Chemical Stoichiometry:
from Memorization to Rationale

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This curriculum unit is recommended for Chemistry Grades 10-12

Keywords: science, chemistry, mathematics, writing

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit.

Synopsis: Chemistry is considered the central science because it bridges concepts from other areas of science and mathematics. This makes it highly important that chemistry is accessible for all students due to the impact it can have in their education or professional lives. Unfortunately, chemistry is often seen as a very daunting class for many high school students. It's unclear if the intimidation comes from how chemistry was taught historically, but chemistry is generally the first science students will take in high school that can be considered an intersection between math and science. My goal for this unit is to transform one of the most mathematics-heavy units, stoichiometry, into a more manageable topic for students to be successful by developing a conceptual understanding. A focus will be on students using explanatory writing to support their theoretical understanding of the topic.

I plan to teach this unit during the coming year to 90 students in standard and honors chemistry classes.

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Introduction

All students should have the opportunity to be successful in any area they choose to pursue. As educators, we constantly strive to ensure that the content and material we provide to our students is rigorous, but at an appropriate level. I constantly tell my students that there is a lot of value in learning how to deal with a difficult concept. When I allow my students to "struggle" that generally means that I refuse to immediately give them an answer because they could not come up with their own answer after a few minutes. Instead, I try to facilitate understanding by going back a few steps and seeing what is clear to the students and where understanding might have turned into a misconception or misunderstanding. This process takes more time and the students will sometimes get frustrated, but taking a moment to assess the needs of students is something a teacher is constantly doing in their classroom.

In general, nobody is born good at science in a similar way that many athletes are not innately experts in their sport of choice without a significant amount of time and effort invested in the development of the skills and processes needed to be considered an expert. I tell my students that if they come prepared to learn, can take constructive criticism, and have a positive attitude when dealing with difficult content, they can succeed in virtually anything, including high school chemistry.

My goal is to have students better understand the math behind what they are doing, so they are able to think critically about the process of these types of questions instead of rote memorization of the process. The stoichiometry test is broken up into three main components: amount conversions (grams -> moles -> particles and any combination of the three). Chemistry is a state testing class and they are provided a reference table that has many formulas and information that minimizes what students have to memorize. Unfortunately, information for these conversions are not directly given to students on the reference table, which means they are forced to memorize the "formulas" needed to answer these questions.

What I'm excited to try and implement is having students dissect the problem and be able to determine the correct process of answering a question without having to rely on memorization. I plan on putting support systems in place to help students navigate through the vocabulary in a more thoughtful manner. I very frequently have students explain how they got an answer in class (they learn this in the first week that when I ask a question it is always a two-part question and the most important part it "why do you think that" or "what is your thought process"). I want the norm for students to be able to write about their thought process and explain the math they are doing in written expression.

Class Demographics

William Amos Hough High School is a large suburban high school of over 2500 students located in Cornelius, North Carolina just north of Charlotte. We opened our doors in 2010 to serve the northern part of the Charlotte-Mecklenburg School District. Of the student body, approximately 63% attend a 4-year institution, 20% attend a community or junior college, and

16% join the military or workforce. My school has about 26% of the student body that falls into an ethnic minority. My school offers 26 AP classes and about 900 students take 1800 AP exams each year. The school motto is "Going Beyond Great." Hough currently has standard, honors, and advanced placement levels of chemistry. The school day is 90 minute block schedule.

Background Information

The concept of "stoichiometry" can be very simply described as quantitatively (using numerical amounts) converting between different units of measurement when dealing with chemical compounds. One of the concepts we discuss when beginning stoichiometry is the mole. A mole, in chemistry, is essentially a chemists' dozen and is used to represent a very large number of particles (6.022×10^{23}).

Figure 1: Various definitions of the mole[1]

If you have ever recycled cans, you already understand the idea of counting by mass. The idea is that instead of individually counting the recycled cans one by one, we can simply get the total mass of the cans and determine the amount recycled. Atoms range in size from 0.0000000001 to 0.0000000005 meters. It would be impractical, tedious, essentially impossible to individually count atoms to get an accurate number of molecules in even a drop of water. On the periodic table, the number under the element symbol is the average atomic mass. That is the weighted average of all particles of the same element. The number is also the number of grams that are equal to one mole of that substance. For example, if you have one mole of carbon, that is equal to

12.011 grams (molar mass) of carbon, and equal to 6.022×10^{23} particles of carbon.[2]

