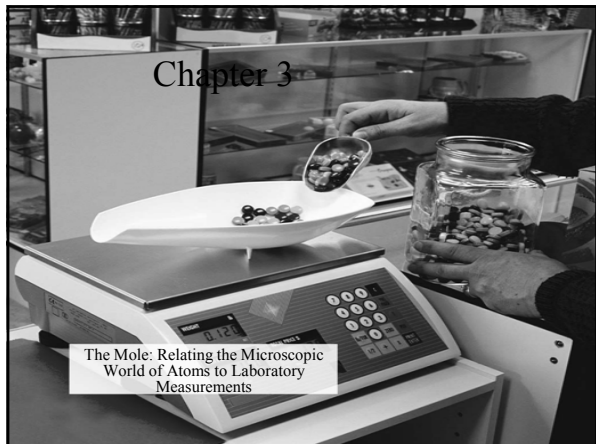
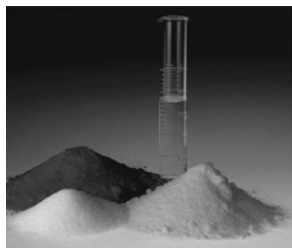


Chapter 3



3.1 The mole conveniently links mass to number of atoms/molecules

- Atoms are very small (as we already know)
- So if you have a sample in your hand, how many atoms or molecules will it be?
- Too many for us to count
- Mole (aka mol): the number of atoms in exactly 12 g of ^{12}C atoms.



2

Atomic, Molecular and Formula Mass

- Atomic mass – the mass of one atom of an element, given in units of “u”
 - 1 atom of C = 12.01 u
 - 1 u = $1.66 \times 10^{-24}\text{g}$

$\frac{12.01\text{u}}{1\text{atom C}} \times \frac{1.66 \times 10^{-24}\text{g}}{1\text{u}} = 1.99 \times 10^{-23}\text{g}/1\text{atom C}$
--

 - How much does 1 atom of C weigh?
 - Where is it found on the periodic table?
- Molecular mass – the sum of all the atomic masses of all the atoms in a compound’s formula.
- Formula mass – the sum of all the atomic masses of all the atoms in an ionic compound, used when referring to ionic compounds.

3

Practice Problems

- What is the molecular mass of
 - $C_9H_8O_4$ (aspirin)

 - $MgSO_4 \cdot 4H_2O$

4

The mole

- Mole – the amount of a substance that contains the same number of formula units as the number of atoms in exactly 12 g of ^{12}C
 - 1 mol = 12 g of ^{12}C
- But how many atoms are there in 12g of ^{12}C ?
- From our previous calculation (slide 3), we know
 - 1 atom of $^{12}C = 1.99 \times 10^{-23}g$
- So, let's do the math...

5

The mole (aka Avogadro's Number)

$$1 \text{ mole} = 6.022136736 \times 10^{23} \text{ atoms}$$

- 1 mole = 6.02×10^{23} "items"
- "items" = molecules, atoms, students, bugs, etc...
- The symbol is $N_A = 6.02 \times 10^{23}$ "items"/mol
- Avogadro's number is a conversion unit.
- You can convert between moles and atoms, molecules, etc...

6

Molar Mass

- Molar mass - the mass (in g) of one mole of any substance.
- Let's look at helium:
 - Atomic mass of He = 4.00 u
 - Molar mass of He = 4.00 g/mol

- 4.00 u He = 1 atom of He
- 4.00 g He = 1 mol of He

7

Moles, grams and unit conversion

- What are the units of molar mass?
- How many units does it have?
- Turns out molar mass is a conversion unit.
- You can use it to convert moles to grams and grams to moles.

8

Practice Problems

- How many grams of silver are in 0.263 mol of Ag?

9

A sample of 45.8 g of $\text{MgSO}_4 \cdot 4\text{H}_2\text{O}$ contains how many moles of $\text{MgSO}_4 \cdot 4\text{H}_2\text{O}$?

10

How many atoms are in 1.00×10^{-9} g of lead?

11

A typical aspirin, $\text{C}_9\text{H}_8\text{O}_4$, tablet contains 0.36g, how many molecules are present?

