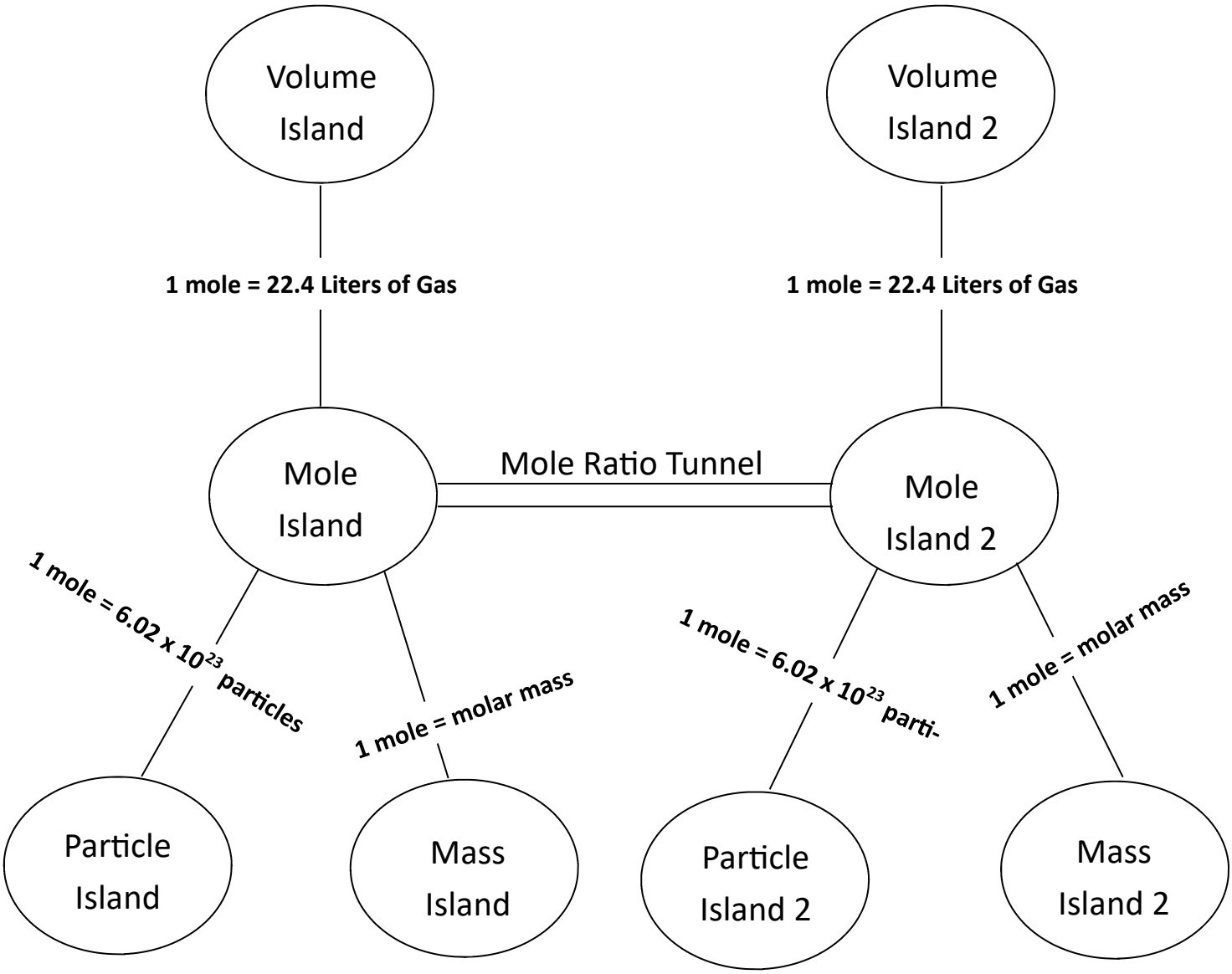
Step 3: Once you calculate the number of moles of water that will form, using Avogadro's number of molecules per mole, you can make this third conversion.