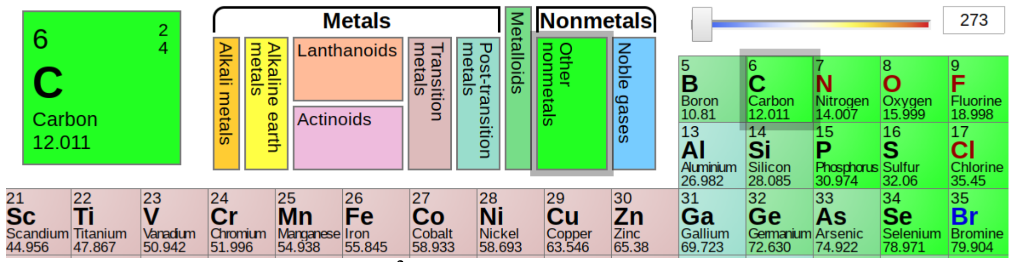


Figure 1: A portion of the periodic table[3]

If you are trying to find the number of moles of a compound (two or more elements in a stable configuration) you would add the molar mass of each element found in that compound. For example to find the molar mass of glucose $C_6H_{12}O_6$ you could set up the following math problem, 6(12.01g/mole) + 12(1.0 g/mole) + 6(16 g/mole) = 180.16 g/mole. If you don't have exactly 180.16 grams of glucose, you can calculate the number of moles (or particles) you have using the flowchart shown below or the notes shown in Appendix 2.[1]

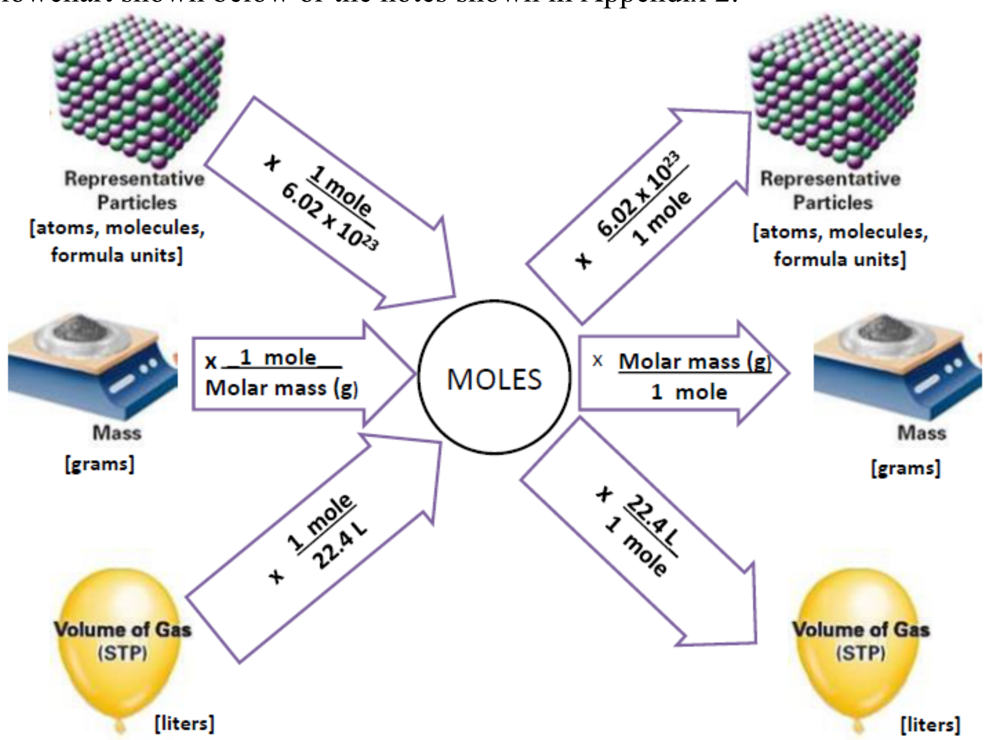


Figure 2: A molar conversion flowchart

Until this point, the students in my class have been taking one compound and converting units. However; for stoichiometry, students will need to be able to go from a numerical unit of one compound to another compound (example: grams of compound A to grams of compound B). In order to do this, we need a balanced chemical equation. The notes that I used in class are shown in Appendix 2.

When discussing stoichiometry, we also talk about a concept known as limiting reactants. A limiting reactant is a chemical that is limiting (we don't have enough) and stops the reaction at a certain points because we are now missing one of the chemical starting materials. An example of this would be if you were making peanut butter and jelly sandwiches and you had 12 pieces of bread, 1 jar of 28oz peanut butter, and half a jar of 28oz jelly. The equation I will use to explain the concept of limiting is: .2 B + 1 PB + 1 J → 1 PBJ. In this equation, 2B is represents two slices of bread, 1 PB represents 1 ounce of peanut butter, 1 J represents 1 ounce of jelly, and 1 PBJ represents one peanut butter and jelly sandwich.

