Chapter 5: Calculations and the Chemical Equation

The Mole Concept and Atoms

Atoms are exceedingly small, yet their masses have been experimentally determined for each of the elements. The periodic table provides atomic masses in atomic mass units (amu). A more practical unit for defining a "collection" of atoms is the mole, Avogadro's number of particles.

Why we need to use the concept of "mole" of atoms (6.022 x 10^23 particles) in chemical stoichiometry?

Chemical equations are written in terms of atoms and molecules. However, we cannot pick atoms individually and do reactions. Chemists always use mass in grams as the amount in the reaction. Therefore, we need a conversion factor to convert atoms and molecules to grams. Mole is the connection or the conversion factor between atoms and grams.

Avogadro's number

The name "Avogadro's Number" is just an honorary name attached to the calculated value of the number of atoms, molecules, etc. in a gram mole of any chemical substance. Of course if we used some other mass unit for the mole such as "pound mole", the "number" would be different than 6.022 x 10^23.

Calculations based on the chemical equation relate the number of atoms, moles and their corresponding mass. Conversion factors are used to relate the information provided in the problem to the information requested by the problem. It is often useful to map a pattern for the required conversion before beginning the problem.

1 mol = M.W. (molecular weight) taken in grams
1 mol = 6.022 x 10^23 particles
1 mol = 6.022 x 10^23 atoms
1 mol = 6.022 x 10^23 molecules
1 mol = 6.022 x 10^23 ions

Converting amu to g/mole

1 amu = 1 g/mole

An atom weighs 7.47 x 10^-23 g. What is the name of the element this atom belongs to?
First convert g to amu and look up in the periodic table and find out the element. Conversion factor: 1 g = 6.022 x 10^23 amu

\[
\begin{array}{c|c|c}
7.47 \times 10^{-23} \text{ g} & 6.022 \times 10^{23} \text{ amu} & = 44.98 \text{ amu} \\
\hline
1 \text{ amu} & & \\
\end{array}
\]

In the periodic table atomic masses increase generally with atomic number. Element with an atomic mass closer to the value calculated is Sc (Scandium).
The element is Sc.

Convert atomic mass of Hg in amu to g/mole

\[
\frac{200.59 \text{ amu Hg}}{1 \text{ atom Hg}} \times \frac{1.661 \times 10^{-24} \text{ g Hg}}{1 \text{ amu Hg}} \times \frac{6.022 \times 10^{23} \text{ atoms Hg}}{1 \text{ mol Hg}} = 200.59 \frac{\text{ g Hg}}{\text{ mol Hg}}
\]

Relating Avogadro's number to molar mass: calculation of the mass of Avogadro's number of
sodium atoms
Calculate the number moles of Na in $9.03 \times 10^{23}$ atoms Na.

$$\text{mol Na} = \frac{9.03 \times 10^{23} \text{ atoms Na}}{6.022 \times 10^{23} \text{ atoms Na}} \times 1 \text{ mol Na} = 1.50 \text{ mol Na}$$

$$\text{moles} = \frac{\text{Grams}}{\text{Molecular weight}}$$

$$\text{Molecular weight} = \frac{\text{Grams}}{\text{moles}}$$

$$\text{Grams} = \text{moles} \times \text{Molecular weight}$$

**Converting grams to atoms**

$$\frac{1 \text{ mol O}}{16.00 \text{ g O}} \times \frac{6.022 \times 10^{23} \text{ atoms O}}{1 \text{ mol O}} = 1.51 \times 10^{24} \text{ O atoms}$$

**The Mole and Avogadro's Number: Calculating Atoms, Moles, and Mass**

$$\frac{12.01 \text{ g C}}{5.24} \times \frac{1 \text{ mol C}}{1 \text{ mol C}} = 1.80 \times 10^{2} \text{ g C}$$

**Converting moles to atoms:** Moles $\times$ Avogadro’s number

**Converting atoms to moles:** Atoms $\div$ Avogadro’s number

**Converting moles of a substance to mass in grams:** moles $\times$ molar mass

**Converting grams to moles:**

How many moles of iron, Fe are in 4.00 g of Fe?

$$\frac{1 \text{ mol Fe}}{55.85 \text{ g Fe}} \times 4.00 \text{ g Fe} = 7.16 \times 10^{-2} \text{ mol Fe}$$

**Converting kilograms to moles:** kg $\rightarrow$ g $\rightarrow$ moles

How many moles of N$_2$ 2.00 kg of N$_2$?

$$\frac{10 \text{ mol N}_2}{28.02 \text{ g N}_2} \times \frac{1 \text{ mol N}_2}{1 \text{ kg N}_2} \times \frac{2.00 \text{ kg N}_2}{1 \text{ kg N}_2} = 71.4 \text{ mol N}_2$$

**Converting pounds to moles:** lb $\rightarrow$ g $\rightarrow$ moles

How many moles of calcium, Ca is in 0.10 g of Ca?

$$\frac{454 \text{ g Ca}}{1 \text{ lb Ca}} \times \frac{1 \text{ mol Ca}}{40.08 \text{ g Ca}} = 1.1 \text{ mol Ca}$$

**Converting grams to number of atoms:** grams $\div$ atomic mass $\rightarrow$ moles $\rightarrow$ atoms

**Chemical Compounds**

In chemistry, a compound is a substance formed from two or more elements, with a fixed ratio
determining the composition. For example, dihydrogen monoxide (water, H$_2$O) is a compound composed of two hydrogen atoms for every oxygen atom.

**The Chemical Formula**

A chemical formula (also called molecular formula) is a concise way of expressing information about the atoms that constitute a particular chemical compound. It identifies each type of element by its chemical symbol and identifies the number of atoms of such element to be found in each discrete molecule of that compound. The number of atoms (if greater than one) is indicated as a subscript. For example, methane, a simple molecule consisting of one carbon atom bonded to four hydrogen atoms has the chemical formula: CH$_4$ and glucose with six carbon atoms, twelve hydrogen atoms and six oxygen atoms has the chemical formula: C$_6$H$_{12}$O$_6$.