The biggest stoichiometry problem is three steps, find your starting point, and use the map on the next page to plot your trip, using the "tolls" or the conversion factors each step of the way. Don't get eaten by the shark!

In mole math, we would covert one thing from mass to moles to volume or particles. In stoichiometry, you can look at 2 different parts of a chemical equation at once. If there are 3 or more parts, they will take care of themselves in another problem. Here we will focus on 2 things at once now, not more than that.

For example: using the last problem, we'd start at Volume Island, convert the liter of hydrogen to moles of hydrogen, then make a ratio between the hydrogen and water, moving through the Mole Ratio Tunnel, to Mole Island 2. From there, we'd covert to get to Particle Island 2. The biggest problem in stoich is 3-steps.

The math for this problem follows on the next page. Go slowly through it, because this is the whole key. Finding your starting point, and doing the steps in order. Use your formulas, watch your SF, think, and remember that: "Paper is cheap, knowledge is valuable".



$$2H_2 + O_2 \rightarrow 2H_2O$$

If you start with 34.7 Liters of hydrogen, how many molecules of water form?

Step 1: $\frac{34.7\ \text{L}\ H_2}{1} \times \frac{1\ \text{mole}\ H_2}{22.4\ \text{L}\ H_2} = 1.55\ \text{moles}\ H_2$

MR stands for Mole Ratio
In this case, the ratio between hydrogen + water, the 2 parts of this equation we are dealing with.
The oxygen is not part of this problem at all.

Step 2: MR $\frac{H_2}{H_2O}\ \frac{2}{2}\ \frac{1.55\ \text{moles of hydrogen}}{X\ \text{moles of water}}$ Solving for X: X = 1.55 moles H_2O form

Step 3: $\frac{1.55\ \text{mole}\ H_2O}{1} \times \frac{6.02 \times 10^{23}\ \text{molecules}\ H_2O}{1\ \text{mole}\ H_2O} = 9.38 \times 10^{23}\ \text{molecules}\ H_2O\ \text{form}$

This is as hard as it could get, 3 steps of math. Each balanced chemical equation sets the MOLE RATIO for all the parts, and we just need to focus on two of them. All other parts are in "other" problems, but not the one we're doing.

With "mole math" we use one part, or one thing, but in "stoich" we look at two parts of the equation at once.

The most common problems to avoid: SF, putting other units than moles into the MOLE RATIO, or not following the map and doing the math out of sequence (wrong). Step by step, use the big map. Add the second part of the map and the Mole Ratio Tunnel to the bottom of Table H in your reference table at any time.

Second big problem: When ammonia forms this way: $N_{2(G)} + 3H_{2(G)} \rightarrow 2NH_{3(G)}$

If you use 632 Liters of hydrogen, how many grams of nitrogen gas are necessary? (assume STP).

Step 1: $\frac{632\ \text{L}\ H_2}{1} \times \frac{1\ \text{mole}\ H_2}{22.4\ \text{L}\ H_2} = 28.2\ \text{moles}\ H_2$

Step 2: MR $\frac{H_2}{N_2}\ \frac{3}{2}\ \frac{28.2\ \text{moles of hydrogen}}{X\ \text{moles of nitrogen}}$ Solving for X: X = 18.8 moles N_2 are necessary

Step 3: $\frac{18.8\ \text{mole}\ N_2}{1} \times \frac{28\ \text{grams}\ N_2}{1\ \text{mole}\ N_2} = 526\ \text{moles}\ N_2\ \text{are necessary}$

Third problem: the combustion of ethane gas,

$$2C_2H_{6(G)} + 7O_{2(G)} \rightarrow 4CO_{2(G)} + 6H_2O_{(G)}$$

How many grams of oxygen are used up when 308 liters of ethane combusts completely?

