Chapter 3
Stoichiometry: Calculations with Chemical Formulas and Equations

3.1 Chemical Reactions

- What happens during a chemical reaction?
- What distinguishes a chemical change from changes in physical properties?
- Draw a picture of a chemical reaction, showing the changes that occur at a molecular level.

Reactants ➔ Products

- Several levels of examining chemical reactions:
- Macroscopic changes accompanying the chemical changes
- Changes in microscopic structure
- Rearrangement of atoms
- Representation of reactions with equations:
  thermite reaction: $2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(l)$

Writing Chemical Equations

- Compact representation of chemical reactions
- Features: reactants → products (with physical state noted)

$$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(l)$$

Balancing Equations

- Law of Conservation of Mass
- Conservation of atoms
- Do we need to conserve molecules?
  $2H_2O_2(aq) \rightarrow 2H_2O(g) + O_2(g)$
- Adjust coefficients and not subscripts to balance an equation
- Coefficients are usually integers
- Action of Drano (Al/NaOH)
  $2Al(s) + 2NaOH(aq) + 6H_2O(l) \rightarrow 2NaAl(OH)_4(aq) + 3H_2(g)$
- Represents single atoms or molecules, or several molecules, or moles

Examples of chemical reactions

- Fe burning: $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$
- What is wrong with this drawing?

Balancing chemical equations

- Demo: methanol cannon
  Balance the reaction:
  $CH_3OH(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$
- Software: Balance.exe available in the Learning Resource Center

Guidelines to balancing equations

- Write correct formulas for reactants and products
- Begin balancing with the most complex formula

- Balance polyatomic ions as a single unit
- Check each reactant and product to verify the coefficients (check atom balance)

- Balance the following equations:
- $Ca_3N_2 + H_2O \rightarrow Ca(OH)_2 + NH_3$
- $H_2O_2 \rightarrow H_2O + O_2$
- $KClO_3 \rightarrow KCl + O_2$
- $N_2O_5 + H_2O \rightarrow HNO_3$
- $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$
- $Na + H_2O \rightarrow NaOH + H_2$

3.2 Patterns of Chemical Reactivity

- Demo: Pour together two clear colorless liquids
- Did a chemical reaction occur? How do you know?
- Demo: AlkaSeltzer in water, or calcium in water
- Did a chemical reaction occur?

Observing and Predicting Reactions

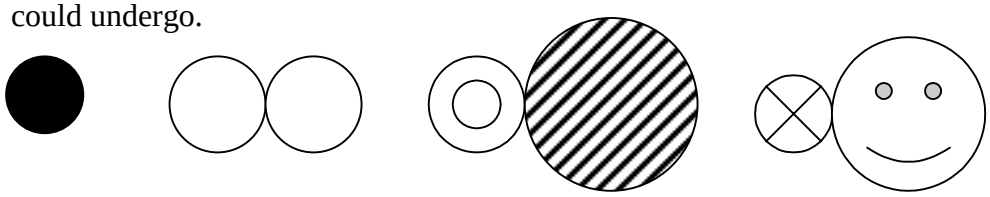
- How do we know whether a reaction occurs? What clues does nature offer? Make a list.
- What clues does nature offer that a chemical reaction occurred?

Observing and Predicting Reactions

- Predictions:
  - do an experiment
  - use periodicity
  - use classifications of reactions
- example: combustion reactions involve the reaction of an element or a compound with oxygen, usually with the evolution of heat

Reaction Classifications

- In the following particulate representations, a circle represents an atom and different circles represent different elements. Using these representations, draw pictures of all the different types of atomic/molecular changes these substances could undergo.



- Classify the following reactions, based on the changes happening at an atomic/molecular level.

1. $AlF_3(aq) + 3H_2O(l) \rightarrow Al(OH)_3(s) + 3HF(aq)$
2. $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaCl(aq)$
3. $Ca(OH)_2(s) \rightarrow CaO(s) + H_2O(g)$
4. $Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$
5. $CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$
6. $Cl_2(aq) + 2NaI(aq) \rightarrow 2NaCl(aq) + I_2(aq)$
7. $Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$
8. $Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$
9. $H_2SO_3(aq) \rightarrow H_2O(l) + SO_2(g)$
10. $2HgO(s) \rightarrow 2Hg(l) + O_2(g)$
11. $KOH(aq) + HNO_3(aq) \rightarrow KNO_3(aq) + H_2O(l)$
12. $4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$
13. $Na_2S(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2S(g)$
14. $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$
15. $NiCO_3(s) \rightarrow NiO(s) + CO_2(g)$
16. $P_4(s) + 10F_2(g) \rightarrow 4PF_5(g)$

Reaction Classes
Combination Reactions

- element + element → compound
- metal + nonmetal → ionic compound
- $2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$
- nonmetal + nonmetal → covalent cmpd
- $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
- Draw a molecular diagram of this type of reaction
- Combination: $K + Cl_2$