From our example, we see that we have enough pieces of bread to make 6 sandwiches, enough peanut butter to make 28 sandwiches, and enough jelly to make 14 sandwiches. This means that the limiting (reactant) in this example would be bread. Once we have used the bread to make 6 sandwiches, we do not have anymore and cannot continue to make peanut butter and jelly sandwiches. This concept works the same way in chemistry, but instead of slices of bread and other commodities, we use moles. Again, using our example equation, we can summarize the information to say "2 moles of B, 1 mole of PB, and 1 mole of J combine to form one mole of PBJ." This example begins to explain what is known Law of conservation of mass and the Law of definite proportions. The Law of conservation of mass states that matter is neither created nor destroyed only redistributed. This means that in any chemical reaction we are limited by how much of a chemical we can make due to the amounts we had in the beginning. The Law of definite proportions states that chemical compounds always have the same number or proportion of each element in the compound. Meaning a molecule of water will always have one oxygen atom and two hydrogen atoms. The reason that compounds will always have the same proportion of each element is due, primarily, to stability. Each element wants to be in a low energy or stable state. Some elements will naturally be in this state (noble gases), but many other elements will need to combine in some way (either by losing, gaining, or sharing electrons) to reach a stable configuration.[3]

One of the main reasons I went into such detail for the background information for this unit is to show that there are many different and complicated concepts that students have to understand before we can even begin to discuss the mathematics involved in this topic. When compared with an inquiry-based or a more conceptual activity, students are generally more comfortable with memorizing information and presenting the information exactly as they were given on an assessment. Memorization is an important skill and has value in certain areas within education, but generally students conflate memorization with understanding within mathematics and science. I think this might be due to students being able to do a low level recall based question, because they have a similar situation complete in class or notes. Science and mathematics generally focus on learning how to use the information and apply it appropriate given the situation. In these areas, we want students to apply what they are learning to new situations which is generally impossible with memorization alone. Making students' thinking more visible allows teachers to find gaps or misconceptions in their understanding. One of the primary ways in which I plan on making thinking more visible for this topic is to incorporate mathematical writing as checkpoints throughout the unit to allow students an opportunity to show me how well they understand the chemistry we are discussing and push them beyond simply trying to memorize huge numbers of example problems.

One way we can think about categorizing mathematical writing are the following types: exploratory, informative/explanatory, argumentative, or mathematically creative[4]. Each writing type can be used for different purposes; Exploratory writing is used to summarize one's thoughts as a way in which students can make sense of the problem at hand. Explanatory writing is mathematics is used to describe or explain a process or reasoning, which allows students to explain their thought process involved when coming up with rationale behind their answer.

Argumentative writing allows students to critique another viewpoint with additional examples to support or use counterexamples to disagree with a claim. Mathematically creative writing is used to document original ideas or solutions, but this type of mathematical writing tends to happen infrequently.[4-7]

To elicit more thoughtful verbal responses, the research-based mathematical verbal discourse has many interesting ideas that can be easily adapted to a chemistry curriculum. Some examples are revoicing/repeating (asking somebody else to restate somebody else's reasoning), reasoning (asking somebody else to apply their own reasoning to somebody else's reasoning, adding on, and waiting). These strategies can be implemented to as whole class discussion, small group, or with partner[7]. These peer-reviewed strategies have likely been incorporated at some level in most classrooms, but it may not be clear to teachers that research has shown how valuable these techniques can be to students of all levels in terms of mathematical writing. Revoicing is used in my classes to reinforce key information. After a student provides the class with a clear and correct answer, I will have another student summarize the first students' answer is one or two sentences. This ensures that students are paying attention and coding the information in their own words. Reasoning is used in my class as a checkpoint when we break up example problems among larger numbers of people. After providing the initial group with time to generate an answer and reasoning. I have other groups see if they believe the answer is correct (with a why or why not component) and if there were any other ways in which to complete the problem. This method works well after community has been thoroughly built into the expectation of the class and students know that feedback is only meant to be constructive.