Going step by step, slowly, follow along. You should do this problem on loose leaf paper now.

	Look at map first: Start at 308 L ethane (Volume Island 1). Move to Mole Island 1, then to Mole Island 2, and finally to Mass Island 2. Watch SF.
Step 1 Convert mass of ethane to moles of ethane	$\frac{308 \text{ Liters ethane}}{1} \times \frac{1 \text{ mole ethane}}{22.4 \text{ Liters}} = 13.8 \text{ moles (3SF)}$
Step 2 Mole Ratio of moles of ethane to moles of oxygen	MR: $\frac{\text{ethane}}{\text{oxygen}} \quad \frac{2}{7} = \frac{13.8}{X}$ Solve for X $2X = 96.6$ $X = 48.3$ moles of O_2
Step 3 Convert moles of oxygen into grams of oxygen	$\frac{48.3 \text{ moles } O_2}{1} \times \frac{32 \text{ g } O_2}{1 \text{ mole } O_2} = 1550 \text{ grams } O_2 \text{ (3SF)}$

Stoichiometry is easy. The basic parts you already know. It's only an extra step. Sometimes the problems are shorter: 2 steps, or even one step mole to mole ratio conversions.

Examples:

Ex4: When 308 liters of ethane combust how many moles of oxygen are required? (2 steps)

Ex5: When 13.8 moles of ethane combust, how many grams of oxygen are required? (2 steps)

Ex6: When 13.8 moles of ethane combust, how many moles of oxygen are required? (1 step)

Stoichiometry (stoich) notes

1. What is Stoichiometry? _____

_____

_____

To make brownies, the recipe calls for you to mix together 1 box of mix, 3 eggs, 1 cup water, and ½ cup oil.

The "recipe" ratio is 1 box mix : 3 eggs : 1 cup of water : ½ cup of oil

2. A double recipe would be: _____ box mix : _____ eggs : _____ cup of water : _____ cup of oil

That was easy. How many cups of oil are required to make 3.75 batches of brownies? Not an impossible task to figure out, but you'd need to do some calculations. That's what stoich is about, except we use balanced equations instead of recipes.

3. $4Al_{(S)} + 3O_{2(G)} \rightarrow 2Al_2O_{3(S)}$ What is the mole ratio for this equation? _____

4. If you used up 8 moles of Al, how much O_2 would you need to complete the reaction? _____

5. If you used up only one mole of Al, how many moles of $2Al_2O_{3(S)}$ would form? _____

Before we do that, take out table H and we will draw in the Stoich Mole Map now. That will be our guide through all of stoichiometry, now and even in college. All problems are on this map.

_____

6. If you react 316.5 grams of Al, how many liters of O_2 would be necessary to complete the reaction?

Start at mass island I - and convert grams Al into moles of Al (this is mole math from earlier in the year)

Second step is called going through the MOLE RATIO TUNNEL.

The last step is converting the moles of oxygen into liters of oxygen (more old mole math work here)

7. There are 3 “levels” of questions in stoich. Not harder, just longer or shorter.

The longest are called 3 step stoich problems. Examples include

The medium long ones are called 2 step stoich problems. Examples include

The shortest problems are called one-step—or moles to moles problems. The only example is

---

New Reaction now…

8. Propane (C_3H_8) gas burns with oxygen and forms carbon dioxide and water gases.
   If 56.8 grams of $C_3H_{8(G)}$ is used up, how many liters of CO_2 form?
   (3 steps) Start with a balanced equation:

---

9. If you use up 23.1 moles HCl, how many formula units of aluminum chloride form?
   Use this reaction: $2Al_{(S)} + 6HCl_{(AQ)} \rightarrow 2AlCl_{3(AQ)} + 3H_{2(G)}$

10. If 371.5 grams of candle wax ($C_{21}H_{44}$) combusts. Assume STP; how many liters of CO_2 gas form?
    Write the balanced equation first.

