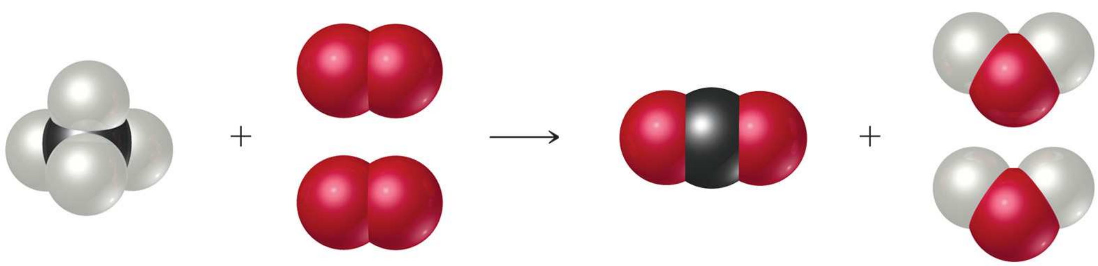
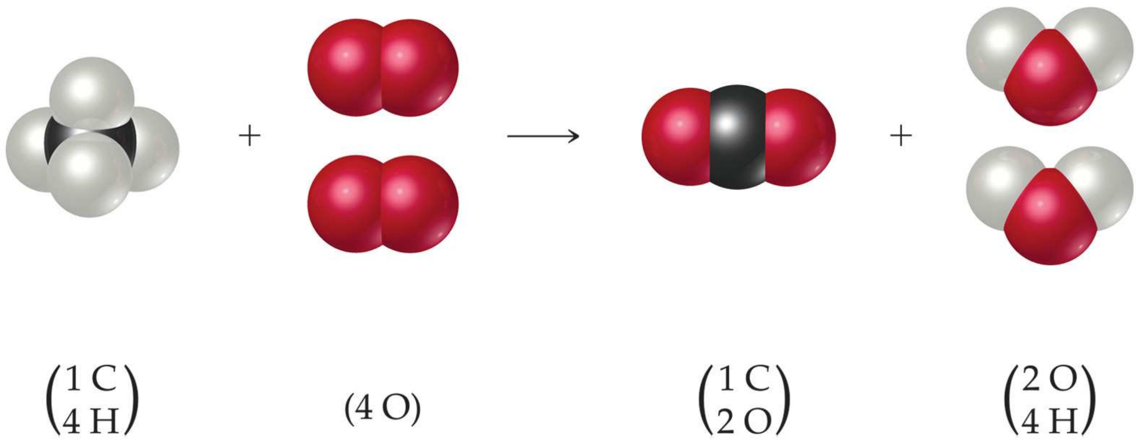
Chapter 3
Stoichiometry:
Calculations with Chemical Formulas and Equations

"We may lay it down as an incontestable axiom that, in all the operations of art and nature, nothing is created; an equal amount of matter exists both before and after the experiment.  Upon this principle, the whole art of performing chemical experiments depends."
--Antoine Lavoisier, 1789

Concise representations of chemical reactions



CH4 (*g*) + 2 O2 (*g*)                CO2 (*g*) + 2 H2O (*g*)

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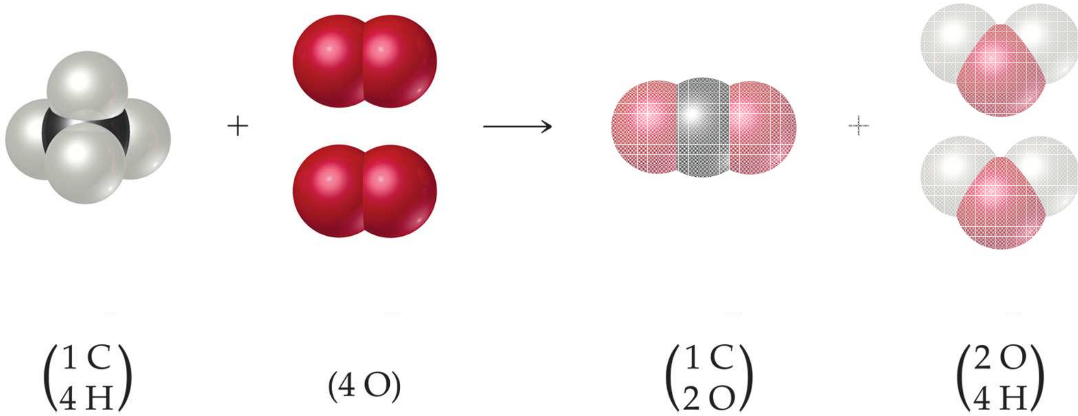


Reactants appear on the left side of the equation.
Products appear on the right side of the equation.
The states of the reactants and products are written in parentheses to the right of each compound.
Coefficients are inserted to balance the equation.