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3.2 Chemical formulas relate amounts of substances

- Within chemical compounds, moles of atoms always combine in the same ratio as the individual atoms themselves.
- WHAT?????
- First, let's examine a bicycle.
 - What components do you need to make bicycle?
 - For two bikes, how many tires would I need?
 - For a mole of bikes, how many tires would I need?

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Now, the chemical side...

- Let's look at tetraphosphorous decaoxide.
 - What is the formula?
 - How many P and how many O atoms?
 - If I had 1.0 mol P_4O_{10} , how many moles of P and O would I have?
 - If I had 2.5 mol P_4O_{10} , how many moles of P and O would I have?

14

Stoichiometry (my favorite word!)

- The study of the mass relationships in chemical compounds.
- Also, it allows us to relate the masses of reactants and products in a balanced chemical equation.

15

How many moles of nitrogen atoms are in 15 g of N_2O_5 ? (MM of $\text{N}_2\text{O}_5 = 108.010 \text{ g/mol}$)

16

How many moles of sodium ions, Na^+ , are there in 5.63 g of Na_2SO_4 ? (MM of $\text{Na}_2\text{SO}_4 = 142.04 \text{ g/mol}$)

17

How many grams of iron are in a 15.0 g sample of Fe_2O_3 ? (MM of $\text{Fe}_2\text{O}_3 = 159.69 \text{ g/mol}$)

18

Molecular and Empirical Formulas

- **Empirical Formula** – formula in which the atom ratio is the simplest possible



- **Molecular Formula** – the true number of atoms of each kind in a molecule, gives identity of the molecule, obtained by multiplying the empirical formula by a whole number



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Percentage Composition

- The percent (by mass) of an element present in a compound.

$$\frac{\text{mass of element}}{\text{mass of whole samples}} \times 100\%$$

- Problem: A sample of a liquid with a mass of 8.657 g was decomposed into its elements and gave 5.217 g of C, 0.9620 g of H and 2.478 g of O. What is the percentage composition of each element in this compound?

20

3.3 Chemical formulas can be determined from experimental mass measurements

- It is possible to determine empirical formulas from three types of data:
 - (1) Mass data
 - (2) Percentage composition
 - (3) Indirect Analysis – also known as combustion analysis
- Also, it is possible to determine molecular formulas from the empirical formula, if given molar mass.

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(1) Empirical formulas
from mass data

- One of the compounds of iron and oxygen occurs naturally in the mineral magnetite. When a 2.447 g sample was analyzed it was found to have 1.771 g of Fe. Calculate the empirical formula of this compound.
 - Determine grams of each element
 - Convert grams to moles
 - Look at mole ratio

22

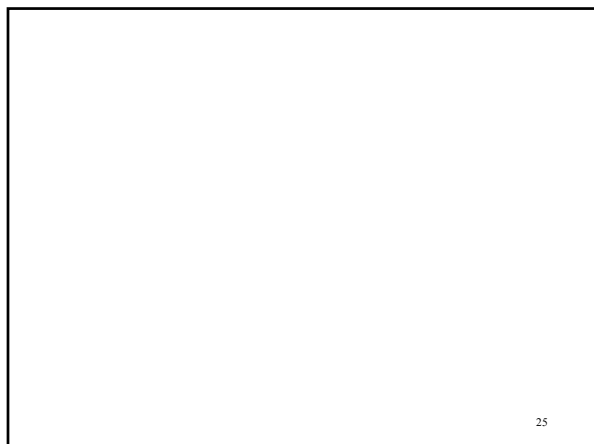
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23

(2) Empirical Formulas mass
percentages

- A white powder used in paints, enamels and ceramics has the following percentage composition: Ba (69.6%), C (6.09%) and O (24.3%). What is the empirical formula?
 - Assume 100 g.
 - Determine grams of each element
 - Convert grams to moles
 - Look at mole ratio

24



25

(3) Empirical formulas from indirect analysis

- A 0.5438 g sample of a liquid containing C, H and O was burned in pure oxygen and 1.039 g of CO₂ and 0.6369 g of H₂O were obtained. What is the empirical formula of the compound?
 - Determine the mass of C and H from the original compound.
 - Determine the mass of oxygen
 - Convert to moles
 - Look at mole ratio

26



27

Molecular Formulas from Empirical Formulas

- Styrene, the raw material for polystyrene foam plastics, has an empirical formula of CH. Its molar mass is 104 g/mol. What is its molecular formula?