11. Using the same combustion reaction, if you consume 23.9 moles of O_2, how many moles of H_2O form?
$C_{21}H_{44} + 32O_{2(G)} \rightarrow 21CO_{2(G)} + 22H_2O_{(G)}$

12. You have 4.56×10^{25} atoms of Zn that you put into $H_3PO_{4(AQ)}$ to make them fizz away.
How many grams of hydrogen gas form? Write the balanced equation first.

14. How many liters of $N_{2(G)}$ are required to combine with 809 liters of hydrogen when $NH_{3(G)}$ forms?
Write the balanced equation first.

15. If exactly 15.6 moles of ethane gas combusts like this, how many moles of oxygen are used?

$2C_2H_{6(G)} + 7O_{2(G)} \rightarrow 4CO_{2(G)} + 6H_2O_{(L)}$

16. If exactly 649.6 L of $NO_{(G)}$ form like this, how many liters of O_2 are used?

$4NH_{3(G)} + 5O_{2(G)} \rightarrow 4NO_{(G)} + 6H_2O_{(L)}$

17. During this combustion, 125 g of oxygen are used up. How many g of H_2O are produced?

$2C_8H_{18(L)} + 25O_{2(G)} \rightarrow 16CO_{2(G)} + 18H_2O_{(G)}$

18. 105 g of N_2 react with oxygen to form dinitrogen pentoxide. How many molecules of O_2 are required in this reaction? $2N_{2(G)} + 5O_{2(G)} \rightarrow 2N_2O_{5(G)}$

19. In an odd chemical reaction shown below, if 0.135 moles of H_2 reacts, how many grams of NH_3 are produced? $2NO_{2(G)} + 7H_{2(G)} \rightarrow 2NH_{3(G)} + 4H_2O_{(L)}$

This is hardest stoich problem I could ever imagine, and the last one you have to do:

20. When 9.42×10^{29} atoms of phosphorous react with sufficient chlorine to make phosphorous pentachloride, how many molecules of chlorine gas are necessary?

name: _____

STOICH
HW#1

Read Stoich BASICS. These are simple 1 step conversion math problems. They are sometimes called Moles To Moles problems. They require just a balanced equation and no conversions to solve.

Carbon disulfide is an important industrial solvent. It is prepared by the reaction of solid carbon & sulfur dioxide gas forming solid carbon disulfide & carbon monoxide gas.

Balance this equation with phase symbols
How many moles of carbon disulfide form when 2.7 moles of carbon react?
How many moles of carbon are needed to react are needed to react with 5.44 moles of SO_2?
How many moles of carbon monoxide form at the same time 0.246 moles carbon disulfide form?
How many moles of sulfur dioxide are needed to make 118 moles of carbon disulfide?

name: _____

STOICH
HW#2

These are 2 STEP problems, not just moles to moles, but an additional step either before, or after the mole ratio math. You must show ALL math and ratio! Watch your SF

Ammonia is formed by combining H_2 gas & N_2 gas, as shown in the balanced equation:

$$N_{2(G)} + 3H_{2(G)} \rightarrow 2NH_{3(G)}$$

How many grams of ammonia form when 512 moles of $N_{2(G)}$ react?

How many liters of nitrogen are needed to react with 2.2 moles of H_2?

How many moles of NH_3 form at the same time 8.32×10^{24} molecules of H_2 gas reacts?

name: _____

Zinc reacts with $HCl_{(AQ)}$ releasing hydrogen gas while forming a new solution.

STOICH
HW#3

Balance this equation with phase symbols

You start with 548 g of Zn + sufficient acid to completely react all of the zinc.
How many formula units of zinc chloride form?

If 4.91×10^{24} atoms of zinc completely react, how many liters of H_2 gas form?

Stoich Practice QUIZ with answers

Put your answers below. All work must be shown on white paper. Be neat.

