Chapter 1

1. Chapter 1: The Chemical World
   2. 1.1: The Scope of Chemistry
   3. 1.2: Chemicals Compose Ordinary Things
   4. 1.3: Hypothesis, Theories, and Laws
   5. 1.4: The Scientific Method: How Chemists Think
   6. 1.5: A Beginning Chemist: How to Succeed

• Chapter 2

1. Chapter 2: Measurement and Problem Solving
   2. 2.1: Taking Measurements
   3. 2.2: Scientific Notation: Writing Large and Small Numbers
   4. 2.3: Significant Figures: Writing Numbers to Reflect Precision
   5. 2.4: Significant Figures in Calculations
   6. 2.5: The Basic Units of Measurement
   7. 2.6: Problem Solving and Unit Conversions
   8. 2.7: Solving Multistep Conversion Problems
   9. 2.8: Units Raised to a Power
   10. 2.9: Density
   11. 2.10: Numerical Problem-Solving Strategies and the Solution Map
   12. 2.E: Measurement and Problem Solving (Exercises)

• Chapter 3

1. Chapter 3: Matter and Energy
   2. 3.1: In Your Room
   3. 3.2: What is Matter?
   4. 3.3: Classifying Matter According to Its State: Solid, Liquid, and Gas
   5. 3.4: Classifying Matter According to Its Composition
   6. 3.5: Differences in Matter: Physical and Chemical Properties
   7. 3.6: Changes in Matter: Physical and Chemical Changes
   8. 3.7: Conservation of Mass: There is No New Matter
   9. 3.8: Energy
   10. 3.9: Energy and Chemical and Physical Change
   11. 3.10: Temperature: Random Motion of Molecules and Atoms
   12. 3.11: Temperature Changes: Heat Capacity
   13. 3.12: Energy and Heat Capacity Calculations
   14. 3.E: Exercises
1. Chapter 7: Chemical Reactions
   2. 7.1: Grade School Volcanoes, Automobiles, and Laundry Detergents
   3. 7.2: Evidence of a Chemical Reaction
   4. 7.3: The Chemical Equation
   5. 7.4: How to Write Balanced Chemical Equations
   6. 7.5: Aqueous Solutions and Solubility: Compounds Dissolved in Water
   7. 7.6: Precipitation Reactions: Reactions in Aqueous Solution That Form a Solid
   8. 7.7: Writing Chemical Equations for Reactions in Solution: Molecular, Complete Ionic, and Net Ionic Equations
   9. 7.8: Acid–Base and Gas Evolution Reactions
   10. 7.9: Oxidation–Reduction Reactions
   11. 7.10: Classifying Chemical Reactions
   12. 7.11: The Activity Series

   • Chapter 8

   1. Chapter 8: Quantities in Chemical Reactions
   2. 8.1: Climate Change: Too Much Carbon Dioxide
   3. 8.2: Stoichiometry
   4. 8.3: Making Molecules: Mole-to-Mole Conversions
   5. 8.4: Making Molecules: Mass-to-Mass Conversions
   6. 8.5: Limiting Reactant, Theoretical Yield, and Percent Yield
   7. 8.6: Limiting Reactant, Theoretical Yield, and Percent Yield from Initial Masses of Reactants
   8. 8.7: Enthalpy: A Measure of the Heat Evolved or Absorbed in a Reaction

   Chapter 9

   1. Chapter 9: Electrons in Atoms and the Periodic Table
   2. 9.1: Blimps, Balloons, and Models of the Atom
   3. 9.2: Light: Electromagnetic Radiation
   4. 9.3: The Electromagnetic Spectrum
   5. 9.4: The Bohr Model: Atoms with Orbits
   6. 9.5: The Quantum-Mechanical Model: Atoms with Orbitals
   7. 9.6: Quantum-Mechanical Orbitals and Electron Configurations
   8. 9.7: Electron Configurations and the Periodic Table
   9. 9.8: The Explanatory Power of the Quantum-Mechanical Model
   10. 9.9: Periodic Trends: Atomic Size, Ionization Energy, and Metallic Character

   • Chapter 10

   1. Chapter 10: Chemical Bonding
   2. 10.1: Bonding Models and AIDS Drugs
   3. 10.2: Representing Valence Electrons with Dots
Learning Objectives

• Convert from mass or moles of one substance to mass or moles of another substance in a chemical reaction.

