



# CHAPTER 4

## Quantities of Reactants and Products

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### Objectives

You will be able to do the following.

1. Write a description of the information given by a chemical equation.
2. Write or identify the symbols used in chemical equations to describe solid, liquid, gas and aqueous.
3. Balance chemical equations.
4. Given a balanced chemical equation (or enough information to get one), convert from mass of one reactant or product to mass of any other reactant or product.
5. Write an explanation for why an excess of one or more of the reactants are added in a chemical reaction and explain why other reactants are limiting.
6. Given the mass of two or more reactants, calculate the maximum mass of product that could form from the reaction between them.
7. Explain why the actual yield in a chemical reaction is less than the theoretical yield.
8. Given an actual yield and a theoretical yield (or enough information to calculate a theoretical yield) for a chemical reaction, calculate the percent yield for the reaction.
8. Given a chemical equation for a reaction (or enough information to write one) and a value that describes the percentage of one of the reactants or products in a mixture, convert between mass of the mixture and mass of any one of the reactants or products in the reaction.
10. Write or identify descriptions of combination, decomposition, combustion, displacement (or single displacement), and exchange (or double displacement) reactions.
11. Write chemical equations for combustion reactions of compounds that contain carbon, hydrogen, sulfur, and/or oxygen.
12. Given a chemical equation, identify it as representing a combination, decomposition, combustion, displacement (or single displacement), and exchange (or double displacement) reaction.
13. Convert between the definition and the term for the following words or phrases.

Skip section 4.7 of the text.

## Chapter 4 Glossary

**Chemical reaction or chemical change** The conversion of one or more pure substances into one or more different pure substances.

**Reactants** The substances that change in a chemical reaction. Their formulas are on the left side of the arrow in a chemical equation.

**Products** The substances that form in a chemical reaction. Their formulas are on the right side of the arrow in a chemical equation.

**Coefficients** The numbers in front of chemical formulas in a balanced chemical equation.

**Equation stoichiometry** Calculations that make use of the quantitative relationships between the substances in a chemical reaction to convert the amount of one substance in the chemical reaction to the amount of a different substance in the reaction.

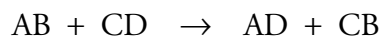
**Limiting reactant** The reactant that runs out first and limits the amount of product that can form.

**Theoretical yield** The calculated maximum amount of product that can form in a chemical reaction.

**Actual yield** The amount of product that is actually obtained in a chemical reaction.

**Percent yield** The actual yield divided by the theoretical yield times 100.

**Double-displacement reaction (exchange)** A chemical reaction that has the following form



**Combination or synthesis reaction** The joining of two or more elements or compounds into one product.

**Decomposition reaction** The conversion of one compound into two or more simpler substances.

**Combustion reaction** Rapid oxidation accompanied by heat and usually light.

**Single-displacement reaction (displacement)** Chemical change in which atoms of one element displace (or replace) atoms of another element in a compound.

TIP-OFF You are asked to balance a chemical equation.

#### GENERAL STEPS

- Consider the first element listed in the first formula in the equation.  
If this element is mentioned in two or more formulas on the same side of the arrow, skip it until after the other elements are balanced.  
If this element is mentioned in one formula on each side of the arrow, balance it by placing coefficients in front of one or both of these formulas.
- Moving from left to right, repeat the process for each element.
- When you place a number in front of a formula that contains an element you tried to balance previously, recheck that element and put its atoms back in balance.
- Continue this process until the number of atoms of each element is balanced.

The following strategies can be helpful for balancing certain equations.

**STRATEGY 1** Often, an element can be balanced by using the subscript for this element on the left side of the arrow as the coefficient in front of the formula containing this element on the right side of the arrow and vice versa (using the subscript of this element on the right side of the arrow as the coefficient in front of the formula containing this element on the left side).

**STRATEGY 2** It is sometimes easiest, as a temporary measure, to balance the pure nonmetallic elements ( $\text{H}_2$ ,  $\text{O}_2$ ,  $\text{N}_2$ ,  $\text{F}_2$ ,  $\text{Cl}_2$ ,  $\text{Br}_2$ ,  $\text{I}_2$ ,  $\text{S}_8$ ,  $\text{Se}_8$ , and  $\text{P}_4$ ) with a fractional coefficient ( $\frac{1}{2}$ ,  $\frac{3}{2}$ ,  $\frac{5}{2}$ , etc.). If you do use a fraction during the balancing process, you can eliminate it later by multiplying each coefficient in the equation by the fraction's denominator (usually the number 2).