We can add another layer of support by allowing students to work collaboratively on formative activities. Having students work together allows both the higher and lower level students to grow in their understanding. The students that are at a higher level have the opportunity to test their understanding by one of the most difficult means possible, teaching. Lower level students have the benefit of having a peer walk them through the material. This may make the content easier for lower level students to understand, because the students that are slightly more advanced are still relatively new to the material and are more intimately familiar with the misconceptions that arise as you are learning the material.[8] Teachers are generally aware of many misconceptions, but as teachers become masters and the complicated topics become second nature, they may lose some of the valuable lessons that come from struggling to learn that material. Also, there might be cultural changes within new student generations that add or change the repository of misconceptions that a teacher had never previously encountered or considered. As a personal example, I was told in school that I needed to know how to solve basic math by hand because I won't always have a calculator with me. As smart phones become the norm, many mathematical functions are easily done without necessarily needing to be adept at doing the math by hand. As an adjustment to this trend, now teachers have to instruct students how to accurately input mathematical processes in their smartphone/calculators in order to get the correct answer.

Another method to help elicit collaboration and have students write or communicate to show their understanding is to use a resource known as POGILs (Performance oriented guided inquiry lessons). POGILs are guided learning activities that use models to facilitate students to learn relatively difficult concepts. POGILs started as only chemistry based activities, but the idea has since been used in a wide range of topics including: other sciences, mathematics, computer programming, and even finance. In general, the activity will have 2-3 models and the information in each model is closer to the concept that is ideally more clear after the activity.

Through these activities students are using concise explanations, data patterns, and counterexamples to make general claims about the topic. There are several checkpoints throughout the activity that students are supposed to speak to the teacher to ensure they are going along the correct path. POGIL activities are very heavily reliant on collaborative learning and each student has a role (manager [responsible for: time management, ensures group is focused, makes sure each voice in group is heard] , presenter [responsible for asking the teacher for assistance if needed, ensures all members agree on question to ask teacher, presents answers to class], reflector [ensures all agree on answer, everybody is respectful, reports on group dynamics], recorder [summarizes important findings, records the names and roles of each student].[9] Below I have a series of models from the "Relative mass and the mole" POGIL activity to more clearly show how the models will typically begin with virtually no relationship to chemistry to build an idea. As students work through the models, the ideas progressively get more directly related to the specific topic we are stressing.

Model 1 – Eggs

Chicken		**Quail**		**Ratio of numbers of eggs**	**Ratio of masses of eggs**
Number of eggs in the sample	Mass of the sample	Number of eggs in the sample	Mass of the sample		
1	37.44 g	1	2.34 g	1 : 1	16 : 1
10		10			
438		438			
1 dozen		1 dozen			
1 million		1 million			

Model 2 – Atoms

Oxygen		**Sulfur**		**Ratio of numbers of atoms**	**Ratio of masses of atoms**
Number of atoms in the sample	Mass of the sample	Number of atoms in the sample	Mass of the sample		
1	16.00 amu	1	32.00 amu		
10		10			
1 dozen		1 dozen			
1 million		1 million			
1 mole	16.00 grams	1 mole	32.00 grams		

Model 3 – Molar Mass

Average Mass of a Single Particle	
1 atom of hydrogen (H)	1.01 amu
1 atom of copper (Cu)	63.55 amu
1 molecule of oxygen (O_2)	32.01 amu
1 molecule of water (H_2O)	18.02 amu
1 formula unit of sodium chloride (NaCl)	58.44 amu

Average Mass of One Mole of Particles (Molar Mass)	
1 mole of hydrogen atoms (H)	1.01 g
1 mole of copper atoms (Cu)	63.55 g
1 mole of oxygen molecules (O_2)	32.01 g
1 mole of water molecules (H_2O)	18.02 g
1 mole of sodium chloride formula units (NaCl)	58.44 g

Figure 3: The progression of models (1-3) from the "Relative mass and the mole" POGIL activity[9]

One of the main takeaways that I have come across while in this seminar and during research is that students need to constantly have the expectation that they should be able to support their answers. "Supported answers" can be shown a range of ways in stoichiometry. My students typically have difficulty providing evidence for their thinking and have a hard time explaining why they chose certain numbers/units for numerators and denominators for the factor-label method of stoichiometry (this common method has several other names including "train-tracks" and can be seen in activity 1). One tool that I have identified to help students understand the conceptual ideas of stoichiometry are particulate models. A particulate model is a visual model that shows the individual atoms reacting in a chemical equation. A particulate diagram relies on the law of definite proportions and the law of conservation of mass that were described earlier. Essentially, instead of having students write a balanced equation, we can have them draw models that outline what is going on within the chemical reaction.[11] Particulate diagrams also have the ability to check a students understanding with limiting reactants.