Mole to Mass Conversions

We have established that a balanced chemical equation is balanced in terms of moles as well as atoms or molecules. We have used balanced equations to set up ratios, now in terms of moles of materials, that we can use as conversion factors to answer stoichiometric questions, such as how many moles of substance A react with so many moles of reactant B. We can extend this technique even further. Recall that we can relate a molar amount to a mass amount using molar mass. We can use that ability to answer stoichiometry questions in terms of the masses of a particular substance, in addition to moles. We do this using the following sequence:
Collectively, these conversions are called mole-mass calculations.

As an example, consider the balanced chemical equation

\[ \text{Fe}_2\text{O}_3 + 3\text{SO}_3 \rightarrow \text{Fe}_2(\text{SO}_4)_3 \] \(\text{Eq1}\)

If we have 3.59 mol of Fe\textsubscript{2}O\textsubscript{3}, how many grams of SO\textsubscript{3} can react with it? Using the mole-mass calculation sequence, we can determine the required mass of SO\textsubscript{3} in two steps. First, we construct the appropriate molar ratio, determined from the balanced chemical equation, to calculate the number of moles of SO\textsubscript{3} needed. Then using the molar mass of SO\textsubscript{3} as a conversion factor, we determine the mass that this number of moles of SO\textsubscript{3} has.

As usual, we start with the quantity we were given:

\[ \text{3.59} \times \cancel{\text{mol}\text{Fe}_2\text{O}_3} \times \left( \frac{3\text{mol}\text{SO}_3}{1\cancel{\text{mol}\text{Fe}_2\text{O}_3}} \right) = 10.77\text{mol}\text{SO}_3 \] \(\text{Eq2}\)

The mol Fe\textsubscript{2}O\textsubscript{3} units cancel, leaving mol SO\textsubscript{3} unit. Now, we take this answer and convert it to grams of SO\textsubscript{3}, using the molar mass of SO\textsubscript{3} as the conversion factor:

\[ 10.77 \times \cancel{\text{mol}\text{SO}_3} \times \left( \frac{80.06\text{g}}{1\cancel{\text{mol}\text{SO}_3}} \right) = 862\text{g}\text{SO}_3 \] \(\text{Eq3}\)

Our final answer is expressed to three significant figures. Thus, in a two-step process, we find that 862 g of SO\textsubscript{3} will react with 3.59 mol of Fe\textsubscript{2}O\textsubscript{3}. Many problems of this type can be answered in this manner.
The same two-step problem can also be worked out in a single line, rather than as two separate steps, as follows:

\[
3.59 \text{ mol Fe}_2\text{O}_3 \times \left( \frac{3 \text{ mol SO}_3}{1 \text{ mol Fe}_2\text{O}_3} \right) \times \left( \frac{80.06 \text{ g SO}_3}{1 \text{ mol SO}_3} \right) = 862 \text{ g SO}_3
\]

We get exactly the same answer when combining all the math steps together as we do when we calculate one step at a time.

Example (PageIndex{1}): Generation of Aluminum Oxide

How many moles of HCl will be produced when 249 g of AlCl\textsubscript{3} are reacted according to this chemical equation?

\[
2\text{AlCl}_3 + 3\text{H}_2\text{O}(l) \rightarrow \text{Al}_2\text{O}_3 + 6\text{HCl}(g)
\]

**Solution**

**Steps for Problem Solving**

Identify the "given" information and what the problem is asking you to "find."

- Given: 249 g AlCl\textsubscript{3}
- Find: moles HCl

List other known quantities

- 1 mol AlCl\textsubscript{3} = 133.33 g/mol
- 6 mol of HCl to 2 mol AlCl\textsubscript{3}

Prepare a concept map and use the proper conversion factor.

\[
\begin{align*}
\text{g AlCl}_3 & \rightarrow \text{mol AlCl}_3 \\
\frac{1 \text{ mol AlCl}_3}{133.33 \text{ g AlCl}_3} & \rightarrow \frac{6 \text{ mol HCl}}{2 \text{ mol AlCl}_3}
\end{align*}
\]

Cancel units and calculate.

\[
(249 \text{ g AlCl}_3) \times \left( \frac{1 \text{ mol AlCl}_3}{133.33 \text{ g AlCl}_3} \right) \times \left( \frac{6 \text{ mol HCl}}{2 \text{ mol AlCl}_3} \right) = 5.60 \text{ mol HCl}
\]

Think about your result.