- Determine molar mass of empirical formula (MM of EF).
- Look at ratio of MM of MF to MM of EF

$$\frac{\text{MM of MF}}{\text{MM of EF}}$$

28

Blank box for student work.

29

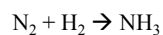
3.4 Chemical Equations link amounts of substances in a reaction

Molecular nitrogen reacts with molecular hydrogen to yield ammonia.

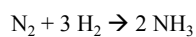
Molecular nitrogen + molecular hydrogen → ammonia

30

- Using the molecular formulas, we are able to express what occurs in the chemical reaction



- We do have one problem; it does not give amounts correctly.
- It is not balanced.
- In chemical reaction, atoms cannot be created or destroyed.*



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Balancing Equations

To balance, we place **counting numbers** in front of the formulas until the equation is balanced.

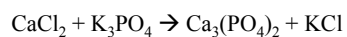
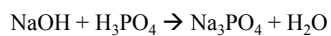
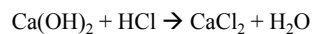
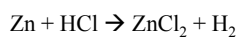
- Balance elements other than H and O first.
- Balance as a group those **polyatomic ions** that appear unchanged on both sides of the arrow.
- Balance separately those elements that appear somewhere by themselves.

As a general rule you should use the smallest whole-number coefficients when writing balanced chemical equations

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Practice Problems



33

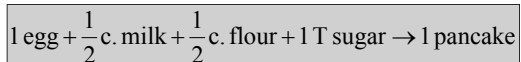
Mole-to-mole relationships

- If you have a balanced equation, you can use it to relate the reactants and products of a chemical reaction.

The key is the coefficients!

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Making a pancake



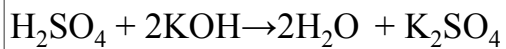
- If I have 2 eggs and an unlimited supply of the rest of the ingredients how many tasty pancakes can I make?
- From practical knowledge, you would say 2 pancakes.
- In chemistry, stoichiometric calculations are based on the mole.

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How to complete MOST chemistry calculations for this class

1. If there is a reaction going on, write down the balanced equation
2. Write down what you know with units.
3. Write down what you are looking for with the desired units.
4. Start with the measurement that only has one unit. Never start at the question marks!
– 15 cm or 25 m/s
5. Use what you know and any unit conversions to get to the correct answer with the desired units.

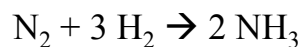
36



How many moles of KOH are required to make 3.0 moles of K_2SO_4 ?

37

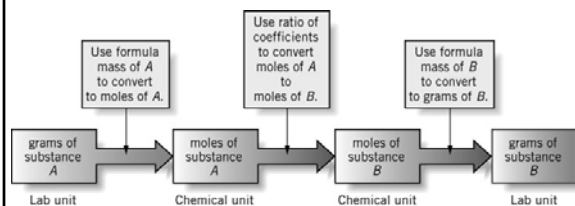
How many grams of hydrogen are needed to produce 68g of ammonia? (MM of $\text{NH}_3 = 12.031 \text{ g/mol}$, MM of $\text{H}_2 = 2.01488 \text{ g/mol}$)



Once your problem is in units of moles, you should think to yourself, "I should be using the balanced equation!"

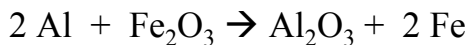
38

Stoichiometry road map



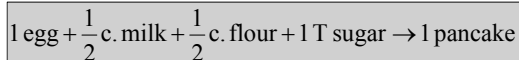
39

One of the most spectacular reactions of aluminum, the thermite reaction, is with iron oxide, Fe_2O_3 , by which metallic iron is made. So much heat is generated that the iron forms in the liquid state. A certain welding operation requires at least 86.0 g of Fe be produced. What is the minimum mass in grams of Fe_2O_3 needed? How much Al_2O_3 is produced? (MM of $\text{Fe}_2\text{O}_3 = 159.489 \text{ g/mol}$, MM of $\text{Al}_2\text{O}_3 = 101.961 \text{ g/mol}$)