Calculating formula weight and molar mass ($C_2F_2C_2$).

\[
\begin{align*}
2 \text{ atoms of carbon} & \times 12.01 \text{ g/mole} = 24.02 \\
2 \text{ atoms of fluorine} & \times 19.00 \text{ g/mole} = 38.00 \\
4 \text{ atoms of chlorine} & \times 35.45 \text{ g/mole} = 141.80 \\
\end{align*}
\]

The average mass of a single molecule of $C_2F_2Cl_4$ is 203.82 g/mole.

**Calculating formula weight and molar mass of following ionic compounds: NaCl and K$_2$CO$_3$**

Formula weight of an ionic compound is the sum of all weights (i.e. atomic weight multiplied by their subscripts) in the chemical formula of the ionic compound.

a) Calculating formula weight and molar mass (NaCl).

\[
\begin{align*}
1 \text{ atom of sodium} & \times 23.00 \text{ g/mole} = 23.00 \\
1 \text{ atom of chlorine} & \times 35.45 \text{ g/mole} = 35.45 \\
\end{align*}
\]

The average mass of a single formula unit of NaCl is 58.45 g/mole.

b) Calculating formula weight and molar mass (K$_2$CO$_3$).

\[
\begin{align*}
2 \text{ atoms of potassium} & \times 39.10 \text{ g/mole} = 78.20 \\
1 \text{ atom of carbon} & \times 12.01 \text{ g/mole} = 12.01 \\
3 \text{ atoms of oxygen} & \times 48.00 \text{ g/mole} = 45.00 \\
\end{align*}
\]

The average mass of a single formula unit of K$_2$CO$_3$ is 138.21 g/mole.

**The Mole Concept Applied to Compounds**

Just as a mole of atoms is based on the atomic mass or atomic weight, a mole of a compound is based upon the molar mass/formula mass or formula weight. To calculate the moles from formula weight, the formula unit must be known.

How many moles of MgCl$_2$ are present in 35.0 g of MgCl$_2$?

\[
\frac{1 \text{ mol MgCl}_2}{35.0 \text{ g MgCl}_2} \times 95.21 \text{ g MgCl}_2 = 0.368 \text{ mol MgCl}_2
\]

How many moles of K$_2$SO$_4$ are present in 180.1g of potassium sulfate?

\[
\frac{1 \text{ mol K}_2\text{SO}_4}{180.1 \text{ g K}_2\text{SO}_4} \times 174.26g \text{ K}_2\text{SO}_4 = 1.033 \text{ mol K}_2\text{SO}_4
\]

**The Chemical Equation and the Information It Conveys**

In a chemical equation, the identity of reactants and products must be specified. Reactants are written to the left of the reaction arrow ($\rightarrow$) and products to the right. The physical states of reactants
and products are shown in parentheses. The symbol $\Delta$ over the reaction arrow means that heat energy is necessary for the reaction to occur. The equation must be balanced to reflect the law of conservation of mass, which states that matter can neither be gained nor lost in the process of a chemical reaction.

**Chemical Equations:** An equation with coefficients and formulas showing the starting and final substances maintaining atomic balance.

**Features of a Chemical Equation**

- **Chemical Equations show:**
  1. The **reactants** which enter into a reaction.
  2. The **products** which are formed by the reaction.
  3. The amounts (moles) of each substance used and each substance produced.

**The Numbers in a Chemical Equation:**

1. **Subscripts:** The small numbers to the lower right of chemical symbols. Subscripts represent the number of atoms of each element in the molecule.
2. **Stoichiometric Coefficients:** The large numbers in front of chemical formulas. Coefficients represent the number of molecules of the substance in the reaction.

**Physical State of reactants and products**

1. If a reactant or product is a solid, (s) and liquid, (l) is placed after the formula.
2. If a reactant or product is a gas, (g) is placed after it.
3. If a reactant or product is in water solution, (aq) is placed after it.

**A Recipe for Chemical Change**

A chemical equation is similar to a cookbook recipe in that it shows how many units of each substance is required to give the desired result. It shows the combination of various elements and/or molecules and then the resulting elements and/or molecules.

**Balancing Chemical Equations**

Chemical equations do not come already balanced. This must be done before the equation can be used in a chemically meaningful way. All chemical calculations to come must be done with a balanced equation. A balanced equation has equal numbers of each type of atom on each side of the equation. The Law of Conservation of Mass is the rationale for balancing a chemical equation.

For a chemical equation to be balanced, the same number of each kind of atom must be present on both sides of the chemical equation. The French chemist Antoine Lavoisier described the law of conservation of matter -- in a chemical reaction matter can neither be created nor destroyed. From Dalton's atomic theory we know that all substances are composed of atoms. During a chemical reaction atoms may be combined, separated, or rearranged, but not created or destroyed.

**Equations Must Be Balanced Because:** Atoms Can Be Neither Created Nor Destroyed By Ordinary Chemical Means, so there must be the same number of atoms on both sides of the equation.

**Seven Steps to Balance Equations By Inspection**

1. Check for Diatomic Molecules - H$_2$ - N$_2$ - O$_2$ - F$_2$ - Cl$_2$ - Br$_2$ - I$_2$
   - If these elements appear By Themselves in an equation, they Must be written with a subscript of 2
2. Balance Metals
3. Balance Nonmetals
4. Balance Oxygen
5. Balance Hydrogen
6. Recount All Atoms
7. If EVERY coefficient will reduce, rewrite in the simplest whole-number ratio.
Balance following chemical equations and give the sum of stiochiometric coefficients:

It is of most importance for a chemist to be able to write correctly balanced equations and to interpret equations written by others. It is also very helpful if he/she knows how to predict the products of certain specific types of reactions.

