Energy

Every chemical change involves the loss or gain of energy. Most physical changes also give off or absorb energy. In most cases, this energy occurs in the form of heat. The amount of heat energy gained or lost in a chemical or physical change is measured in units of **calories**. A calorie is defined as the amount of heat needed to raise the temperature of one gram of water by one degree Celsius. Another unit used to measure energy is the **joule**. A joule is equivalent to 0.239 calorie.

Temperature is the condition of a body which determines the transfer of heat to or from other bodies. It is an indication of the average kinetic energy of the particles of which that body is made.

Heat energy applied to a body may produce one of two effects in that body: (1) it may raise the temperature of that body, or (2) it may bring about a change of state of that body. The amount of heat needed to change a substance from a solid to a liquid is called its **heat of fusion**. The amount of heat needed to change a substance from a liquid to a gas is known as its **heat of vaporization**.

The heat energy absorbed or released during a chemical change is known as the **heat of reaction**. The heat of reaction is usually expressed in units of kilocalories per mole.

Solved Examples

Example 1: Change a temperature reading of 36.5°F to its equivalent in degrees Celsius and degrees Kelvin.

Solution:

$$
\begin{aligned}
{}^\circ C &= 5/9\ ({}^\circ F - 32) \\
&= 5/9\ (36.5^\circ F - 32) \\
&= 2.5^\circ C
\end{aligned}
$$

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$$\begin{aligned} K &= {}^\circ C + 273 \\ &= 2.5^\circ C + 273 = 275.5\ K \end{aligned}$$

Example 2: How much heat (H) is released when 52.5 g of water cools from 67.5°C to 23.2°C? The specific heat (C_p) of water is 1.00 cal/°C · g.

Solution: $H = C_p \times \text{mass of water} \times \text{temperature change}$

$$= 1.00\ \frac{\text{cal}}{{}^\circ\cancel{\text{C}} \cdot \cancel{\text{g}}} \times 52.5\,\cancel{\text{g}} \times 44.3^\circ\cancel{\text{C}}\,(67.5^\circ\text{C} - 23.2^\circ\text{C})$$

$$= 2330\ \text{cal}$$

Example 3: What mass (M) of aluminum can be melted by the addition of 250. cal of heat? The heat of fusion (H_f) of aluminum is 94.5 cal/g.

Solution:

$$H = H_f \times M \qquad \text{or} \qquad M = \frac{H}{H_f}$$

$$W = \frac{250.\,\cancel{\text{cal}}}{94.5\,\cancel{\text{cal}}/\text{g}}$$

$$= 2.65\ \text{g}$$

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Energy

Practice Problems (Level 1)

1. Each of the following is a temperature reading in one of three systems: Fahrenheit, Celsius, or Kelvin. Change the reading to its equivalent in both of the other scales.

a. 70.°F
b. 25°C
c. 100.°F
d. 373 K
e. 85°C
f. 215°C
g. 90.°F
h. 285 K
i. 35°C
j. 305 K

2. Calculate the number of calories of heat absorbed or released in each of the following changes.

a. 40.0 g of water at 25.0°C raised to 60.0°C.
b. 125 g of water at 10.0°C raised to 90.0°C.
c. 75.0 g of water at 9.8°C raised to 22.4°C.
d. 44.8 g of iron at 80.5°C cooled to 62.6°C. The specific heat of iron is 0.11 cal/°C · g.
e. 64.82 g of aluminum metal at 100.0°C cooled to 82.5°C. The specific heat of aluminum metal is 0.215 cal/°C · g.

3. Calculate the amount of heat given off or taken on during each of the following changes:

a. the melting of 25.0 g of iron; the heat of fusion of iron is 63.7 cal/g.
b. the boiling of 125 g of antimony; the heat of vaporization of antimony is 380 cal/g.
c. the melting of 235 g of bismuth; the heat of fusion of bismuth is 12.4 cal/g.
d. the boiling of 350 g of chromium; the heat of vaporization of chromium is 1560 cal/g.