40

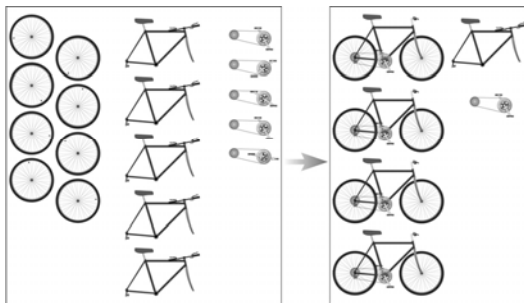
3.5 The reactant in shortest supply limits the amount of product that can form



- Let's return to the tasty pancake example.
- If I have 12 eggs, 1 gallon of milk, 1 cup of flour and 1 lb of sugar, what is my limiting reactant?
- **Limiting reactant** – determines or limits the amount of product formed.

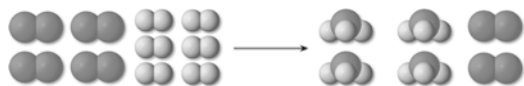
41

And the bicycle example...



42

And the chemical example...



- If we start with six molecules of H_2 and four molecules of N_2 , the six molecules of H_2 will combine with two molecules of N_2 to make four molecules of NH_3
- Two molecules of N_2 will be left over.
- The H_2 is the limiting reactant
- Once again, it is best to work in units of moles.

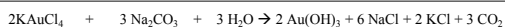
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Determining the LR

1. First, write a balanced equation
2. Start with each reactant and determine how many grams of the product you can make using the balanced reaction.
3. Which ever reactant makes the least amount of product is the limiting reactant.

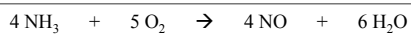
44

Gold(III) hydroxide, $Au(OH)_3$, is used for electroplating gold onto other metals. It can be made by the reaction below. To prepare a fresh supply of $Au(OH)_3$ a chemist at an electroplating plant has mixed 20.00 g of $KAuCl_4$ with 25.00 g of Na_2CO_3 . What is the maximum number of grams of $Au(OH)_3$ that can form? (MM of $KAuCl_4$ = 377.877 g/mol, MM of $Au(OH)_3$ = 247.988 g/mol, MM of Na_2CO_3 = 105.989 g/mol)



45

In an industrial process for making nitric acid, the first step is the reaction of ammonia with oxygen at high temperature in the presence of a platinum glaze. How many grams of nitrogen monoxide can form if a mixture of 30.00 g of NH₃ and 40.00 g of O₂ are taken initially? (MM of NH₃ = 17.031 g/mol, MM of NO = 30.01 g/mol, MM of O₂ = 31.9988 g/mol)



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3.5 Yields of Chemical Reaction

- Theoretical yield – the maximum quantity of a product that can be obtained from a chemical reaction (*in a perfect world*)
- Actual yield – the quantity of a product that is actually obtained from a chemical reaction in the laboratory

$$\text{Percent Yield} = \frac{\text{actual yield}}{\text{theoretical yield}} * 100\%$$

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Reality check...

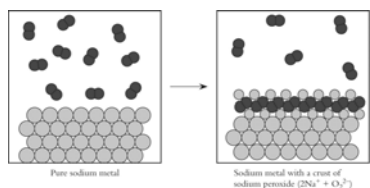
- When you mix the tasty pancakes, do you always make the amount that the box predicts is possible?
- Or, when baking cookies... it says you can make 3 dozen, do you really? Or do you eat some dough?

- The same follows for chemical reactions, except we don't eat any products or reactants.
- Almost always, chemical reactions produce smaller amounts of products than predicted by stoichiometric analysis.

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WHY?

1. Many reactions stop before reaching completion.
2. Competing reactions often consume starting materials.
3. When the product of a reaction is purified and isolated, some of it is inevitably lost during the collection process.



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Practice Problem

- Back to the thermite reaction (slide 40):
 - What is the percentage yield if the actual yield of iron produced is 78.0g?

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