1. Balance this equation ____ $Al_{(S)}$ + ___ $CuSO_{4(AQ)}$ → ___$Al_2(SO_4)_{3(AQ)}$ + ___ $Cu_{(S)}$

2. What is the mole ratio for this equation? _____

   What type of reaction does this represent? _____

3. If you were to use up 11.0 moles of Al, how many moles of Cu would form? _____

4. If you use up 912 grams of Al, how many grams of Cu would form? _____

5. Balance this equation ____ $Rb_{(S)}$ + ____ $MgSO_{4(AQ)}$ → ____ $Mg_{(S)}$ + ____ $Rb_2SO_{4(AQ)}$

6. What is the mole ratio for this equation? _____

   What type of reaction does this represent? _____

7. When 41.3 grams of Rb are used in a complete reaction, how many moles of Rb_2SO_4 form? _____

8. If you use up 8.49×10^{26} atoms of Rb, how many atoms of Mg form? _____

Baking Soda - Stoichiometry Lab name: _____ (40 min)

When you heat up baking soda, gas is given off, but the actual chemical reaction is vague at the moment. During this lab, we will decompose baking soda, also known as sodium hydrogen carbonate, but heating it up in an evaporating dish with a Bunsen burner. When we're done, we can measure the mass of the left over solid salt, and we will determine which of three possible chemical reactions actually happened.

We'll use stoichiometry 3 times, on the 3 possible reactions, and know which reaction happened in the lab.

Baking soda is also called by its old fashioned name: sodium bicarbonate, but we will not call it that in our class. That naming protocol has been abandoned by real chemists, but not by food chemists.

Procedure: Put on your goggles first. Then, set up a ring stand, get Bunsen burner at the ready. Get a clean and dry evaporating dish. Mass the empty dish. Measure out exactly 3.40 grams of the sodium hydrogen carbonate and make sure it's ALL INSIDE the dish - not on the scale.

Heat the dish for at least 20 minutes under moderate heat. Your teacher should check the intensity. We don't need to burn the heck out of it. Then we will cool the dish, and mass it. After, we will heat again for 2 minutes, cool it down, and mass it again for a final time.

Clean up: warm water, soap, put the dish next to sink UPSIDE down to dry. Put equipment away.
The "cooked" baking soda can go into the sink or into the trash, it's not harmful.

The reason that this is such a cool lab is that you probably don't know what really happened in that dish. Here are 3 possible equations, they all look possible but only one of them happens.

A. Baking soda decomposes into sodium hydroxide solid + carbon dioxide gas

B. Baking soda decomposes into sodium oxide solid + carbon dioxide and water gas

C. Baking soda decomposes into sodium carbonate solid + carbon dioxide and water gas

Data	Measure on the scale	Mass in grams
A	Empty evaporating dish	
B	Sodium hydrogen carbonate alone (B - A)	3.40 grams
C	Dish + Sodium hydrogen carbonate	
D	After heating for 24 minutes; dish + solid	
E	Mass of left over solid only (D - A)	

Lab Questions, to be done on loose leaf paper, in order, neatly, with plenty of space to write you back some fun notes and hints on how to think more.

1. Write the balanced chemical equation for possible reaction A.
2. If you used 3.40 g of sodium hydrogen carbonate, how many grams of sodium hydroxide should form?

3. Write the balanced chemical equation for possible reaction B.
4. If you used 3.40 g of sodium hydrogen carbonate, how many grams of sodium oxide should form?

5. Write the balanced chemical equation for possible reaction C.
6. If you used 3.40 g of sodium hydrogen carbonate, how many grams of sodium carbonate should form?