1) **Heating sodium hydroxide**

   Sodium Hydroxide $\rightarrow$ Sodium Oxide + Water

   $2\text{NaOH} \rightarrow \text{Na}_2\text{O} + \text{H}_2\text{O}$

2) **Rusting of iron**

   Iron + Oxygen $\rightarrow$ Iron (III) Oxide

   $4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3$

3) **Carbonation of water**

   Carbon Dioxide + Water $\rightarrow$ Glucose + Oxygen

   $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

4) **Double displacement**

   Iron (II) Sulfide + Hydrochloric Acid $\rightarrow$ Iron (II) Chloride + Hydrogen Sulfide

   $\text{FeS} + 2\text{HCl} \rightarrow \text{FeCl}_2 + \text{H}_2\text{S}$

5) **Burning of hydrogen in oxygen**

   Oxygen + Hydrogen $\rightarrow$ Water

   $\text{O}_2 + 2\text{H}_2 \rightarrow 2\text{H}_2\text{O}$

6) **Single displacement**

   Chlorine + Sodium Iodide $\rightarrow$ Sodium Chloride + Iodine

   $\text{Cl}_2 + 2\text{NaI} \rightarrow 2\text{NaCl} + \text{I}_2$

7) **Double displacement**

   Aluminum Nitrate + Sulfuric Acid $\rightarrow$

   $2\text{Al(NO}_3\text{)}_3 + 3\text{H}_2\text{SO}_4 \rightarrow \text{Al}_2(\text{SO}_4)_3 + 6\text{HNO}_3$

8) **Silver smelting**

   Silver Oxide $\rightarrow$ Silver + Oxygen

   $2\text{Ag}_2\text{O} \rightarrow 4\text{Ag} + \text{O}_2$

9) **Double displacement**

   Ammonium Phosphate + Barium Hydroxide $\rightarrow$

   $2(\text{NH}_4\text{)}_3\text{PO}_4 + 3\text{Ba(OH)}_2 \rightarrow \text{Ba}_3(\text{PO}_4)_2 + 6\text{NH}_4\text{OH}$

10) **Acid Base reactions**

    Calcium Hydroxide + Nitric Acid $\rightarrow$ Salt + Water

    $\text{Ca(OH)}_2 + 2\text{HNO}_3 \rightarrow \text{Ca(NO}_3\text{)}_2 + 2\text{H}_2\text{O}$

11) **Single replacement**

    MgO(s) + Si(s) = Mg(s) + SiO$_2$(s)

    $2\text{MgO} (s) + \text{Si} (s) = 2\text{Mg} (s) + \text{SiO}_2(s)$

12) **Acid formation: Non-metal oxides with water**

    $\text{P}_4\text{O}_{10}(s) + \text{H}_2\text{O}(l) = \text{H}_3\text{PO}_4(l)$

    $\text{P}_4\text{O}_{10} (s) + 6\text{H}_2\text{O} (l) = 4\text{H}_3\text{PO}_4 (l)$

13) **Double dispalcement**

    $\text{K}_2\text{CO}_3(aq) + \text{BaCl}_2(aq) = \text{KCl(aq)} + \text{BaCO}_3(s)$
Calculations Using the Chemical Equation

General Principles

Limiting reactant

The reactant used up first in a chemical reaction.

Before reaction has started

After reaction is complete

In real life it is rare for a chemical reaction to use up all the reactants in the formation of products. When reactants are not used up in equal amounts, we say that the reactants are not present in stoichiometric quantities. Problems of this type are referred to as limiting reactant problems. Reactions in one reactant in limited Supply.

Analogy in Recipe: Making cheese sandwiches

You were given 20 slices bread, 5 slices of cheese, 4 slices of ham

If you want to make sandwiches containing two slices bread and one slice of cheese and one slice of ham, how many sandwiches you could make? What is the limiting ingredient?

Stoichiometry

The quantitative relationship among reactants and products is called stoichiometry. The term stoichiometry is derived from two Greek words: stoicheion (meaning "element") and metron (meaning "measure"). On this subject, you often are required to calculate quantities of reactants or products.

We are already familiar with converting grams to moles.

Calculating reacting quantities:

Use of Conversion Factors

Mole conversion factors for the following equation:

\[ 4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO(g)} + 6 \text{H}_2\text{O(g)} \]

Mole ratios of reactants and products
Converting moles of Reactants to Products

Calculate the following using the chemical equation given below:
\[4 \text{ NH}_3(g) + 5 \text{ O}_2(g) \rightarrow 4 \text{ NO}(g) + 6 \text{ H}_2\text{O}(g)\]

a) moles of NO(g) from 2 moles of NH\(_3\)(g) and excess O\(_2\)(g).
b) moles of H\(_2\text{O}\)(g) from 3 moles of O\(_2\)(g) and excess NH\(_3\)(g).
c) Moles of NO(g) from 2 mole of NH\(_3\)(g) and excess O\(_2\)(g).

How many Moles of NO(g) are produced from 2 mole of NH\(_3\)(g) and excess O\(_2\)(g)

\[4 \text{ NH}_3(g) + 5 \text{ O}_2(g) \rightarrow 4 \text{ NO}(g) + 6 \text{ H}_2\text{O}(g)\]

There are several conversion factors that you can obtain from S.C. of the balanced chemical equation

\[4 \text{ mol NH}_3 = 5 \text{ mol O}_2\]
\[5 \text{ mol O}_2 = 6 \text{ mol H}_2\text{O}\]
\[4 \text{ mol NH}_3 = 4 \text{ mol NO} \quad \text{1 mole NH}_3 = 1 \text{ mole NO}\]
\[1 \text{ mol NH}_3 = 1 \text{ mol NO}\]

Now the problem is to convert 0.80 moles of O\(_2\) to H\(_2\text{O}\)

2.00 mol NH\(_3\) ---? mol H\(_2\text{O}\)

We need the conversion factor: 1 mol NH\(_3\) = 1mol NO

\[
2.00 \text{ mol NH}_3 \times \frac{1 \text{ mol NO}}{1 \text{ mol NH}_3} = 2 \text{ mol NO}
\]

b) Moles of H\(_2\text{O}\)(g) from 3 moles of O\(_2\)(g) and excess NH\(_3\)(g).