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Energy

Practice Problems (Level 2)

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1. Each of the following is a temperature reading in one of three systems: Fahrenheit, Celsius, or Kelvin. Change the reading to its equivalent in both of the other scales.

    a. 215°C
    b. 6.0°F
    c. 145 K
    d. -95°C
    e. 2120°F
    f. -325°F
    g. 25.6°C
    h. 35 K
    i. 3565°C
    j. -166°F

2. Calculate the number of calories of heat lost or gained during each of the following changes:

    a. 114.32 g of water at 14.85°C raised to 18°C.
    b. 132 g of copper at 32.2°C raised to 45.0°C; the specific heat of copper is 0.092 g/°C · g.
    c. 24.5 g of ice at -10.0°C warmed to 42.5°C. The specific heat of ice is 0.50 cal/°C · g. The heat of fusion for ice is 80 cal/g.
    d. 354 g of ice at -40.0°C heated to steam at 112°C. The specific heats of ice and steam are 0.50 cal/°C · g. The heat of vaporization for water is 540 cal/g.

3. What is the final temperature of 250.0 g of water whose initial temperature is 25.0°C if 80.0 g of aluminum initially at 70.0°C is dropped into the water? The specific heat of aluminum is 0.215 cal/°C · g.

4. Calculate the specific heat of mercury metal if 250. g of the metal, warmed from 20.2°C to 37.4°C gives of 145 cal of heat.

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Energy

Practice Problems (Level 3)

1. A sample of mercury metal is heated from 25.5° C to 52.5° C. In the process, 187 cal of heat are absorbed. What mass of mercury was in the sample? The specific heat of mercury is 0.033 cal/° C · g.
2. A block of aluminum weighing 140 g is cooled from 98.4° C to 62.2° C with the release of 1080 cal of heat. From these data, calculate the specific heat of aluminum.
3. A cube of gold weighing 192.4 g is heated from 30.0° C to some higher temperature, with the absorption of 226 cal of heat. The specific heat of gold is 0.030 cal/° C · g. What was the final temperature of the gold?
4. A total of 54 cal of heat are absorbed as 58.3 g of lead is heated from 12.0° C to 42.0° C. From these data, what is the specific heat of lead?
5. A piece of erbium metal weighing 100.0 g and heated to 95.0° C is dropped into 200.0 g of water initially at 20.0° C. The final temperature of the mixture is 21.5° C. What is the specific heat of erbium metal?
6. A block of rhenium metal (specific heat = 0.0329 cal/g · ° C) is heated to 88.2° C and then dropped into 100.0 g of water initially at 26.4° C. The final temperature of the mixture is 32.4° C. What was the mass of the block of rhenium?
7. When 258.6 g of benzene vapor is condensed to a liquid at its boiling point, 33,875 cal of heat are released. What is the heat of vaporization for benzene?
8. A sample of ethyl alcohol is converted from a liquid to a vapor with no temperature change. In the process, 30,640 cal of heat are absorbed. What mass of ethyl alcohol was in the sample? The heat of vaporization of ethyl alcohol is 210. cal/g.
9. The heat of combustion of methane is 212.8 kcal per mole. How much heat will be produced in the combustion of 100.0 g of methane?
10. The heat of combustion of toluene is 934.2 kcal per mole. How much heat will be released during the combustion of 250.0 g of toluene? The formula for toluene is $C_6H_5CH_3$.

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Energy

Teacher Notes

1. Explanation of Levels

Level 1: Conversion of temperature readings at simple level; calculation of heat gain and loss for simple cases; calculation of heat gain and loss during melting and boiling.

Level 2: Conversion of temperature readings at more advanced levels (decimal, very large, and negative values); calculation of heat change, specific heat, and temperature for a variety of situations.

Level 3: Calculation of heat change, specific heat, weight, and temperature for complex changes; two simple problems on heat of combustion.