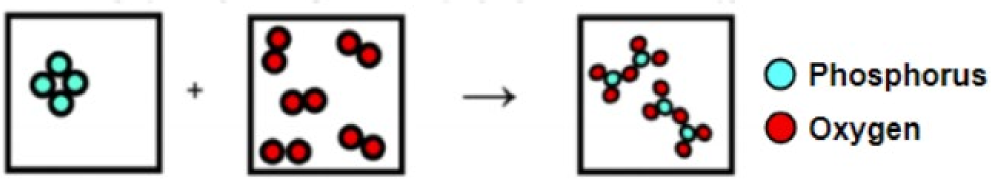


Figure 4: Particulate model example[11]

Using the figure 4, if we instead had two molecules of P_4, we would have a molecule of P_4 left over that should be represented in the products bos (the left side of the arrow is known as the reactants and the right side of the arrow is known as the products). This can help to supplement the what can be difficult mathematical problems by allowing students to convey their understanding in an alternative manner or to support them to grow in their abilities by seeing the relationship in an alternative perspective. Drawing particulate diagrams is a valuable learning exercise, because it can help to exemplify many different chemical phenomena other than stoichiometry. Based on kinetic molecular theory, we know that gases generally maximize space between themselves and completely fill a container. Teachers can also check for misconceptions by having students draw a particulate diagram when the products are mixed phases (solids do not completely fill a container and are tightly compacted, liquids or aqueous species are more spread out compared to solid substances). Particulate diagrams can also be used to qualitatively show the difference in the size of difference chemicals. Particulate diagrams can be used in nearly every unit of study within chemistry.

Learning Experiences

Activity 1) POGIL: Relative Mass and the Mole. This resource is copywritten material, but the resource can be purchased from the POGIL website[9].

Learn: Students will work through the activity with their defined roles. The activity has students work through a series of activities that show students the relationship between mass and moles. Students will check in with the teacher at each stop sign during the activity to make sure they are on the correct pathway to mastery of the content.

Apply: The POGIL activity has 3 extension questions that summarize the ideas developed in the activity in a slightly different manner to see if students can transfer the knowledge from the activity to new situations.

Assess: Given a chemical formula, students should be able to calculate conversions based on mass and representative particles shown in Figure 2. Very quick ways to assess this could be a premade quiz on quizizz.com or quizlet.com, but there are a huge number of resources available on the internet if needed.

Activity 2) Where do these numbers come from? This activity is included in Appendix 3.

Learn: Students will be given a stoichiometry problem that has been solved. Students will identify where the correct numbers came from. There are two versions of this problem a "higher level" and "lower level." The lower level activity gives students hints and can be used before the "higher level" activity or can be used to differentiate student work.

Apply: On whiteboards, students will work in small groups to use this information to complete a stoichiometry problem using this as a guide or students can be provided with additional examples be asked to explain the origin of the numbers.

Assess: Given a chemical equation, students generate their own stoichiometry problem (grams of one substance to grams of another substance is recommended) and an explanation of the origin of each number in their work. Sentence stems can be used if necessary. (Example: Using the labeling system in activity 1 lower level as reference). The number in the first box comes from the question. This number tells your the known quantity. If students need additional examples of solved stoichiometry problems, many solved problems can be found online and used as references.

Activity 3) Intro to particulate models and limiting reactants (Appendix 4)

Learn: Students will be introduced to a particulate model and a balanced equation. In this activity, I want students to identify that the information in both the model and balanced equation are identical, but when we are given different starting amount of reactants, the balanced equation alone is not clear enough to show how a reaction will progress quantitatively.

Apply: Small magnets (or coins) and stickers can be inexpensively used to create particulate models on any magnetic surface. Using these manipulatives, students can generate an appropriate particulate model of an equation given by the teacher.

Assess: Students can be given a particulate diagram of the reactants and products of a chemical equation. Students will have to determine the balanced equation from the particulate diagram. Students should be able to communicate their answers both verbally and written (using models if necessary). A gallery walk or poster presentation could be used to stress to students the importance of both verbal and written information.

Appendix 1: North Carolina Essential Standards

Chm.2.2.3 Analyze the law of conservation of matter and how it applies to various types of chemical equations (synthesis, decomposition, single replacement, double replacement, and combustion).
Chm.2.2.4 Analyze the stoichiometric relationships inherent in a chemical reaction.

Students will convey the process and logic used to solve stoichiometry based problems.

Appendix 2: Teacher resources

The below notes walk students through the three major topics covered in my stoichiometry unit. I typically will give students a copy of the notes after we have covered the topic in class as another support system.