This problem is to convert 3 mole O\(_2\) to mole of H\(_2\text{O}\)

We need the conversion factor: 5 mol O\(_2\) = 6 mol H\(_2\text{O}\)

\[
\frac{3 \text{ mol O}_2}{1} \times \frac{6 \text{ mol H}_2\text{O}}{5 \text{ mol O}_2} = 3.6 \text{ mol H}_2\text{O}
\]

How many moles of H\(_2\text{O}\) will be produced by 0.80 mole of O\(_2\), according to the equation?

\[2\text{H}_2(g) + \text{O}_2(g) = 2 \text{H}_2\text{O}(l)\]

\[2\text{H}_2(g) + \text{O}_2(g) = 2 \text{H}_2\text{O}(l)\]

\[2\text{H}_2(g) + \text{O}_2(g) = 2 \text{H}_2\text{O}(l)\]

0.80 mol O\(_2\) = ? mol H\(_2\text{O}\)

There are several conversion factors that are coming from the chemical equation:
2 mol H₂ = 1 mol O₂
2 mol H₂ = 2 mol H₂O ; 1 mol H₂ = 1 mol H₂O
1 mol O₂ = 2 mol H₂O

We need the conversion factor is:
1 mol O₂ = 2 mol H₂O

\[
\frac{0.80\text{mol O}_2}{1} \times \frac{2\text{ mol H}_2\text{O}}{1\text{ mol O}_2} = 1.6\text{ mol H}_2\text{O}
\]

Calculating grams of product from moles of reactant

Calculate the mass of CO₂ produced burning C₂H₅OH in excess oxygen.

\[
\text{C}_2\text{H}_5\text{OH} + 5 \text{ O}_2 \rightarrow 2 \text{ CO}_2 + 6 \text{ H}_2\text{O}
\]

\[
\frac{2\text{ mol CO}_2}{1\text{ mol C}_2\text{H}_5\text{OH}} \times \frac{44.0\text{ g CO}_2}{1\text{ mol CO}_2} = 88.0\text{ g CO}_2
\]

Relating masses of reactants and products
Calculating grams of product from grams of reactant

Barium carbonate is BaCO₃.

a. Write a chemical equation for the decomposition of BaCO₃.

b. How many grams of CO₂ will be produced from 50.0 g BaCO₃?

\[
a. \quad \text{BaCO}_3(s) \xrightarrow{\Delta} \text{BaO(s)} + \text{CO}_2(g)
\]

\[
b. \quad 50.0\text{ g BaCO}_3 \times \frac{1\text{ mol BaCO}_3}{197\text{ g BaCO}_3} \times \frac{1\text{ mol CO}_2}{1\text{ mol BaCO}_3} \times \frac{44.0\text{ g CO}_2}{1\text{ mol CO}_2} = 11.2\text{ g CO}_2
\]

Theoretical and Percent Yield

Evaluating Success of Synthesis

One of the most important contribution of chemistry to other areas of sciences providing chemicals or raw materials for building various components of complex structures. Chemists come up with chemical reactions and optimize the conditions at which highest yield of the products could be synthesized. The amount of product measured in grams is called the yield. There are several descriptions of yield: theoretical and actual. Theoretical and actual yields will be discussed below. Therefore, yield of a chemical reaction plays an important role evaluating the success of a synthesis. If reactant are in stoichiometric amounts and the reaction take place as written in the chemical equation the percent yield should be 100%. However, there are side reactions and reaction yield are always less than 100%. Side reaction are competing chemical reactions that take place other than the one you think is taking place. They produce by products. By products are the products of the unwanted competing reactions. Situations occur where yield could be more than 100% pointing to products containing moisture and other contaminants.

Theoretical Yield

The amount of product predicted by the balanced equation when all of the limiting reagent has reacted.
Actual Yield

The amount of product actual obtained in a real chemical reaction that is carried out in the laboratory.

Percent Yield or % Yield

Percent yield compares the actual yield to theoretical yield and shows the efficiency of a chemical synthesis.

The % yield is given by the equation:

\[
\text{Yield} = \frac{\text{actual no. of moles of product}}{\text{maximum no. of moles of product}} \times 100\%
\]

Example: Calculate the percent yield of chloroform, CHCl₃, produced in a reaction excess methane, CH₄ is reacted with 105 g of chlorine, Cl₂. In this reaction 10.0 g of chloroform, CHCl₃ is actually produced.

a. Step 1. Write down information about the reaction:

\[
\text{CH}_4(g) + 3 \text{Cl}_2(g) \rightarrow 3 \text{HCl}(g) + \text{CHCl}_3(g)
\]

(excess) 105 g

Step 2. Convert the mass of Cl₂ to moles of Cl₂:

\[
1 \text{ mol Cl}_2 \quad 105 \text{ g Cl}_2 \quad 70.90 \text{ g Cl}_2 = 1.48 \text{ mol Cl}_2
\]