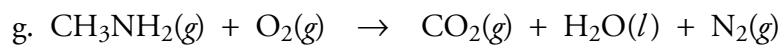
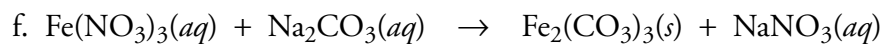
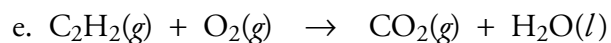
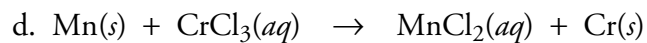
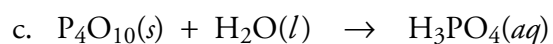
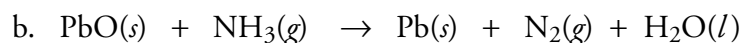
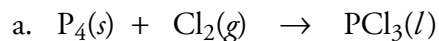
**STRATEGY 3** If polyatomic ions do not change in the reaction, and therefore appear in the same form on both sides of the chemical equation, they can be balanced as if they were single atoms.

**STRATEGY 4** If you find an element difficult to balance, leave it for later.

## Sample Study Sheet 4.1: Balancing Chemical Equations

## EXERCISE 4.1 - Balancing Chemical Equations

Balance the following chemical equations.



**TIP-OFF** - The calculation calls for you to convert from an amount of one substance in a given chemical reaction to the corresponding amount of another substance participating in the same reaction.

**GENERAL STEPS** – Use a unit analysis format. Set it up around a mole-to-mole conversion in which the coefficients from a balanced equation are used to generate a mole ratio. The general steps are

1. If you are not given it, write and balance the chemical equation for the reaction.
2. Start your unit analysis in the usual way. You want to calculate amount of substance 2, so you set that unknown equal to the given amount of substance 1. (In this section, the given units will be mass of an element or compound.)
3. If you are given a unit of mass other than grams for substance 1, convert from the unit that you are given to grams. This may require one or more conversion factors.
4. Convert from grams of substance 1 to moles of substance 1, using the substance's molar mass.
5. Convert from moles of substance 1 to moles of substance 2 using their coefficients from the balanced equation to create a molar ratio to use as a conversion factor.
6. Convert from moles of substance 2 to grams of substance 2, using the substance's molar mass.
7. If necessary, convert from grams of substance 2 to the desired unit for substance 2. This may require one or more conversion factors.
8. Calculate your answer and report it with the correct significant figures (in scientific notation, if necessary) and unit.

The general form of the unit analysis setup is:

$$? \text{ (unit) } 2 = (\text{given}) \text{ (unit) } 1 \left( \frac{\text{--- g}}{\text{--- (unit)}} \right) \left( \frac{1 \text{ mol } 1}{(\text{formula mass}) \text{ g } 1} \right) \left( \frac{(\text{coef. } 2) \text{ mol } 2}{(\text{coef. } 1) \text{ mol } 1} \right) \left( \frac{(\text{formula mass}) \text{ g } 2}{1 \text{ mol } 2} \right) \left( \frac{\text{--- (unit)}}{\text{--- g}} \right)$$

**Sample Study Sheet 4.2:**  
**Basic Equation Stoichiometry, Converting Mass of One Substance in a Reaction to Mass of Another**