2. Answers

Level 1:

1. a. 21°C; 294°C; b. 77°F; 298 K; c. 37.8°C; 311.0 K; d. 100°C; 212°F; e. 185°F; 358 K; f. 419°F; 488 K; g. 32°C; 305 K; h. 12°C; 54°F; i. 95°F; 308 K; j. 32°C; 90°F
2. a. $14\bar{0}0$ cal; b. $10{,}\bar{0}00$ cal; c. 940 cal; d. −88 cal
3. a. 1,590 cal; b. 47,500 cal; c. 2,910 cal; d. 546,000 cal

Level 2:

1. a. 419°F; 488 K; b. −14°C; 259 K; c. −128°C; −198°F; d. −139°F; 178 K; e. 1160°C; 1433 K; f. −198°C; 75 K; g. 78.1°F; 298.8 K; h. −238°C; −396°F; i. 6449°F; 3838 K; j. −110°C; 163 K
2. a. 360 cal; b. 155 cal; c. 3120 cal; d. 264,000 cal
3. 27.9°C
4. 0.0337 cal/°C · g

Level 3: 1. 210 g; 2. 0.213 cal/°C · g; 3. 69°C; 4. 0.031 cal/°C · g;
5. .0408 cal/°C · g; 6. 327 g; 7. 131.0 cal/g; 8. 146 g;
9. 1326 kcal; 10. 2534 kcal

Stoichiometry

Many times, one would like to know the weight and/or volume relationships among substances involved in a chemical reaction. The study of these relationships is known as **stoichiometry**. The ability to solve stoichiometric problems depends upon two skills: (1) the ability to convert between grams and moles, and (2) the ability to express the mole relationships of reactants and products in a reaction. The first solved example below will serve as a model for the steps to be followed in attacking any stoichiometric problem.

Solved Examples

Example 1: What mass, in grams, of hydrogen is needed in order to prepare 200.0 g of ammonia from its elements?

Solution: The following steps are necessary in solving most stoichiometric problems.

Step 1: Write a balanced equation for the reaction.

$$3\,H_2 + N_2 \rightarrow 2\,NH_3$$

Step 2: Select the two substances in the reaction with which you will work. One of these involves a known quantity. The other is the one for which you must obtain a quantity. In this case, the known quantity is **200.0 g of ammonia**. The unknown quantity is an **unknown weight of hydrogen**.

Step 3: Express the known quantity in terms of moles.

$$200.0\text{ g }NH_3 \times \frac{1\text{ mol}}{17.03\text{ g }NH_3} = 11.74\text{ mol }NH_3$$

Step 4: Express the mole ratio between the known and unknown quantities.

$$NH_3 : H_2 = 2 : 3 \text{ (from equation)}$$

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Step 5: Find the number of moles of unknown needed.

$$11.74 \text{ mol } NH_3 \times \frac{3 \text{ mol } H_2}{2 \text{ mol } NH_3} = 17.61 \text{ mol } H_2$$

Step 6: Convert the answer found in moles to its equivalent in grams.

$$17.61 \text{ mol } H_2 \times \frac{2.016 \text{ g } H_2}{1 \text{ mol } H_2} = 35.50 \text{ g } H_2$$

Example 2: What volume of hydrogen gas is needed to produce 200.0 g of ammonia?

Solution: Problems involving volume are solved in exactly the same way as shown in Example 1. Simply remember that, for all gases, 1 mol = 22.4 L. Then, steps 1 – 5 from Example 1 would be the same. But for step 6, convert the answer found in moles to its equivalent **in liters.**

$$17.6 \text{ mol } H_2 \times \frac{22.4 \text{ L}}{1 \text{ mol}} = 394 \text{ L } H_2$$

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Stoichiometry

Practice Problems (Level 1)

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1. In the reaction shown here, what weight of iron is needed to react completely with 32.0 g of sulfur? $Fe + S \rightarrow FeS$

2. When zinc reacts with sulfuric acid, as shown here, what weight of hydrogen is produced from 31.8 g of zinc? $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2\uparrow$

3. How much sulfurous acid can be produced when 128 g of sulfur dioxide combines with water? $SO_2 + H_2O \rightarrow H_2SO_3$

4. Silver bromide can be precipitated by the reaction of silver nitrate with sodium bromide. What weight of precipitate can be produced starting with 34.3 of sodium bromide? $NaBr + AgNO_3 \rightarrow NaNO_3 + AgBr\downarrow$

5. Hydrochloric acid is added to 50.0 g of iron (II) sulfide. What weight of hydrogen sulfide is produced? $FeS + 2\,HCl \rightarrow FeCl_2 + H_2S\uparrow$