Stoichiometry notes part 1: conversions

1) Molar mass:

Molar mass = #(Mass of $element_1$) + #(Mass of $element_2$) + #(Mass of $element_n$)

Example: **What is the molar mass of $Fe(C_2H_3O_2)_2$**

Molar mass = 1(Fe)+ 4(C) + 6(H) + 4(O)

Molar mass = 1(55.85 g/mol) + 4(12.01 g/mol) + 6(1.008 g/mol) + 4(16.00 g/mol)

Molar mass = *173.94 g/mol*

2) Grams, moles, molar mass

$$Moles = \frac{grams\ (mass)}{molar\ mass}$$

Example: **38.01 grams of $Fe(C_2H_3O_2)_2$ is how many moles?**

$m\square\square\square\square = \frac{38.01\ \square\square\square\square\square}{173.94\ \square/\square\square\square}$ = *0.219 moles $Fe(C_2H_3O_2)_2$*

3) Moles, $6.022\text{x}10^{23}$, particles (atoms, formula units, molecules)

Moles x 6.022E23 = particles OR moles x $6.022\text{x}10^{23}$ = particles

Example: **Convert 45 grams of $Fe(C_2H_3O_2)_2$ to particles**

Use formula 2 to get moles (0.259 moles)

Then use formula 3: 0.259 moles x 6.022E23 = *1.560E23 particles of $Fe(C_2H_3O_2)_2$*

MISC notes

- Use three (3) decimal places for your answers on canvas
- How to put scientific notation on canvas $1.560\text{x}10^{23}$ = 1.560e+23

Stoichiometry notes part 2: empirical and molecular formula

Empirical formula = simplified formula

1) Find the percent of each element in the problem (sometimes is already done)
   Analysis of a compound composed of iron and oxygen yields 174.86 g Fe and 75.12 g O. What is the empirical formula for this compound? The molecular weight of the compound is 319.4 grams/mole.

   % Fe = 174.86 g Fe / (174.86 g Fe + 75.12 g O) x 100% = **69.950% Fe**

   % O = 75.12 g O / (174.86 g Fe + 75.12 g O) x 100% = **30.050% O**

2) Convert the % to grams (assume we have 100g, so the % = grams)

   69.950% Fe = **69.950 grams Fe**

   30.050% O = **30.050 grams O**

3) Convert grams to moles (using moles = grams / molar mass formula)

   Moles Fe = 69.950 grams / 55.85 grams/mole = **1.252 moles Fe**

   Moles O = 30.050 grams / 16.00 grams/mole = **1.878 moles O**

4) Divide all mole amounts by the smallest mole amount

   1.252 moles Fe / 1.252 = 1 mole Fe

   1.878 moles O / 1.252 = 1.5 mole O

   The formula $Fe_1O_{1.5}$ but we know this is incorrect (subscripts). In this case, we would multiple both subscripts by 2 to get $\mathbf{Fe_2O_3}$

5) When solving for the molecular formula, divide the molecular weight by the molar mass of the empirical formula. You should get a whole number, multiply all subscripts by the whole number to get the molecular formula.

   $$\frac{molecular\ formula\ mass}{molecular\ formula\ mass} = \frac{319.4\ grams/mole\ (from\ problem)}{157.9\ grams/mole\ (answer\ from\ 4)} = 2,$$

The answer is $\mathbf{Fe_4O_6}$ (this is ionic and is technically wrong, but used as an example).

Stoichiometry notes part 3: stoichiometry using ratios

Stoichiometry

$NH_4NO_3 \rightarrow N_2O + 2H_2O$

1) Make sure you are starting with moles
2) Using the balanced equation and the information from the question, make a ratio.

$$\frac{\text{From balanced reaction}}{\text{From balanced reaction}} = \frac{\text{From question/unknown}}{\text{From question/unknown}}$$

   a) How do we decide what information to use (see below)?
      i) Ammonium nitrate (NH_4NO_3), an important fertilizer, produces dinitrogen monoxide (N_2O) gas and H_2O when it decomposes. Determine the mass of H_2O produced from the decomposition of 55.0 g of solid NH_4NO_3.
      ii) The question mentions that we are solving for the mass of water (unknown) and that we have 55.0 grams of NH_4NO_3 (known)
         (1) The "from balanced reaction" side of the ratio will look like:

$$\frac{\text{2 moles } H_2O}{\text{1 mole } NH_4NO_3} = \frac{\text{From question/unknown}}{\text{From question/unknown}}$$

      iii) To figure out the units for the from "question/unknown side," we carry over the information from the other side of the ratio

$$\frac{\text{2 moles } H_2O}{\text{1 mole } NH_4NO_3} = \frac{\text{X moles } H_2O}{\text{\_\_ mole } NH_4NO_3}$$

      iv) To figure out the "question/unknown" side of the ratio we need to make sure we are following step 1. Converting 55g to moles, we get 0.687 moles. We fill in this information on the

$$\frac{\text{2 moles } H_2O}{\text{1 mole } NH_4NO_3} = \frac{\text{X moles } H_2O}{\text{0.687 moles } NH_4NO_3}$$

3) Make sure the units your end units are what the question wants.