7. How many grams of solid formed in your lab experiment? Which of these 3 reactions do you think happened? Try to support your choice with a few well worded sentences so I can see if you guessed or if you understand.
8. Calculate your percent error (of grams of solid product forming).
   Remember: % Error always gets a sign and proper SF!
9. The mass of the solid product is noticeably less than the mass of the solid reactant in this reaction. Explain how the mass is so much less than the starting mass. Is even possible or did this reaction just break the Law of Conservation of Matter?
10. Why is baking soda a common ingredient in cake recipes? (for box cake mixes, it's already included into the cake mix)

Points for this lab:

Cover Page: with title, nice optional diagram/picture, and mandatory descriptive sentence. = 2 points

Ten questions above x 2 points each = 20 points

In your Conclusion , for the final 3 points, you must include the following parts:

1. Explain what stoichiometry is, and what is it used for. How did <u>you</u> use stoichiometry in this lab?
2. Name the 5 kinds of chemical reactions you know already.
3. Explain what the letters of TOPIC-B stand for.
4. Write out the (entire) Law of Conservation of Matter. (in full sentences) (check Arbuiso.com glossary)
5. Write out the Law of Conservation of Energy. (in full sentences) (check Arbuiso.com glossary)
6. Name 6 kinds of phase changes (physical changes, not chemical changes) <u>properly paired up</u>.

Fe + $CuSO_4$ Lab

Name: _____ 40/1200

Objective: To produce an exact amount of copper from the single replacement reaction of iron metal and aqueous copper II sulfate. We will then to evaluate our results and check our % Error by comparing our measured results with our predicted calculated results.

Before starting this lab experiment, you must first determine how much iron will be required to produce your exact amount of grams of copper from this single replacement reaction. (2.05 — 3.15 g)

Each student team will choose an amount of copper to produce, the team with the lowest % Error will "win" the prize. Choose by initialing on the white board next to a number that you like.

Word equation & the balanced chemical equation for iron + copper II sulfate solution in a single replacement reaction
Word
Balanced

I am attempting to form _____ grams of copper from this reaction.

Use Stoichiometry (3 steps) to determine how many grams of iron are needed to precipitate out your number of grams of copper. Get the teacher's check before you go to the lab to do this experiment.

How many grams of Iron to start with: _____

Procedure: First: in ink, put your name and your partner's name on the inside of the filter.
Mass filter and record this mass before it gets wet!

Obtain a very clean and dry beaker (about 200 mL). Place it on the scale and zero it out. Put in your iron.
Remove beaker from scale, pour in about 24 mL of copper (II) sulfate solution. Swirl carefully.
Note the instant production of copper which you can see. (copper solution ~ 1.0 M)

Set up your filter in a funnel with a ring stand and be sure to have a beaker to "catch" everything pouring through it. Pour all beaker contents into the filter (do not go over the top of the filter paper!)

Not all of the copper wants to exit the beaker, you will have to spritz deionized water with an eyedropper into the beaker to flush it all out. Do not touch your eyedropper to the beaker itself. Spritz all the copper into the bottom of the filter. Drain completely. Put your filter out overnight to dry.

Wash all glassware, put upside down to dry. In 2-3 days you need to mass filter with copper, then subtract the original mass of the inked filter paper so you can get the mass of just the copper.

DATA TABLE	Mass in grams
(today) mass of filter paper with names	
(in 2 days) mass of dry filter paper + copper	
mass of JUST the copper (MV)	
mass of copper you attempted to produce (AV)	

The Lucky Lab Questions *(1—5 are one point each, 6—10 are two points each = 15 total)*

DO THESE ON WHITE PAPER. Spread out, one column of work on each page, leave room for me to make adjustments and comments. Show your work in math, use units and watch out for your SF too. DO NOT JUDT PUT ANSWERS HERE, or squeeze work in here. That's not okay.

1. Determine your PERCENT ERROR.
2. Why did you have this percent error?

3. If you made a crazy mistake and used Iron II sulfate solution with copper metal, what would happen?
4. In our experiment we form iron (II) sulfate solution. Explain how you know that $FeSO_4$ is aqueous.