6. How much nitric acid is needed to react completely with 25.0 g of magnesium in the following reaction? $Mg + 2\,HNO_3 \rightarrow Mg(NO_3)_2 + H_2\uparrow$

7. How much copper (I) chloride can be produced beginning with 75.0 g of copper (I) oxide? $Cu_2O + 2\,HCl \rightarrow 2\,CuCl + H_2O$

8. What volume of oxygen gas is produced by the decomposition of 100.0 g of sodium nitrate? $2\,NaNO_3 \rightarrow 2\,NaNO_2 + O_2\uparrow$

9. What volume of oxygen is produced when 75.0 g of water is decomposed by electrolysis? $2\,H_2O \rightarrow 2\,H_2 + O_2\uparrow$

10. What volume of carbon dioxide is required to produce 50.0 L of carbon monoxide according to the following reaction? $CO_2 + C \rightarrow 2\,CO\uparrow$

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Stoichiometry

Practice Problems (Level 2)

1. When aluminum is heated in oxygen, aluminum oxide is formed. What weight of the oxide can be obtained from 25.0 g of the metal?
2. When steam (hot water) is passed over iron, hydrogen gas and iron (III) oxide are formed. What weight of steam would be needed to react completely with 100.0 g of iron?
3. How much ammonium hydroxide is needed to react completely with 75.0 g of copper (II) nitrate in a double replacement reaction?
4. When ammonia is burned in oxygen, free nitrogen gas and water are produced. What volume of ammonia will react completely with 25.0 L of oxygen? What volume of nitrogen gas is formed?
5. When sodium carbonate reacts with hydrochloric acid, the carbonic acid that is formed immediately breaks down into carbon dioxide and water. What weight of sodium carbonate would have been present originally if 5.0 L of carbon dioxide were obtained in this way?
6. How much copper metal can be obtained by the single replacement reaction between copper (I) nitrate and 30.0 g of iron metal? (Iron [II] nitrate is formed.)
7. What weight of sulfuric acid will be needed to react completely with 35.5 g of ammonia in the production of ammonium sulfate?
8. What weight of chlorine gas will be needed to react completely with 85.8 g of potassium iodide in a single replacement reaction?
9. In the neutralization reaction between sulfuric acid and potassium hydroxide, how much potassium sulfate can be produced if you have 150.0 g of sulfuric acid to begin with?
10. What volume of nitrogen gas is needed to react completely with 150.0 L of hydrogen in the production of ammonia?

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Stoichiometry

Practice Problems (Level 3)

1. How much aluminum metal is needed to replace all of the iron from 27.8 g of iron (III) oxide?
2. What volume of chlorine gas will react with antimony in order to produce 58.9 g of antimony trichloride?
3. What weight of iron metal will be required to produce 20.8 g of iron (III) oxide in the reaction with pure oxygen?
4. What weight of aluminum bromide can be produced by the reaction of sufficient aluminum sulfate with 8.75 g of ammonium bromide?
5. What weights of water and diphosphorus pentoxide will be needed in order to produce 95.5 g of phosphoric acid?
6. 50.0 g of oxygen are available for the combustion of 25.0 g of carbon. Is this an adequate amount of oxygen? If so, by how much in excess is the oxygen? If not, by how much is the carbon in excess?
7. How many grams of carbon dioxide can be obtained from the reaction of 100.0 g of sulfuric acid and 100.0 g of calcium carbonate?
8. In testing for the efficacy of an antacid compound, 5.0 g of hydrochloric acid is mixed with 24.0 g of magnesium hydroxide. Is this enough base to react with all the acid?
9. In the human body, the toxic compound hydrogen cyanide is neutralized by the acid, $H_2S_2O_3$, according to the reaction: $HCN + H_2S_2O_3 \rightarrow HCNS + H_2SO_3$. If 1.000 mg of $H_2S_2O_3$ is available in the body, will this be enough to neutralize 2.000 mg of HCN swallowed by a person?
10. In the combustion of hydrogen sulfide with oxygen, will 45.0 L be enough oxygen to burn completely 35.0 g of hydrogen sulfide?

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Stoichiometry

Teacher Notes

1. Explanation of Levels

Level 1: Simple reactions; mole ratios no more complex than 1:2; all equations given.