Here our answer would be 1.374 moles of H_2O, but the question is asking for grams. This makes the answer 24.754 grams of water

Appendix 3: Activity 2) Higher level "where do these numbers come from"

The solution for the problem below is shown, answer the bolded questions that explain how we could get those numbers

$$2AgNO_3 + BaCl_2 \rightarrow 2\ AgCl + Ba(NO_3)_2$$

If 410.8 grams of barium nitrate is produced, how many grams of silver nitrate were reacted?

1. **Where are we getting the following numbers?**

410.8 g $Ba(NO_3)_2$	1 mole $Ba(NO_3)_2$	2 moles $AgNO_3$	169.872 g $AgNO_3$	= 534.1 g $AgNO_3$
	261.335 g $Ba(NO_3)_2$	1 mole $BaCl_2$	1 moles $AgNO_3$	

2. **What do the following ratios mean?**

410.8 g $Ba(NO_3)_2$	1 mole $Ba(NO_3)_2$	2 moles $AgNO_3$	169.872 g $AgNO_3$	= 534.1 g $AgNO_3$
	261.335 g $Ba(NO_3)_2$	1 mole $BaCl_2$	1 moles $AgNO_3$	

Activity 2) Lower level “where do these numbers come from”

The solution for the problem below is shown, answer the bolded questions that explain how we could get those numbers

$2AgNO_3 + BaCl_2 \rightarrow 2\ AgCl + Ba(NO_3)_2$

If 410.8 grams of barium nitrate are produced, how many grams of silver nitrate were reacted?

410.8 g $Ba(NO_3)_2$	1 mole $Ba(NO_3)_2$	2 moles $AgNO_3$	169.872 g $AgNO_3$	= 534.1 g $AgNO_3$	
	261.335 g $Ba(NO_3)_2$	1 mole $BaCl_2$	1 moles AgCl		

1	2	4	6	8	
	3	5	7		

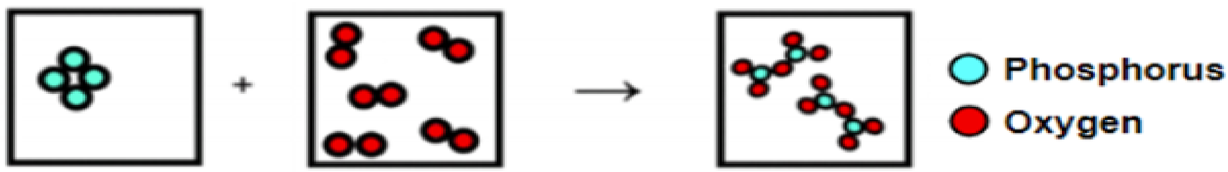
Using the periodic table, show me how we are getting the numbers: 2, 3, 6,7

Using the balanced reaction, walk me through how you get the numbers: 4 and 5

Appendix 4: Activity 3) Intro to particulate models

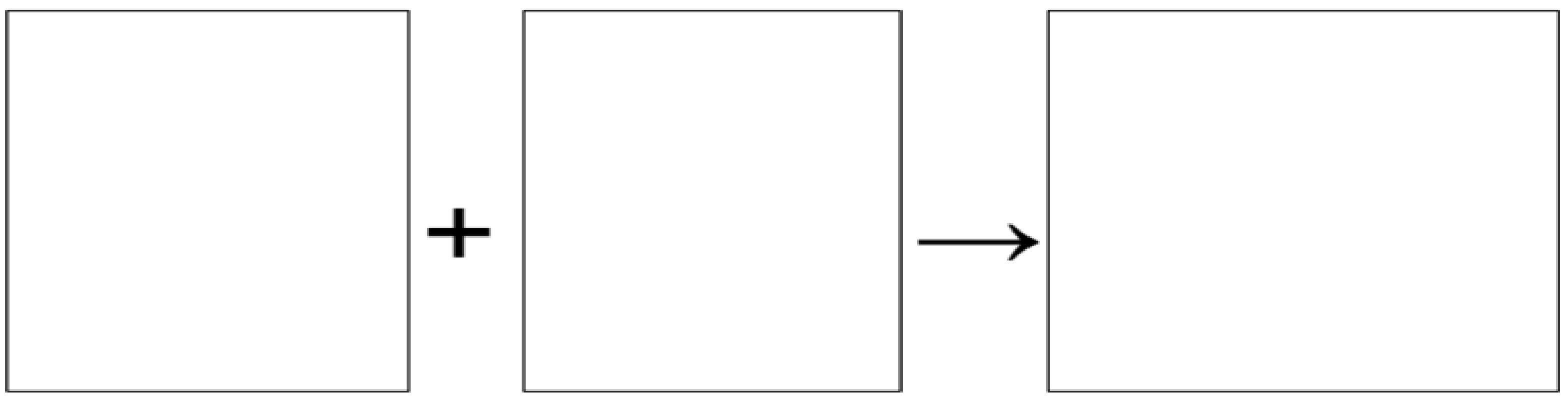
The equation for the synthesis of diphosphorus pentoxide from phosphorus and oxygen can be represented using a **particulate diagram** (shown below)