$CH_{4\,(g)} + 2\ O_{2\,(g)}$ $CO_{2\,(g)} + 2\ H_2O_{(g)}$

Subscripts and Coefficients Give Different Information
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•Coefficients tell the number of molecules

Reaction Types

Combination Reactions
•Examples:
$N_{2\,(g)} + 3\ H_{2\,(g)} \longrightarrow 2\ NH_{3\,(g)}$
$C_3H_{6\,(g)} + Br_{2\,(l)} \longrightarrow C_3H_6Br_{2\,(l)}$
$2\ Mg_{(s)} + O_{2\,(g)} \longrightarrow 2\ MgO_{(s)}$
•Two or more substances react to form one product
$2\ Mg_{(s)} + O_{2\,(g)} \longrightarrow 2\ MgO_{(s)}$

Decomposition Reactions
•Examples:
$CaCO_{3\,(s)} \longrightarrow CaO_{(s)} + CO_{2\,(g)}$
$2\ KClO_{3\,(s)} \longrightarrow 2\ KCl_{(s)} + O_{2\,(g)}$
$2\ NaN_{3\,(s)} \longrightarrow 2\ Na_{(s)} + 3\ N_{2\,(g)}$
•One substance breaks down into two or more substances

Combustion Reactions
•Examples:
$CH_{4\,(g)} + 2\ O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\ H_2O_{(g)}$
$C_3H_{8\,(g)} + 5\ O_{2\,(g)} \longrightarrow 3\ CO_{2\,(g)} + 4\ H_2O_{(g)}$
•Rapid reactions that produce a flame
•Most often involve hydrocarbons reacting with oxygen in the air

Formula Weights
Formula Weight (FW)
•Sum of the atomic weights for the atoms in a chemical formula
•So, the formula weight of calcium chloride, $CaCl_2$, would be
Ca: 1(40.1 amu)
+ Cl: 2(35.5 amu)

111.1 amu

- These are generally reported for ionic compounds

Molecular Weight (MW)

- Sum of the atomic weights of the atoms in a molecule
- For the molecule ethane, $C_2H_6$, the molecular weight would be

Percent Composition

One can find the percentage of the mass of a compound that comes from each of the elements in the compound by using this equation:

Percent Composition

So the percentage of carbon in ethane is…

Moles

- 1 mole of $^{12}C$ has a mass of 12 g

Avogadro's Number

- $6.02 \times 10^{23}$

Molar Mass

- By definition, these are the mass of 1 mol of a substance (i.e., g/mol)
  - The molar mass of an element is the mass number for the element that we find on the periodic table
  - The formula weight (in amu's) will be the same number as the molar mass (in g/mol)

Using Moles

Moles provide a bridge from the molecular scale to the real-world scale

Mole Relationships

- One mole of atoms, ions, or molecules contains Avogadro’s number of those particles
- One mole of molecules or formula units contains Avogadro’s number times the number of atoms or ions of each element in the compound

Finding Empirical Formulas

Calculating Empirical Formulas

One can calculate the empirical formula from the percent composition

Combustion Analysis

- Compounds containing C, H and O are routinely analyzed through combustion in a chamber like this
  - C is determined from the mass of $CO_2$ produced
  - H is determined from the mass of $H_2O$ produced
  - O is determined by difference after the C and H have been determined

Elemental Analyses

Compounds containing other elements are analyzed using methods analogous to those used for C, H and O

Stoichiometric Calculations

The coefficients in the balanced equation give the ratio of *moles* of reactants and products

From the mass of Substance A you can use the ratio of the coefficients of A and B to calculate the mass of Substance B formed (if it's a product) or used (if it's a reactant)

Starting with 1.00 g of $C_6H_{12}O_6$…
we calculate the moles of $C_6H_{12}O_6$…
use the coefficients to find the moles of $H_2O$…
and then turn the moles of water to grams

Limiting Reactants

How Many Cookies Can I Make?

•You can make cookies until you run out of one of the ingredients

•Once this family runs out of sugar, they will stop making cookies (at least any cookies you would want to eat)

In this example the sugar would be the limiting reactant, because it will limit the amount of cookies you can make

The limiting reactant is the reactant present in the smallest stoichiometric amount

The limiting reactant is the reactant present in the smallest stoichiometric amount

–**<u>In other words, it's the reactant you'll run out of first</u>** (in this case, the $H_2$)

Limiting Reactants

In the example below, the $O_2$ would be the excess reagent

Theoretical Yield

- The theoretical yield is the amount of product that can be made
  - In other words it's the amount of product possible as calculated through the stoichiometry problem
- This is different from the actual yield, the amount one actually produces and measures

Percent Yield

A comparison of the amount actually obtained to the amount it was possible to make