Since 249 g of AlCl\textsubscript{3} is less than 266.66 g, the mass for 2 moles of AlCl\textsubscript{3} and the relationship is 6 mol of HCl to 2 mol AlCl\textsubscript{3}, the answer should be less than 6 moles of HCl.

**Exercise (PageIndex{1}): Generation of Aluminum Oxide**

How many moles of Al\textsubscript{2}O\textsubscript{3} will be produced when 23.9 g of H\textsubscript{2}O are reacted according to this chemical equation?

\[
2\text{AlCl}_3 + 3\text{H}_2\text{O}(l) \rightarrow \text{Al}_2\text{O}_3 + 6\text{HCl}(g)
\]

**Answer**

0.442 mol Al\textsubscript{2}O\textsubscript{3}
Mass to Mass Conversions

It is a small step from mole-mass calculations to mass-mass calculations. If we start with a known mass of one substance in a chemical reaction (instead of a known number of moles), we can calculate the corresponding masses of other substances in the reaction. The first step in this case is to convert the known mass into moles, using the substance’s molar mass as the conversion factor. Then—and only then—we use the balanced chemical equation to construct a conversion factor to convert that quantity to moles of another substance, which in turn can be converted to a corresponding mass. Sequentially, the process is as follows:

This three-part process can be carried out in three discrete steps or combined into a single calculation that contains three conversion factors. The following example illustrates both techniques.

ExamplePageIndex(2): Decomposition of Ammonium Nitrate

Ammonium nitrate decomposes to dinitrogen monoxide and water according to the following equation.
In a certain experiment, $45.7 \: \text{g}$ of ammonium nitrate is decomposed. Find the mass of each of the products formed.

**Steps for Problem Solving**

1. **Identify the "given" information and what the problem is asking you to "find."**
   - **Given:** $45.7 \: \text{g} \: \ce{NH_4NO_3}$
   - **Find:**
     - Mass $\ce{N_2O} = ? \: \text{g}$
     - Mass $\ce{H_2O} = ? \: \text{g}$

2. **List other known quantities**
   - $1 \: \text{mol} \: \ce{NH_4NO_3} = 80.06 \: \text{g/mol}$
   - $1 \: \text{mol} \: \ce{N_2O} = 44.02 \: \text{g/mol}$
   - $1 \: \text{mol} \: \ce{H_2O} = 18.02 \: \text{g/mol}$

3. **Prepare two concept maps and use the proper conversion factor.**

4. **Cancel units and calculate.**

   \[
   45.7 \: \text{g} \: \ce{NH_4NO_3} \times \dfrac{1 \: \text{mol} \: \ce{NH_4NO_3}}{80.06 \: \text{g} \: \ce{NH_4NO_3}} \times \dfrac{1 \: \text{mol} \: \ce{N_2O}}{1 \: \text{mol} \: \ce{NH_4NO_3}} \times \dfrac{44.02 \: \text{g} \: \ce{N_2O}}{1 \: \text{mol} \: \ce{N_2O}} = 25.1 \: \text{g} \: \ce{N_2O}
   \]

   \[
   45.7 \: \text{g} \: \ce{NH_4NO_3} \times \dfrac{1 \: \text{mol} \: \ce{NH_4NO_3}}{80.06 \: \text{g} \: \ce{NH_4NO_3}} \times \dfrac{2 \: \text{mol} \: \ce{H_2O}}{1 \: \text{mol} \: \ce{NH_4NO_3}} = 18.02 \: \text{g} \: \ce{H_2O}
   \]
Steps for Problem Solving

Example (PageIndex{2})

\[ \times \dfrac{18.02 \; \text{g} \; \ce{H_2O}}{1 \; \text{mol} \; \ce{H_2O}} = 20.6 \; \text{g} \; \ce{H_2O} \]

Think about your result.

The total mass of the two products is equal to the mass of ammonium nitrate which decomposed, demonstrating the law of conservation of mass. Each answer has three significant figures.

Exercise (PageIndex{2}): Carbon Tetrachloride

Methane can react with elemental chlorine to make carbon tetrachloride (\(\ce{CCl_4}\)). The balanced chemical equation is as follows.

\[ \ce{CH4 (g) + 4 Cl2 (g) → CCl2 (l) + 4 HCl (l) }\]

How many grams of HCl are produced by the reaction of 100.0g of \(\ce{CH4}\)?

Answer

908.7g HCl

Summary

- Calculations involving conversions between moles of a substance and the mass of that substance are described.
- The balanced chemical reaction can be used to determine molar and mass relationships between substances.

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