Level 2: Somewhat more complex reactions, with mole ratios greater than 1:2; equations not given.

Level 3: Somewhat more complex reactions, without equations; problems involving excess of one reagent.

2. Answers

Level 1: 1. 55.7 g; 2. .982 g; 3. 164 g; 4. 62.6 g; 5. 19.4 g; 6. 130 g; 7. 104 g; 8. 13.2 L; 9. 46.7 L; 10. 25.0 L

Level 2: 1. 47.2 g; 2. 48.2 g; 3. 28.0 g; 4. 33.3 L; 16.7 L; 5. 23.6 g; 6. 68.1 g; 7. 102 g; 8. 18.3 g; 9. 266.5 g; 10. 50.0 L

Level 3: 1. 9.39 g; 2. 8.67 L; 3. 14.5 g; 4. 7.94 g; 5. 69.2 g P_2O_5; 26.3 g H_2O; 6. carbon in excess by 0.5 mol; 7. 43.97 g; 8. magnesium hydroxide in excess by 0.343 mol; 9. no; HCN is in excess; 10. yes; 34.6 L needed

Ionic Equations

$$NaNO_3 + KCl \rightarrow KNO_3 + NaCl$$

A **molecular equation** like this one is useful in many respects. It can be used, for example, to solve stoichiometric problems. But in some ways, a molecular equation is incorrect. It may not show the real changes that take place during a chemical reaction. In many situations, an **ionic** or **net ionic** equation is more descriptive and more accurate.

An ionic equation shows the state in which each part of the reaction actually exists in the reaction. For example, in the reaction shown above, all four species are strong electrolytes that would exist completely ionized in water solution. It would be more accurate to represent that reaction, then, as follows:

$$Na^+ + NO_3^- + K^+ + Cl^- \rightarrow K^+ + NO_3^- + Na^+ + Cl^-$$

A net ionic equation shows all changes which actually took place during the reaction. Notice that in the above example each ion that was present at the beginning of the reaction was also present at the conclusion of the reaction. In this case, that is, there was really no change at all. For the net ionic equation, we would simply write: NR (no reaction).

Solved Examples

Example 1: Write the molecular, ionic and net ionic equations for the reaction between sodium hydroxide and hydrochloric acid.

Solution: Write the molecular equation first:

$$NaOH + HCl \rightarrow NaCl + H_2O$$

Now, determine the status of each species in a water solution:

$$Na^+ + OH^- + H^+ + Cl^- \rightarrow Na^+ + Cl^- + H_2O$$

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Finally, determine the changes which actually took place during the reaction. Notice that sodium ions and chloride ions are present as both products and reactants. They did not change during the course of the reaction. They are known as **spectator ions**. The only change which did occur (the net ionic reaction) is:

$$OH^- + H^+ \rightarrow H_2O$$

Example 2: Write the molecular, ionic and net ionic equations for the reaction between barium chloride and silver nitrate.

Solution: Molecular: $BaCl_2 + 2\ AgNO_3 \rightarrow Ba(NO_3)_2 + 2\ AgCl \downarrow$

Ionic: $Ba^{+2} + 2\ Cl^- + 2\ Ag^+ + NO_3^- \rightarrow Ba^{+2} + 2\ NO_3^- + 2\ AgCl \downarrow$

Net Ionic: $2\ Cl^- + 2\ Ag^+ \rightarrow 2\ AgCl \downarrow$

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Ionic Equations

Practice Problems (Level 1)

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1. Write ionic and net ionic equations for each of the following reactions.