Step 3. The reaction states that 3 moles of Cl₂ will react to form one mole of CHCl₃, so the mole ratio is 3:1. Use this conversion factor to calculate the mass of product:

\[
1.48 \text{ mol Cl}_2 \quad 1 \text{ mol Cl}_2 \quad \frac{3 \text{ mol CHCl}_3}{119.37 \text{ g CHCl}_3} = 58.9 \text{ CHCl}_3
\]

b. % yield = \( \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% \)

\[
\frac{10.0 \text{ g}}{58.9 \text{ g} \times 100\%} = 17.0\% \text{ yield}
\]
HW 5. Homework Problems: Chapter 5

1. To convert a given number of moles into the number of atoms, you would multiply by which of the following factors?
   a. $6.02 \times 10^{23}$ atoms/1 mol
   b. $1 \text{ mol}/6.02 \times 10^{23}$ atoms
   c. $1.66 \times 10^{-24}$ atoms/1 mol
   d. $1 \text{ mol}/1.66 \times 10^{-24}$ atoms

2. How many molecules of water are there in 4.00 mol of water?
   a. $1.41 \times 10^{23}$
   b. $3.41 \times 10^{23}$
   c. $2.41 \times 10^{24}$
   d. $6.45 \times 10^{24}$

3. How many grams of sulfur make up 3.01 mol of sulfur atoms? [Use atomic weight: $S = 32.06 \text{ g/mol}$]
   a. $1.81 \times 10^{24}$ g
   b. $32.06$ g
   c. $3.01$ g
   d. $0.150$ g
   e. $96.5$ g

4. Calculate the number of grams in 0.125 moles of nitrogen molecules.
   a. $0.0107$ g
   b. $3.50$ g
   c. $112$ g
   d. $1.75$ g
   e. $0.0046$ g

5. How many atoms are in a 10.0 g sample of molybdenum (Mo)?
   a. $1.10 \times 10^{23}$
   b. $1.43 \times 10^{23}$
   c. $6.27 \times 10^{22}$
   d. $2.53 \times 10^{26}$
   e. $5.78 \times 10^{26}$

6. The Haber process combines nitrogen gas with hydrogen gas at high temperature and pressure to produce ammonia:
   \[ \text{N}_2(g) + \text{H}_2(g) \rightarrow \text{NH}_3(g) \]
   The coefficient of the hydrogen in the balanced equation is
   a. 1
   b. 2
   c. 3
   d. 6

7. What is the sum of all coefficients when the following equation is balanced?
   \[ \text{C}_2\text{H}_6(g) + \text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(g) \]
   a. 13
   b. 15
   c. 17
   d. 19
   e. 21

8. Given $\text{Fe}_2\text{O}_3(s) + 3\text{CO}(g) \rightarrow 2\text{Fe}(s) + 3\text{CO}_2(g)$; How many CO molecules are required to react with 25 formula units of $\text{Fe}_2\text{O}_3$?
   a. 15 CO molecules
   b. 75 CO molecules
   c. 55 CO molecules
   d. 40 CO molecules

9. How many moles of HCl can be formed when 2 mol of hydrogen gas react with chlorine? $\text{H}_2(g) + \text{Cl}_2(g) \rightarrow \text{HCl}(g)$ (unbalanced)
   a. 0.5 mol
   b. 1 mol
   c. 2 mol
   d. 4 mol
   e. 8 mol

10. $\text{Fe}_2\text{O}_3(s) + 3\text{CO}(g) \rightarrow 2\text{Fe}(s) + 3\text{CO}_2(g)$; What mass of CO is required to react with 146 grams of $\text{Fe}_2\text{O}_3$?
    a. 16.3 g CO
    b. 56.8 g C
    c. 76.7 g
    d. 94.7 g CO
    e. 14.2 g CO

11. For the reaction given below, how many moles of $\text{AlBr}_3$ will be produced if 12 moles of $\text{Br}_2$ react with 8 moles of aluminum?
    \[ 2\text{Al}(s) + 3\text{Br}_2(l) \rightarrow 2\text{AlBr}_3(s) \]
    a. 4
    b. 8
    c. 12
    d. 16
    e. 20

12. In the reaction given below, how many grams of sodium metal are consumed if 14.2 g of chlorine gas react to produce 23.4 g of sodium chloride?
    \[ 2\text{Na}(s) + \text{Cl}_2(g) \rightarrow 2\text{NaCl}(g) \]
    a. 4.3 g
    b. 9.2 g
    c. 14.2 g
    d. 18.8 g
    e. 33.0 g

13. The efficiency of a particular synthesis method is evaluated by determining the:
    a. limiting reactant
    b. theoretical yield
    c. percent yield
    d. molecular weight of the product
    e. stoichiometric coefficients

14. If 95.0 g of cesium reacts in sufficient chlorine to produce cesium chloride, what is the theoretical yield?
    \[ 2\text{Cs}(s) + \text{Cl}_2(g) \rightarrow 2\text{CsCl}(s) \]
    a. 95.0 g
    b. 120. g
    c. 146 g
    d. 236 g
    e. 285 g

15. If 4 $\text{Fe}_2\text{O}_3(s)$ (4.00 g) + $\text{O}_2(g)$ (excess) $\rightarrow 6\text{Fe}_2\text{O}_3$ and actual yield is 3.55 g, what is the theoretical yield of $\text{Fe}_2\text{O}_3$?
    a. 50.5 %
    b. 91.1 %
    c. 85.7 %
    d. 100 %
Sample Test: Chapter 5, Calculations and the Chemical Equation

1. How many iron atoms are present in one mole of iron?
Ans. $6.02 \times 10^{23}$ atoms

2. How many grams of sulfur are found in 0.150 mol of sulfur? [Use atomic weight: S, 32.06 amu]
Ans. 4.81 g

3. How many moles of sulfur are found in $1.81 \times 10^{24}$ atoms of sulfur? [Use atomic weight: S, 32.06 amu]
Ans. 3.01 mol

4. How many atoms are present in a 7.31 g sample of copper? [Use atomic weight: Cu, 63.55 amu]
Ans. $6.93 \times 10^{22}$ atoms

5. What is the mass, in grams, of 1.79 mol of helium, the gas commonly used to fill party balloons and lighter-than-air ships? [Use atomic weight: He, 4.00 amu]
Ans. 7.16 g

6. An iodine sample contains $2.91 \times 10^{22}$ atoms of iodine. What is its mass in grams? [Use atomic weight: I, 126.9 amu]
Ans. 6.13 g

7. Give the symbol(s) needed to show the smallest unit of nitrogen as it is normally found in nature.
Ans. N$_2$

8. When a solid compound is described as a "hydrate", what does this mean?
Ans. The compound contains water molecules in its structure.

