2•Stoichiometry: Chemical Arithmetic
Formula Conventions
(1 of 24)

Superscripts
used to show the charges on ions
Mg^{2+} the 2 means a 2+ charge (lost 2 electrons)

Subscripts
used to show numbers of atoms in a formula unit
H_2SO_4 two H's, one S, and 4 O's

Coefficients
used to show the number of formula units
$2Br^-$ the 2 means two individual bromide ions

Hydrates $CuSO_4 \cdot 5\ H_2O$
some compounds have water molecules included

2•Stoichiometry: Chemical Arithmetic
Stoichiometry Terms
(2 of 24)

stoichiometry	study of the quantitative relationships in chemical formulas and equations.
atomic mass	weighted average mass of an atom, found on the periodic table
formula mass	sum of the atomic masses of the atoms in a formula
molecular mass	sum of the atomic masses of the atoms in a molecular formula
gram molecular mass	molecular mass written in grams
molar mass	same as **gram molecular mass**
empirical formula	formula reduced to lowest terms

2•Stoichiometry: Chemical Arithmetic
Calculating Formula Mass
(3 of 24)

Formula or molecular mass is found by simply summing the atomic masses (on the periodic table) of each atom in a formula.

H_2SO_4
1.01 + 1.01 + 32.06 + 16.0 + 16.0 + 16.0 + 16.0 = 98.08 u
2(1.01) + 32.06 + 4(16.0) = **98.06 u** or **98.06 g/mole**

Generally, round off your answers to the **hundredths** or **tenths** place. Don't round off <u>too</u> much (98.06 g/mol or 98.1 g/mol is OK, but don't round off to 98 g/mol)

Units
Use **u** or **amu** if you are referring to **one atom or molecule**

2•Stoichiometry: Chemical Arithmetic
Mole Facts
(4 of 24)

A **mole** (abbreviated **mol**) is a certain number of things. It is sometimes called the **chemist's dozen**.
A dozen is 12 things, a mole is 6.02×10^{23} things.

Avogadro's Number
1 mole of any substance contains 6.02×10^{23} molecules

Molar Volume (measured at P = 760 mmHg and T = 0 °C)
1 mole of any gas has a volume of 22.4 Liters

Molar Mass (see gram formula mass)

$$\frac{1\ \text{mole}}{6.02 \times 10^{23}\ \text{molecules}} \qquad \frac{1\ \text{mole}}{22.4\ \text{L}} \qquad \frac{1\ \text{mole}}{\text{molar mass}}$$

2•Stoichiometry: Chemical Arithmetic Line Equations (5 of 24)

A **Line Equation** is the preferred way to show conversions between **quantities** (amount, mass, volume, and number) by canceling **units** (moles, grams, liters, and molecules)

The line equation consists of the **Given Value**, the **Desired Unit,** and the **line equation** itself.

Example: What is the mass of 135 Liters of CH_4 (at STP)?

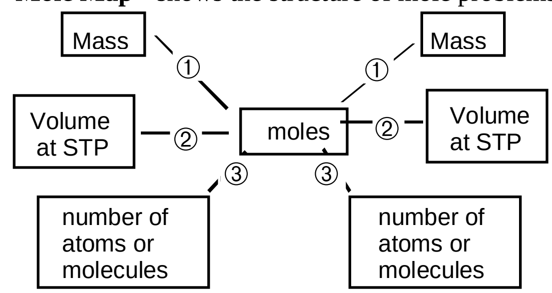
Given: 135 L CH_4

Desired: ? g CH_4

$$135 \text{ L } CH_4 \times \frac{1 \text{ mol } CH_4}{22.4 \text{ L } CH_4} \times \frac{16.0 \text{ g } CH_4}{1 \text{ mol } CH_4} = 96.43 \text{ g } CH_4$$

2•Stoichiometry: Chemical Arithmetic Mole Relationships (6 of 24)

The “**Mole Map**” shows the structure of mole problems



1) $\frac{1 \text{ mol}}{\text{molar mass}}$ 2) $\frac{1 \text{ mol}}{22.4 \text{ L}}$ 3) $\frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ molecules}}$

2•Stoichiometry: Chemical Arithmetic Percentage Composition (by mass) (7 of 24)

Percentage Composition quantifies what portion (by mass) of a substance is made up of each element.

Set up a **fraction**: $\frac{\text{mass of element}}{\text{mass of molecule}}$

Change to **percentage**: $100 \times \frac{\text{mass of element}}{\text{mass of molecule}}$

Generally, round off your answers to the tenth’s place.

The percentage compositions of each element should add up to 100% (or very close, like 99.9% or 100.1%)

2•Stoichiometry: Chemical Arithmetic Formula from % Composition (8 of 24)

Given the **Percentage Composition** of a formula, you can calculate the **empirical formula** of the substance.