5. Where does the water to make this iron (II) sulfate solution come from?
6. How much iron did you use this this reaction? _____ grams. Calculate the number of atoms that is.

7. If you were trying to produce 35.46 grams of copper in this experiment, how many grams of iron would you need?

8. Iron reacts with oxygen in the air to form iron III oxide (rust). Write a balanced chemical equation, *with phases,* for this reaction.

9. To produce exactly 454.0 grams of rust, how many molecules of oxygen would react?

10. When 633.05 grams of rust forms, how many atoms of iron were required?

$Fe + CuSO_4$ Lab Report	includes	points
Cover	Title with short intro Include the balanced chemical equation with PHASES	1 + 1 = 2
Page 1 of handout	Fill in the boxes, do the stoich math to calculate your mass of iron needed	3
page 3	10 Lab questions—ON WHITE PAPER. (SF are significant!)	15
page 4	Conclusion: 3-5 sentence summary of what you tried to do, and what you did do during this experiment. Tell what you calculated, what you measured, what your percent error was, why you had this error (over/under?). Include then a general statement about what stoichiometry is, what you can use it for, and why you love it so.	5
Lab due on:		25 points

Answers to Quiz in packet

1 $2Al_{(S)} + 3CuSO_{4(AQ)} \rightarrow Al_2(SO_4)_{3(AQ)} + 3Cu_{(S)}$

2 MR = 2:3:1:3 This is a single replacement reaction (table J)

3 $\text{MR} \quad \frac{\text{Al}}{\text{Cu}} \quad \frac{2}{3} = \frac{11.0}{x}$ $2x = 33.0$ $x = 16.5$ moles copper

4 $\frac{912\text{g Al}}{1} \times \frac{1 \text{ mole Al}}{27 \text{ g Al}} = 33.8$ moles Al

$\text{MR} \quad \frac{\text{Al}}{\text{Cu}} \quad \frac{2}{3} = \frac{33.8}{x}$ $2x = 101.4$ $x = 50.7$ moles copper

$\frac{50.7 \text{ moles Cu}}{1} \text{ X } \frac{64 \text{ g Cu}}{1 \text{ mole Cu}} = 3244.8 \text{ Cu} = 3249 \text{ g Cu with 4 SF}$

5 $2Rb_{(S)} + MgSO_{4(AQ)} \rightarrow Mg_{(S)} + Rb_2SO_{4(AQ)}$

6 MR = 2:1:1:1 This is also a single replacement reaction (table J)

7 $\frac{41.3 \text{ g Rb}}{1} \text{ X } \frac{1 \text{ mole}}{85 \text{ g Rb}} = 0.486$ moles Rb

$\text{MR} \quad \frac{\text{Rb}}{Rb_2SO_4} \quad \frac{2}{1} = \frac{0.486}{x}$ $2x = 0.486$ $x = 0.243$ moles rubidium sulfate

8 $\frac{8.49 \times 10^{26}\text{atoms Rb}}{1} \text{ X } \frac{1 \text{ mole of Rb}}{6.02 \times 10^{23}\text{atoms Rb}} = \frac{8.49}{6.02} \text{ X } \frac{10^{26}}{10^{23}}$ $= 1.41 \times 10^3$ $= 1410$ moles Rb

$\text{MR} \quad \frac{\text{Rb}}{\text{Mg}} \quad \frac{2}{1} = \frac{1410}{x}$ $2x = 1410$ $x = 705$ moles Mg

$\frac{705 \text{ moles Mg}}{1} \text{ X } \frac{6.02 \times 10^{23}\text{atoms Mg}}{1 \text{ mole Mg}} = 4424.1 \times 10^{23} = 4.2441 \times 10^{26} = 4.24 \times 10^{26}$ atoms Mg

Draw the Stoich-Mole Map
All 8 islands and the big shark here.

Explaining it to your family will help you learn.

Give the shark big teeth to scare you into doing the math correctly.