9. What is the difference in meaning between "2O" and "O$_2$" when they occur in chemical equations?
Ans. 2O means 2 separate atoms of oxygen, not combined in the form of a molecule. O$_2$ means a molecule of oxygen, i.e. two atoms bonded to each other.

10. $6.022 \times 10^{23}$ molecules of a covalent compound is equal to how many moles of that compound?
Ans. 1 mol

11. What is the mass, in grams, of one mole of diatomic hydrogen? [Use molar mass: H, 1.0 g/mol]
Ans. 2.0 g

12. How many molecules of water are there in 5.00 mol of water?
Ans. $3.01 \times 10^{24}$ molecules

13. If one atom of oxygen weighs 16.00 amu, what will one mole of oxygen (O$_2$) weigh?
Ans. 32.00 g
Chapter 5, Calculations and the Chemical Equation

14. Dinitrogen monoxide or laughing gas (N\textsubscript{2}O) is used as a dental anesthetic and as an aerosol propellant. How many moles of N\textsubscript{2}O are present in 12.6 g of the compound? [Use atomic weights: N, 14.01 amu, O, 16.00 amu]

Ans. 0.286 mol

15. Dinitrogen monoxide or laughing gas (N\textsubscript{2}O) is used as a dental anesthetic and as an aerosol propellant. How many molecules of N\textsubscript{2}O are present in 12.6 g of the compound? [Use atomic weights: N, 14.01 amu, O, 16.00 amu]

Ans. $1.72 \times 10^{23}$ molecules

16. What law states that matter cannot be gained or lost during a chemical reaction?

Ans. law of conservation of mass

17. What does the symbol "(aq)", often found in chemical equations, mean?

Ans. The reactant or product to which this applies is aqueous, i.e. dissolved in water.

18. In chemical equations, what are the meanings of the symbols s, l and g, used in parentheses?

Ans. s = solid; l = liquid; g = gas

19. Balance the following equation: Ca(s) + HCl(g) → CaCl\textsubscript{2}(s) + H\textsubscript{2}(g)

Ans. Ca(s) + 2HCl(g) → CaCl\textsubscript{2}(s) + H\textsubscript{2}(g)

20. Balance the following equation: Mg(OH)\textsubscript{2}(s) + HCl(g) → MgCl\textsubscript{2}(s) + H\textsubscript{2}O(l)

Ans. Mg(OH)\textsubscript{2}(s) + 2HCl(g) → MgCl\textsubscript{2}(s) + 2H\textsubscript{2}O(l)

21. Balance the following equation: Na(s) + Cl\textsubscript{2}(g) → NaCl(s)

Ans. 2Na(s) + Cl\textsubscript{2}(g) → 2NaCl(s)

22. Balance the equation for the combustion of octane, a component of gasoline, using smallest whole number coefficients:

C\textsubscript{8}H\textsubscript{18}(l) + O\textsubscript{2}(g) → CO\textsubscript{2}(g) + H\textsubscript{2}O(l)

Ans. 2C\textsubscript{8}H\textsubscript{18}(l) + 25O\textsubscript{2}(g) → 16CO\textsubscript{2}(g) + 18H\textsubscript{2}O(l)

23. Balance the equation for the complete oxidation of glucose (C\textsubscript{6}H\textsubscript{12}O\textsubscript{6}), an important metabolic process:

C\textsubscript{6}H\textsubscript{12}O\textsubscript{6}(l) + O\textsubscript{2}(g) → CO\textsubscript{2}(g) + H\textsubscript{2}O(l)

Ans. C\textsubscript{6}H\textsubscript{12}O\textsubscript{6}(l) + 6O\textsubscript{2}(g) → 6CO\textsubscript{2}(g) + 6H\textsubscript{2}O(l)

24. How many moles of hydrogen gas are needed to react with oxygen to form two moles of water? 2H\textsubscript{2}(g) + O\textsubscript{2}(g) → 2H\textsubscript{2}O(l)

Ans. 2 mol

25. How many moles of oxygen gas are needed to react with hydrogen to form one mole of water? 2H\textsubscript{2}(g) + O\textsubscript{2}(g) → 2H\textsubscript{2}O(l)

Ans. 0.5 mol
Chapter 5, Calculations and the Chemical Equation

26. How many grams of sodium hydroxide will react with 73.00 g of aqueous HCl? [Use formula weights: NaOH, 39.99 amu; HCl, 36.45 amu]
   \[ \text{NaOH(aq)} + \text{HCl(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)} \]
   Ans. 80.09 g

27. Calculate the number of grams of oxygen that must react with 46.85 g of C\textsubscript{3}H\textsubscript{8} to produce only carbon dioxide and water. [Use atomic weights: C, 12.01 amu; H, 1.01 amu; O, 16.00 amu]
   Ans. 169.9 g

28. Iron reacts with oxygen to form iron(III) oxide (Fe\textsubscript{2}O\textsubscript{3}). How many grams of product will be formed from 5.00 grams of Fe? [Use atomic weights: Fe, 55.85 amu; O, 16.00 amu]
   Ans. 7.15 g

29. Glucose (C\textsubscript{6}H\textsubscript{12}O\textsubscript{6}) is an important energy-rich compound, produced by photosynthesis: \(6\text{CO}_2(g) + 6\text{H}_2\text{O(l)} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(l) + 6\text{O}_2(g)\)
   What mass of glucose, in grams, can be produced from 2.61 mol of CO\textsubscript{2} and the necessary water? [Use atomic weights: H, 1.01 amu; C, 12.01; O, 16.00]
   Ans. 78.4 g

30. Explain what is meant by the term "limiting reactant" in a chemical reaction.
   Ans. If the amount of one reactant at the start of reaction is less than that required to react completely with the other reactants, according to the balanced equation, it is the limiting reactant.