Step 1 assume you have **100 g** of substance so the **percentages** become **grams**

Step 2 change **grams** of each element to **moles** of **atoms** of that element

Step 3 set up a formula with the moles example: $C_{2.4}\ H_{4.8}$

Step 4 simplify the formula by dividing moles by the smallest value $C_{\frac{2.4}{2.4}}\ H_{\frac{4.8}{2.4}} = CH_2$

Step 5 If ratio becomes… 1:1.5 multiply by 2 1:1.33 or 1:1.66 multiply by 3

2•Stoichiometry: Chemical Arithmetic
Equation Terms
(9 of 24)

equation	condensed statement of facts about a chemical reaction.
reactants →	substances that exist before a chemical rxn. Written left of arrow.
→ **products**	substances that come into existence as a result of the reaction. Written to the right of the arrow.
word equation	an equation describing a chemical change using the names of the reactants and products.
coefficients	a number preceding atoms, ions, or molecules in balanced chemical equationns that showing relative #'s.

2•Stoichiometry: Chemical Arithmetic
Other Mole Problems and Conversions
(10 of 24)

The **gas density** is often converted to **molar mass**:

Example:
The gas density of a gas is 3.165 g/Liter (at STP). What is the molar mass of the gas?

Knowing that 22.4 L is 1 mole, you can set up the ratio:

$$\frac{3.165\text{ g}}{1\text{ Liter}} = \frac{\text{molar mass}}{22.4\text{ L}}$$

Other **metric conversions** you should know:

$$\frac{1000\text{ mL}}{1\text{ Liter}} \qquad \frac{1\text{ kg}}{1000\text{ grams}}$$

2•Stoichiometry: Chemical Arithmetic
Writing Formula Equations
Things To Remember
(11 of 24)

Example: Write the **formula equation** of...
sodium metal + water → sodium hydroxide + hydrogen gas

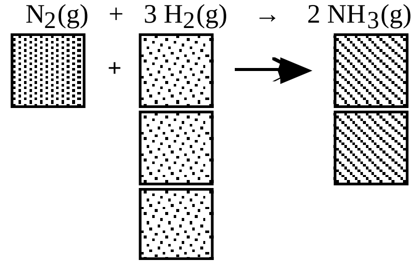
$$Na° + H_2O \rightarrow NaOH + H_2$$

- **metals** often are written with the ° symbol to emphasize that the metal is in the neutral elemental state, not an ion.
- some compounds have **common names** that you should just know... water, H_2O; ammonia, NH_3; methane, CH_4
- remember the seven **diatomic** elements so they can be written as diatomic molecules when they appear in their elemental form. Other elemental substances are written as **single atoms** (e.g. sodium metal or helium gas, He)

2•Stoichiometry: Chemical Arithmetic
Coefficients and Relative Volumes of Gases
(12 of 24)

Since every **gas** takes up the same amount of room (22.4 L for a mole of a gas at STP), the **coefficients** in an equation tell you about the **volumes** of gas involved.

Example: $N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$



2•Stoichiometry: Chemical Arithmetic
Heart of the Problem
(13 of 24)

The "heart of the problem" conversion factor relates the Given and the Desired compounds using the coefficients from the balanced equation.

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

$$\heartsuit \text{ could be } \frac{3 \text{ moles } H_2}{2 \text{ moles } NH_3}$$

…which means that every time 2 moles of NH_3 is formed, 3 moles of H_2 must react.

The format is always, $\frac{\text{moles of } \textbf{Desired}}{\text{moles of } \textbf{Given}}$

2•Stoichiometry: Chemical Arithmetic
Mass-Mass Problems
Mass-Volume Problems
(14 of 24)

Mass-Mass problems are probably the most common type of problem. The Given and Desired are both masses (grams or kg).

The pattern is:

Given x molar mass of Given x ♥ x molar mass of Desired

In **Mass-Volume problems**, one of the molar masses is replaced with $\frac{22.4 \text{ L}}{1 \text{ mole}}$ depending on whether the Given or the Desired is Liters.

2•Stoichiometry: Chemical Arithmetic
Mass-Volume-Particle Problems
(15 of 24)

If the Given or Desired is **molecules**, then the **Avogadro's Number** conversion factor, $\frac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mole}}$ is used and the problem is a Mass-Particle or Volume-Particle problem.

The **units** of the Given and Desired will guide you as to which conversion factor to use:

Mass	grams or kg
Volume	Liters or mL
Particles	molecules or atoms

2•Stoichiometry: Chemical Arithmetic
Limiting Reactant Problems
(16 of 24)

In a problem with **two Given values,** one of the Given's will limit how much product you can make. This is called the **limiting reactant.** The other reactant is said to be **in excess.**

Solve the problem **twice** using each Given… the reactant that results in the **smaller** amount of product is the **limiting reactant** and the **smaller** answer is the **true** answer.

Example: $N_2 + 3\,H_2 \rightarrow 2\,NH_3$
When **28.0 grams of N_2** reacts with **8.00 grams of H_2,** what mass of NH_3 is produced?