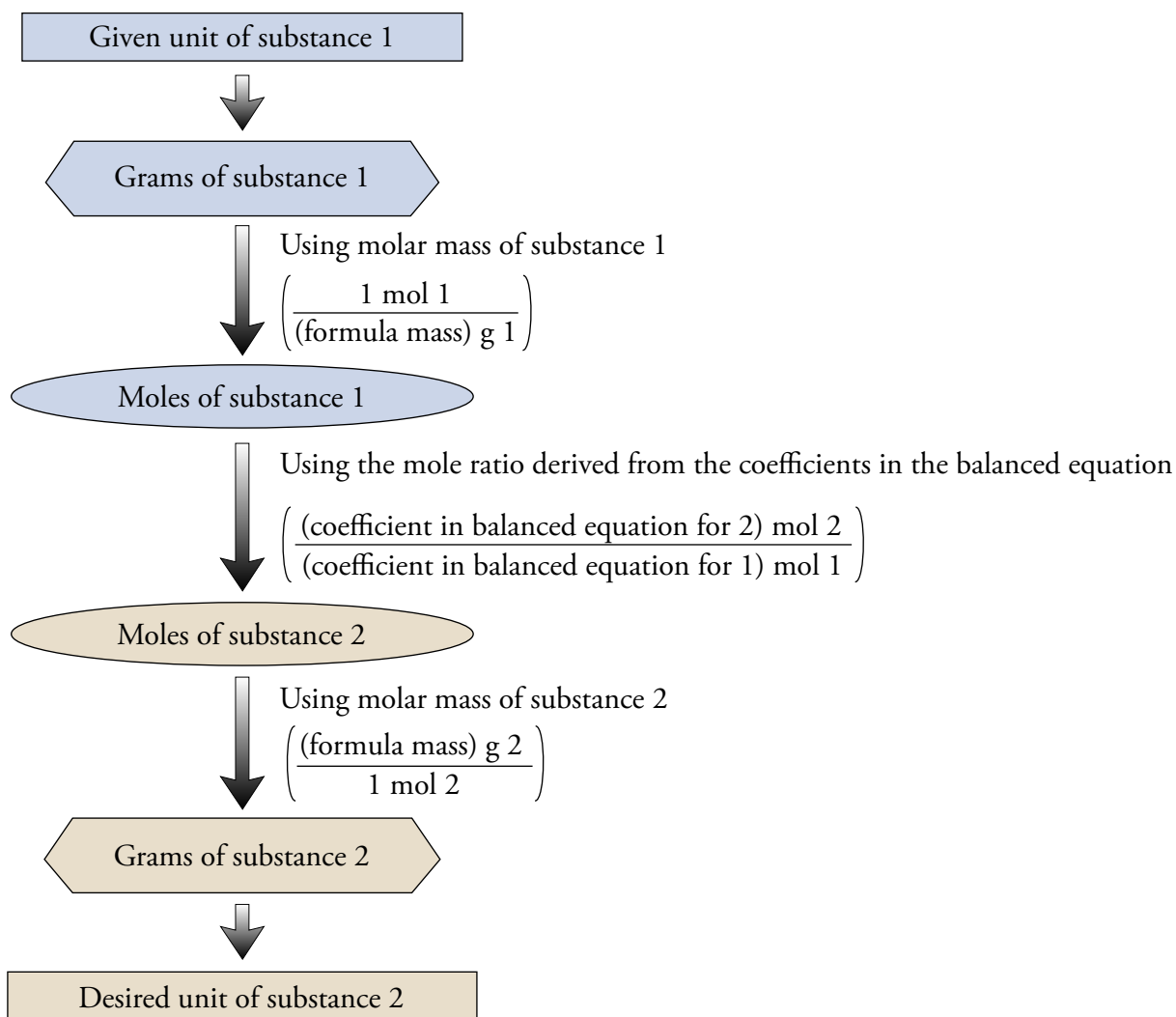


Figure 4.1  
Summary of Steps for Mass-Mass  
Equation Stoichiometry Problems

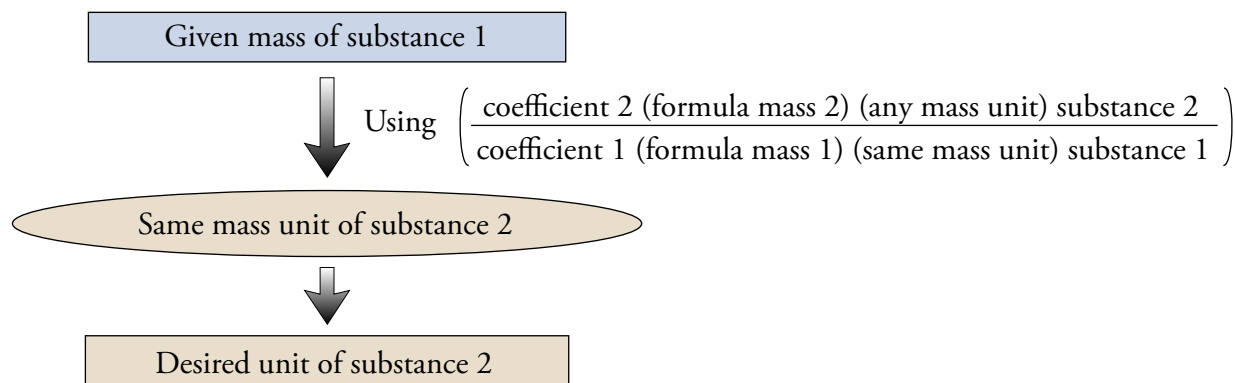


Figure 4.2  
Shortcut for Mass-Mass Equation  
Stoichiometry Problems

**SHORTCUT STEPS** - If the mass unit desired for substance 2 is the same mass unit given for substance 1, the general steps described above can be condensed into a shortcut.

1. If you are not given it, write and balance the chemical equation for the reaction.
2. Start your unit analysis set-up in the usual way. (See step 2 above.)
3. Convert directly from the mass units of substance 1 that you have been given directly to the same mass units of substance 2, using a conversion factor having the following general form.

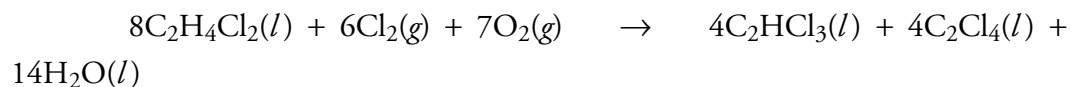
$$? \text{ (unit) } 2 = \text{ (given) (unit) } 1 \left( \frac{\text{coefficient 2 (formula mass 2) (any mass unit) substance 2}}{\text{coefficient 1 (formula mass 1) (any mass unit) substance 1}} \right)$$

4. Calculate your answer and report it with the correct significant figures, in scientific notation if necessary, and with the correct unit.