31. Magnesium hydroxide (Mg(OH)\textsubscript{2}), as "Milk of Magnesia" can be used to neutralize excess stomach acid, represented by HCl(aq):
   \[ \text{Mg(OH)}_2(s) + 2\text{HCl(aq)} \rightarrow \text{MgCl}_2(aq) + 2\text{H}_2\text{O(l)} \]
   When 5.00 g each of Mg(OH)\textsubscript{2} and HCl are combined, which is the limiting reactant, and what mass of MgCl\textsubscript{2} can be produced? [Use atomic weights: H, 1.01 amu; O, 16.00 amu; Mg, 24.31 amu; Cl, 35.45 amu]
   Ans. HCl is limiting reactant; 6.53 g of MgCl\textsubscript{2} can be produced.

32. To convert a given number of moles into the number of atoms, you would multiply by which of the following factors?
   A. \(6.02 \times 10^{23}\) atoms/1 mol
   B. 1 mol/6.02 \(\times 10^{23}\) atoms
   C. 1.66 \(\times 10^{-24}\) atoms/1 mol
   D. 1 mol/1.66 \(\times 10^{-24}\) atoms
   E. molar mass
   Ans. A
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33. To convert from a given mass in grams to the number of moles, you would multiply by which of the following factors?

A. \( \frac{1}{\text{Avogadro's number}} \)
B. \( \text{Avogadro's number}/1 \)
C. \( \text{molar mass}/1 \)
D. \( 1/\text{molar mass} \)
E. \( \text{Avogadro's number}/\text{molar mass} \)

Ans. D

34. To convert from a given number of atoms to the number of moles, you would multiply by which of the following factors?

A. \( \frac{\text{Avogadro's number}}{1} \)
B. \( \frac{1}{\text{Avogadro's number}} \)
C. \( 1/\text{molar mass} \)
D. \( \text{molar mass}/1 \)
E. \( \text{Avogadro's number}/\text{molar mass} \)

Ans. B

35. To convert from a given number of grams to the number of atoms, you would multiply by which of the following factors?

A. \( \frac{\text{Avogadro's number}}{1} \)
B. \( \frac{1}{\text{Avogadro's number}} \)
C. \( 1/\text{molar mass} \)
D. \( \text{molar mass}/1 \)
E. \( \text{Avogadro's number}/\text{molar mass} \)

Ans. E

36. The average mass of one atom of iron is 55.85 amu. What is the mass of Avogadro's number of atoms?

A. 55.85 centigrams
B. 55.85 g
C. 55.85 kg
D. 55.85 atoms
E. 55.85 formula units

Ans. B

37. What is the weight, in grams, of one mole of hydrogen atoms? [Use atomic weight: H, 1.01 amu]

A. 1.01 g
B. 2.02 g
C. 2.52 g
D. 6.02 \( \times 10^{23} \) g
E. 1.81 \( \times 10^{24} \) g

Ans. A
38. How many grams of sulfur make up 3.01 mol of sulfur? [Use atomic weight: S, 32.06 amu]
   A. 1.81 x 10^24 g
   B. 32.06 g
   C. 3.01 g
   D. 0.150 g
   E. 96.5 g
   Ans. E

39. How many moles are there in one ounce (28.4 g) of pure gold? [Use atomic weight: Au, 197.0 amu]
   A. 1.97 x 10^2 mol
   B. 6.94 mol
   C. 0.144 mol
   D. 0.0721 mol
   E. 5.08 x 10^-3 mol
   Ans. C

40. How many atoms of sulfur are present in 155 g of sulfur? [Use atomic weight: S, 32.06 amu]
   A. 2.91 x 10^24 atoms
   B. 6.02 x 10^23 atoms
   C. 3.01 x 10^23 atoms
   D. 2.91 x 10^23 atoms
   E. 2.01 x 10^23 atoms
   Ans. A

41. How many iron atoms are present in 3.01 mol of iron?
   A. 1.81 x 10^23
   B. 6.02 x 10^23
   C. 3.01 x 10^23
   D. 1.81 x 10^24
   E. 58.5
   Ans. D

42. What is the formula weight of carbon dioxide? [Use atomic weights: C, 12.01 amu; O, 16.00 amu]
   A. 28.01 amu
   B. 28.01 g
   C. 44.01 amu
   D. 44.01 g
   E. 44.01 mol
   Ans. C
43. Aspirin is the common name for acetyl salicylic acid, \( \text{C}_9\text{H}_8\text{O}_4 \). A tablet has 0.325 g of aspirin. How many moles is this? [Use formula weight: aspirin, 180.2 amu]

A. \( 1.80 \times 10^{-6} \) mol
B. \( 1.80 \times 10^{-3} \) mol
C. 0.554 mol
D. 554 mol
E. \( 1.96 \times 10^{23} \) mol

Ans. B

44. How many grams are there in 0.0200 mol of nicotine, a yellow liquid?[Use formula weight: nicotine, 162.2 amu]

A. \( 1.23 \times 10^{-4} \) g
B. 0.308 g
C. 3.24 g
D. 32.4 g
E. \( 8.11 \times 10^3 \) g

Ans. C

45. How many molecules are there in 0.0200 mol of nicotine, a yellow liquid?

A. 0.0400 molecules
B. \( 1.20 \times 10^{22} \) molecules
C. \( 2.41 \times 10^{22} \) molecules
D. \( 6.02 \times 10^{23} \) molecules
E. \( 1.20 \times 10^{23} \) molecules