(in this case, the N_2 is the limiting reactant)

2•Stoichiometry: Chemical Arithmetic
How Much Excess Reactant is Left Over
(17 of 24)

Example: $N_2 + 3 H_2 \rightarrow 2 NH_3$

When **28.0 grams of N_2** reacts with **8.00 grams of H_2,** what mass of NH_3 is produced?

(in this case, the N_2 is the limiting reactant)

To find out how much H_2 is left over, do another line equation:

Given: 28.0 g N_2

Desired: ? g H_2

subtract the answer of this problem from 8.00 g H_2

2•Stoichiometry: Chemical Arithmetic
Limiting Reactants
(18 of 24)

It is difficult to simply **guess** which reactant is the limiting reactant because it depends on **two** things:

(1) the molar mass of the reactant and

(2) the coefficients in the balanced equation

The smaller mass is **not** always the limiting reactant.

Example: $N_2 + 3 H_2 \rightarrow 2 NH_3$

1 mole (28 g N_2) will **just react** with 3 moles (6.06 g H_2) so, if we react 28.0 g N_2 with 8.0 g H_2, only 6.06 g H_2 will be used up and 1.94 g of H_2 will be left over.

In this case, N_2 is the L.R. and H_2 is in X.S.

2•Stoichiometry: Chemical Arithmetic
Theoretical Yield and Percentage Yield
(19 of 24)

The answer you calculate from a stoichiometry problem can be called the **Theoretical Yield**. Theoretically, you should get this amount of product.

In reality, you often get less than the theoretical amount due to products turning back to reactants or side reactions. The amount you actually get is called the **Actual Yield**.

$$\textbf{Percentage Yield} = \frac{\textbf{Actual Yield}}{\textbf{Theoretical Yield}} \textbf{ x 100}$$

2•Stoichiometry: Chemical Arithmetic
Balancing Chemical Equations
(20 of 24)

The balanced equation represents what actually occurs during a chemical reaction. Since atoms are not created or destroyed during a normal chemical reaction, the number and kinds of atoms must agree on the left and right sides of the arrows.

$$\_\_Na_2CO_3 + \_\_HCl \rightarrow \_\_ NaCl + \_\_H_2O + \_\_CO_2$$

To balance the equation, you are only allowed to change the **coefficients** in front of the substances... not change the formulas of the substances themselves.

Reduce the coefficients to the lowest terms.

Fractions may be used in front of diatomic elements.

2•Stoichiometry: Chemical Arithmetic
Combustion Equations
(21 of 24)

The burning of fuels made of C, H, and O is called **combustion**. You need to memorize O_2, CO_2 and H_2O

Example: The combustion of propane, C_3H_8, is written:

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

Be careful when writing equations for **alcohols**, such as butanol, C_4H_9OH

- don't forget to add the H's (a total of 10 of them)
- don't forget to take account of the O atom in the alcohol

$$C_4H_9OH + 6O_2 \rightarrow 4CO_2 + 5H_2O$$

2•Stoichiometry: Chemical Arithmetic
Solutions -- Molar Concentration
(22 of 24)

Many reactions are carried out in solution. Solutions are convenient and speed up many reactions.

Concentration is often expressed as

$$\text{Molarity } (\underline{M}) = \frac{\text{moles of solute}}{\text{Liters of solution}}$$

You can **calculate** the molarity of a solution when given moles (or grams) of a substance and its volume.

You can **use** the molarity of a solution as a <u>conversion</u> <u>factor</u>

$$0.150\ \underline{M}\ \text{HCl} \approx \frac{0.150 \text{ moles HCl}}{1 \text{ Liter HCl}} \text{ or } \frac{1 \text{ Liter HCl}}{0.150 \text{ moles HCl}}$$

to convert moles to Liters and vice versa.

Volumetric flasks are used to make solutions.

2•Stoichiometry: Chemical Arithmetic
Dilution Problems
(23 of 24)

You can calculate the moles of a solute using the volume and molarity of the substance. Since diluting a solution adds water and no solute, the moles of solute before and after the dilution remains constant. So...

$$V_i \cdot \underline{M}_i = V_f \cdot \underline{M}_f$$

where "I" means "initial" and "f" means "final"

The units of volume or concentration do not really matter as long as they <u>match</u> on the two sides of the equation.

2•Stoichiometry: Chemical Arithmetic
Acid-Base Titrations
(24 of 24)

Acids form the H^+ ion. Bases form the OH^- ion.

Acids + bases mix to form H_2O (HOH) and a salt.

The moles of H^+ = the moles of OH^- in a neutralization.

An acid-base titration is the technique of carefully neutralizing an acid with a base and measuring the volumes used. An indicator (we used phenolphthalein) allows us to observe when the endpoint is reached.

If a monoprotic acid is neutralized with a base that only has one OH^- ion per formula unit, the simple formula:

$$V_a \cdot \underline{M}_a = V_b \cdot \underline{M}_b$$

allows you to determine the molarity of the unknown.