**Sample Study Sheet 4.3:**  
**Basic Equation Stoichiometry Shortcut**

## EXERCISE 4.2 - Mass-Mass Equation Stoichiometry

Tetrachloroethene,  $C_2Cl_4$ , is a colorless liquid used in dry cleaning. Tetrachloroethene is often called perchloroethylene (perc). It can be formed in several steps from the reaction of dichloroethane, chlorine gas, and oxygen gas. The equation for the net reaction is below.



- a. Write fifteen different conversion factors that relate moles of one reactant or product to moles of another reactant or product.
- b. What is the maximum mass of perchloroethylene,  $C_2Cl_4$ , that can be formed from 23.75 megagrams of dichloroethane,  $C_2H_4Cl_2$ ?
- c. What is the maximum mass in tons of trichloroethene,  $C_2HCl_3$ , formed with perchloroethylene,  $C_2Cl_4$ , in the reaction of 23.75 megagrams of dichloroethylene,  $C_2H_4Cl_2$ ? (Remember that we assume that a ton is an English short ton unless we are told otherwise.)

## Sample Study Sheet 4.4:

### Limiting Reactant Problems

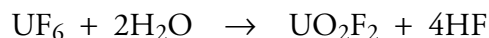
**TIP-OFF** - Given two or more amounts of reactants in a chemical reaction, you are asked to calculate the maximum amount of product that they can form.

#### GENERAL PROCEDURE

- Do separate calculations of the maximum amount of product that can form from each reactant. (These calculations are equation stoichiometry problems, so you can use the procedure described on the previous study sheets for each calculation.)
- The smallest of the values calculated in the step above is your answer. It is the maximum amount of product that can be formed from the given amounts of reactants.

### EXERCISE 4.3 - Limiting Reactants

Uranium(IV) oxide,  $\text{UO}_2$ , is used as fuel in nuclear power plants. The percentage of the fissionable isotope uranium-235 in the  $\text{UO}_2$  used as fuel needs to be higher than that found in nature. To make fuel grade  $\text{UO}_2$ , uranium oxides are first converted to uranium hexafluoride,  $\text{UF}_6$ , which can be enriched in the fissionable isotope of uranium by gas diffusion. The  $\text{UF}_6$  is then converted to  $\text{UO}_2$  in a series of steps. The chemical equation for the first of these steps is below.



- What is the maximum mass in pounds of  $\text{UO}_2\text{F}_2$  that can be formed from the reaction of 24.543 lb  $\text{UF}_6$  with 8.0 lb of water?
- Why do you think the reactant in excess was chosen to be in excess?

Because substances are often found in mixtures, equation stoichiometry problems often include conversions between masses of pure substances and masses of mixtures containing the pure substances, using percentages as conversion factors. To see calculations like these, visit the web address below:

[www.mpcfacyty.net/mark\\_bishop/mixture\\_stoichiometry.htm](http://www.mpcfacyty.net/mark_bishop/mixture_stoichiometry.htm)



## Sample Study Sheet 4.5: Writing Equations for Combustion Reactions

**TIP-OFF** You are asked to write an equation for the complete combustion of a substance composed of one or more of the elements carbon, hydrogen, oxygen, and sulfur.

### GENERAL STEPS

**STEP 1** Write the formula for the substance combusted.

**STEP 2** Write  $\text{O}_2(g)$  for the second reactant.

**STEP 3** Predict the products using the following guidelines.

If the compound contains carbon, one product will be  $\text{CO}_2(g)$ .

If the compound contains hydrogen, one product will be  $\text{H}_2\text{O}(l)$ .

*(Even though water may be gaseous when it is first formed in a combustion reaction, we usually describe it as a liquid in the equation. By convention, we describe the state of each reactant and product as their state at room temperature and pressure. When water returns to room temperature, it is a liquid.)*

If the compound contains sulfur, one product will be  $\text{SO}_2(g)$ .

Any oxygen in the combusted substance would be distributed among the products already mentioned.

**STEP 4** Balance the equation.

## EXERCISE 4.6 - Writing Combustion Equations

Write balanced equations for the complete combustion of (a)  $\text{C}_4\text{H}_{10}(g)$ , (b)  $\text{C}_3\text{H}_7\text{OH}(l)$ , and (c)  $\text{C}_4\text{H}_9\text{SH}(l)$ .

## EXERCISE 4.7 - Classification of Chemical Reactions

Classify each of these reactions with respect to the following categories: combination reaction, decomposition reaction, combustion reaction, and single-displacement reaction.