Reaction Classes
Addition Reactions

- element + compound → compound
- $Cl_2 + 2TiCl_3 \rightarrow 2TiCl_4$
- $Cl_2 + C_2H_4 \rightarrow C_2H_4Cl_2$
- Draw a molecular diagram of this type of reaction

Reaction Classes
Decomposition Reactions

- Compound → 2 elements or element + compound or 2 compounds
- Oxides, peroxides → O_2
- Nitrates → NO_2 or NO_2^-
- Carbonates → CO_2
- Hydrates → H_2O
- Ammonium salts → NH_3
- Draw a molecular diagram of this type of reaction

Reaction Classes
Single-Displacement Reactions

- element + cmpd → cmpd + element
  (The more metallic element in the compound is displaced.)
- carbon + metal oxides
- $3C + Fe_2O_3 \rightarrow 3CO + 2Fe$
- metals + water
- $Ca(s) + 2H_2O(aq) \rightarrow Ca(OH)_2(aq) + H_2(g)$
- Single Displacement: $Li + H_2O$
- metals + acids
- $Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$
- metals + metal salts
- $Zn(s) + SnCl_2(aq) \rightarrow ZnCl_2(aq) + Sn(s)$
  Single Displacement: $Cu + AgNO_3$
- nonmetals + salts
- $Cl_2(aq) + 2KI(aq) \rightarrow 2KCl(aq) + I_2(aq)$
- Draw a molecular diagram of this type of reaction
- Predictions of this type of reaction will be considered in Chapter 4, which deals with reactions occurring in aqueous solution.

Reaction Classes
Double-Displacement Reactions

- compound 1 + compound 2 → compound 3 + compound 4
- Also called metathesis reactions.
- exchange of ionic partners
  AB + CD → AD + CB
- $Pb(NO_3)_2(aq) + K_2CrO_4(aq) \rightarrow PbCrO_4(s) + 2KNO_3(aq)$
- And other related reactions

3.3 Atomic and Molecular Weights

- Demo: large bag of styrofoam peanuts, bottle of sand, 1 L beaker, 18 mL of water
- How can we count very large numbers of particles?
- Demo: weigh pennies of various ages
- If we have a large number of particles of two close but different masses, how do we describe the mass of these particles?

Atomic and Molecular Weights

- How do we accommodate the masses of isotopes of an element?
- Why do we use a C-12 standard for the mass of atoms of elements?
- How can we determine these masses?
- How do we get average atomic weights?
- When would the average atomic weight not be a useful number?
- atomic weight: average mass of 1 atom of an element, expressed in amu
- formula weight: sum of the atomic weights of each atom in a chemical formula

- What is the formula weight of $CaCl_2$?
- molecular weight: same as formula weight when the chemical formula is a molecular formula
- What is the molecular weight of H_2CO_3?

3.4 The Mole

- Demo: different substances
- What do these substances all have in common?

Molar Mass and Moles

- Describe the difference between molar mass, molecular weight, and atomic weight.
- How do we get these quantities?
- Calculations:
  mass ↔ moles ↔ number of particles
- How do we carry out these conversions?
- mass ↔ moles: Use molar mass
- moles ↔ number of particles: Use N_A

Mole Calculations

- Write on the blackboard and calculate the number of $CaCO_3$ units in the writing.
- How do we determine the mass of the writing?
- Mass of writing = 5.473 g - 5.448 g = 0.025 g
- How much Ca, C, O in the writing?

3.5 Empirical Formulas from Analyses

- Calculate the empirical formulas:
  - 50% O, 50% S
  - 60% O, 40% S

Molecular formula from empirical formula

- How to calculate a molecular formula if a molar mass is known?
- Empirical formula = CH_2O, MM = 90 g/mol
- What is the molecular formula?

3.6 Quantitative Information from Balanced Equations

- Mass-Mole Conversions
- 10 g $CaCO_3$ → How many moles?
  MM = 100 g/mol
  10 g x 1 mol/100 g = 0.10 mol
- How many moles in 20 g?
- How many moles in 25 g of NaOH?

Calculations

- Mole-Mole Conversions
- $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$
  0.105 mol xs ? ?
  How many moles of each product?

Mass - Mass Conversion Calculations

- Mass Conversions in a Single Reaction
- $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$
  5.45 g ? ?
  111 g/mol 100.1 g/mol 58.4 g/mol
- Mass Conversions in Sequences of Reactions
  Follow the same sequence of conversions, using the amounts of products from the first reaction as the amount of reactant in the second reaction.

3.7 Limiting Reactants

- Limiting Reactant Demo: Mg or Zn in HCl
- Analogy: making cheese sandwichs
- Limiting Reactant
  $2H_2 + O_2 \rightarrow 2H_2O$

What is the limiting reactant?

Limiting Reactant Problem Calculations

- $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$
  0.105 mol 0.085 mol ? ?
  How many moles of each product?
- $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$
  5.45 g 4.55 g ? ?
  111 g/mol 106 g/mol 100.1 g/mol 58.4 g/mol
  How much $CaCO_3$ is formed?