$$P_{4(g)} + 5O_{2(g)} \rightarrow 2P_2O_{5(g)}$$



1) The above equation and particulate diagram are showing identical information. Provide reasoning to support this statement.

2) If we have **3 moles of phosphorus** and **10 moles of oxygen**, draw a particulate model of what we would observe using means that would allow us to see individual atoms.



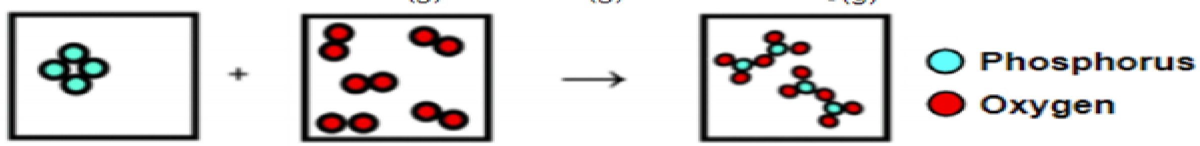
3) Summarize your particulate model:

**Activity is based on the Kimberlin's article referenced in the bibliography.

Activity 3) Answers to "intro to particulate models"

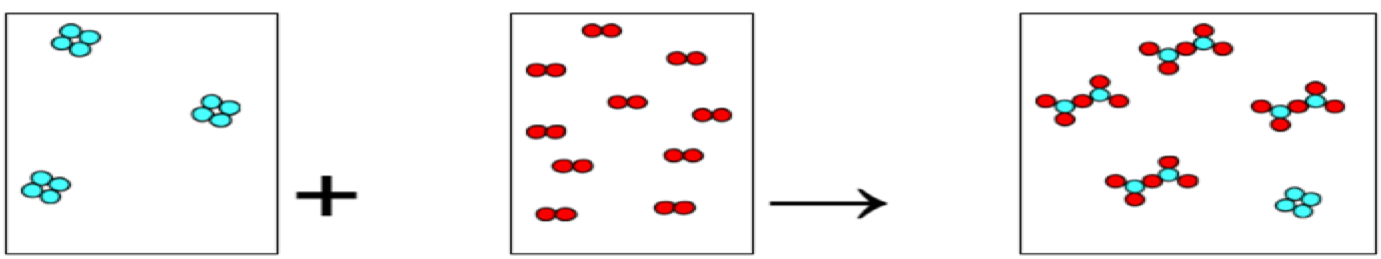
The equation for the synthesis of diphosphorus pentoxide from phosphorus and oxygen can be represented using a **particulate diagram** (shown below)

$$P_{4(g)} + 5O_{2(g)} \longrightarrow 2P_2O_{5(g)}$$



1. The above equation and particulate diagram are showing identical information. Provide reasoning to support this statement. From the balanced equation, we see that one molecule of P_4 and 5 molecules of O_2 react to form two molecules of P_2O_5. The particulate diagram shows this information visually.

2. If we have **3 moles of phosphorus** and **10 moles of oxygen**, draw a particulate model of what we would observe using means that would allow us to see individual atoms. One example of a correct answer is shown below.



3. Summarize your particulate model: In our product box, we have an excess amount of P_4. By definition of the Law of Conservation of Mass, we the amount of reactants and product must be equal. This is the most common student mistake. Other mistakes might include having all the molecules too close to each other. If the students have not covered kinetic molecular theory, they might fail to have this correctly represented in their particulate diagram.

**Activity is based on the Kimberlin's article referenced in the bibliography.

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Endnotes

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