Ans. B

46. How many molecules are there in 0.325 g of aspirin? [Use formula weight: aspirin, 180.2 amu]

A. \( 1.09 \times 10^{21} \) molecules
B. \( 2.17 \times 10^{21} \) molecules
C. \( 1.96 \times 10^{23} \) molecules
D. \( 3.91 \times 10^{23} \) molecules
E. \( 1.85 \times 10^{24} \) molecules

Ans. A

47. What number will be found in front of "Al" when the following equation is balanced with smallest whole number coefficients?
\[
\text{Al(s)} + \text{O}_2(g) \rightarrow \text{Al}_2\text{O}_3(s)
\]

A. 1 B. 2 C. 3 D. 4 E. 8

Ans. D
Chapter 5, Calculations and the Chemical Equation

48. How many moles of HCl can be formed when 2 mol of hydrogen gas react with chlorine? $\text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow \text{HCl}(\text{g})$ (unbalanced)

A. 0.5 mol  
B. 1 mol  
C. 2 mol  
D. 4 mol  
E. 8 mol

Ans. D

49. Which of the choices is the correctly balanced form of the following equation?

$\text{C}_6\text{H}_{14}(\text{l}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$

A. $\text{C}_6\text{H}_{14}(\text{l}) + 13\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 7\text{H}_2\text{O}(\text{l})$
B. $\text{C}_6\text{H}_{14}(\text{l}) + 19\text{O}(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 7\text{H}_2\text{O}(\text{l})$
C. $\text{C}_6\text{H}_{14}(\text{l}) + 19\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 7\text{H}_2\text{O}(\text{l})$
D. $2\text{C}_6\text{H}_{14}(\text{l}) + 19\text{O}_2(\text{g}) \rightarrow 12\text{CO}_2(\text{g}) + 14\text{H}_2\text{O}(\text{l})$
E. $\text{C}_{12}\text{H}_{28}(\text{l}) + 38\text{O}(\text{g}) \rightarrow 12\text{CO}_2(\text{g}) + 14\text{H}_2\text{O}(\text{l})$

Ans. D

50. How many moles of hydrogen gas are needed to react with oxygen to form one mole of water? $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l})$

A. 0.5 mol  
B. 1 mol  
C. 2 mol  
D. 4 mol  
E. 6 mol

Ans. B

51. Calculate the mass in grams of oxygen needed to react with 1.000 mol of $\text{C}_3\text{H}_8$ to form carbon dioxide and water. [Use atomic weight: O, 16.00 amu]

$\text{C}_3\text{H}_8(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ (unbalanced)

A. 80.0 g  
B. 32.00 g  
C. 40.0 g  
D. 320.0 g  
E. 160.0 g

Ans. E

52. Iron reacts with oxygen to form iron(III) oxide ($\text{Fe}_2\text{O}_3$). How many grams of product will be formed from 125.5 g of Fe? [Use atomic weights: Fe, 55.85 amu; O, 16.00 amu]

A. 59.8 g  
B. 179.4 g  
C. 89.7 g  
D. 358.5 g  
E. 159.7 g

Ans. B

53. Consider the hypothetical reaction: $3\text{A}_2 + 2\text{B} \rightarrow \text{C} + 2\text{D}$ How many moles of D can be formed from 5.0 mol of A$_2$ and excess B?

A. 1.7 mol  
B. 3.3 mol  
C. 6.7 mol  
D. 7.5 mol  
E. 10. mol

Ans. B

54. T  F  One atomic mass unit is the same as one gram.

Ans. F

55. T  F  The smallest complete unit of iron is an atom of iron.

Ans. T
56. T  F  One mole of iron atoms contains $6.02 \times 10^{23}$ molecules.
   Ans. F

57. T  F  The formula weight of a compound is calculated by adding together
   the number of atoms that make it up.
   Ans. F

58. T  F  Strictly speaking, it is incorrect to use the term "molecular
   weight" in referring to ionic compounds.
   Ans. T

59. T  F  One mole of Ca$_3$(PO$_4$)$_2$ contains $6.02 \times 10^{23}$ atoms of calcium.
   Ans. F

60. T  F  One mole of oxygen gas contains $6.02 \times 10^{23}$ molecules.
   Ans. T

61. T  F  The formula weight of water is equal to 18.02 g.
   Ans. F

62. T  F  If the atomic weight of hydrogen is 1.01 amu, a mole of H$_2$ will
   weigh 1.01 g.
   Ans. F

63. T  F  One gram of gold (atomic weight 197 amu) contains more atoms than
   one gram of copper (atomic weight 63.55 amu).
   Ans. F

64. T  F  One mole of H$_2$O contains a total of $6.02 \times 10^{23}$ atoms.
   Ans. F

65. T  F  The law of conservation of mass states that matter cannot be
   gained or lost during a chemical reaction.
   Ans. T

66. T  F  The symbol $\Delta$, above or below the reaction arrow in an equation,
   indicates that heating is needed for the reaction to take place.
   Ans. T

67. T  F  Counting the number of moles on both the reactant and product
   sides of an equation is the first step in balancing the equation.
   Ans. F

68. T  F  In a correctly balanced equation, the number of moles of
   reactants and the number of moles of products may differ.
   Ans. T

69. T  F  The term "dynamic equilibrium" is used to describe the condition
   of a reaction when one of the reactants has been completely used
   up.
   Ans. F
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70. T F 0.5 mol of oxygen gas can react with hydrogen gas to form 1.0 mol of water.

Ans. T