a. $KCl + NaI \rightleftharpoons KI + NaCl$

b. $CuNO_3 + LiF \rightleftharpoons CuF + LiNO_3$

c. $NaClO_3 + NH_4Cl \rightleftharpoons NaCl + NH_4ClO_3$

d. $2\ Na_2OH + H_2SO_4 \rightarrow Na^2SO_4 + 2\ H_2O$

e. $SrBr_2 + K_2SO_4 \rightarrow 2\ KBr + SrSO_4 \downarrow$

f. $2\ LiOH + H_2S \rightarrow Li_2S + 2\ H_2O$

g. $AlCl_3 + H_3PO_4 \rightarrow 3\ HCl + AlPO_4 \downarrow$

h. $MgCl_2 + 2\ AgNO_3 \rightarrow Mg(NO_3)_2 + 2\ AgCl \downarrow$

2. Write molecular, ionic, and net ionic equations for each of the following reactions.

a. sulfuric acid + sodium chloride $\rightleftharpoons$ hydrochloric acid + sodium sulfate

b. potassium iodide + ammonium nitrate $\rightleftharpoons$ potassium nitrate + ammonium iodide

c. calcium hydroxide + sulfuric acid → calcium sulfate ↓ + water

d. ammonium chloride + potassium hydroxide → potassium chloride + ammonia ↑ + water

e. aluminum chloride + iron (III) nitrate $\rightleftharpoons$ aluminum nitrate + iron (III) chloride

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Ionic Equations

Practice Problems (Level 2)

1. Write an ionic equation which shows what happens when each of the following substances is put into water.

   a. sodium chloride
   b. hydrogen chloride
   c. calcium bromide
   d. potassium sulfate
   e. aluminum nitrate
   f. hydrogen iodide
   g. ammonium phosphate
   h. hydrogen sulfide

2. Write a molecular, ionic, and net ionic equation for each of the following reactions.

   a. calcium chloride + ammonium hydroxide ⇌ calcium hydroxide + ammonium chloride
   b. potassium hydroxide + sulfuric acid → potassium sulfate + water
   c. lead (II) nitrate + sodium sulfide → lead (II) sulfide ↓ + sodium nitrate
   d. lithium carbonate + hydrochloric acid → lithium chloride + water + carbon dioxide
   e. ammonium bromide + strontium hydroxide → strontium bromide + ammonia ↑ + water
   f. calcium bromide + lithium sulfate → lithium bromide + calcium sulfate ↓
   g. potassium carbonate + sulfuric acid → potassium sulfate + water + carbon dioxide ↑
   h. sodium chlorate + ammonium chloride ⇌ ammonium chlorate + sodium chloride

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Ionic Equations

Practice Problems (Level 3)

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1. Write ionic equations which show what happens when each of the following is put into water.

   a. hydrogen bromide
   b. sodium phosphate
   c. silver chloride
   d. aluminum sulfate
   e. hydrogen selenide
   f. magnesium phosphate
   g. ammonium acetate
   h. hydrogen acetate

2. Write molecular, ionic, and net ionic equations which show what happens in each of the following reactions.

   a. sodium sulfite + hydrochloric acid
   b. ammonium hydroxide + barium chloride
   c. acetic acid + sodium carbonate
   d. zinc chloride + sodium phosphate
   e. iron (III) chloride + sodium sulfide
   f. phosphoric acid + ammonium hydroxide
   g. ammonium carbonate + hydrobromic acid
   h. iron (III) sulfate + lead (II) chlorate

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Ionic Equations

Teacher Notes

1. Explanation of Levels

Level 1: Simple reactions with mole ratios of 1:1 and 1:2; most equations already written in molecular form.

Level 2: Some predictions of dissociation versus ionization; more complex reactions, with mole ratios greater than 1:2; unstable compounds produced as products.

Level 3: Some predictions of dissociation versus ionization; still more complex reactions; all variety of possibilities included; reaction prediction required for most reactions.

2. Answers

Level 1:

1. a. $K^+ + Cl^- + Na^+ + I^- \rightarrow K^+ + I^- + Na^+ + Cl^-$; NR
   b. $Cu^+ + NO_3^- + Li^+ + F^- \rightarrow Cu^+ + F^- + Li^+ + NO_3^-$; NR
   c. $Na^+ + ClO_3^- + NH_4^+ + Cl^- \rightarrow Na^+ + Cl^- + NH_4^+ + ClO_3^-$; NR
   d. $2\,Na^+ + 2\,OH^- + 2\,H^+ + SO_4^{-2} \rightarrow 2\,Na^+ + SO_4^{-2} + 2\,H_2O$; $2\,OH^- + 2\,H^+ \rightarrow 2\,H_2O$
   e. $Sr^{+2} + 2\,Br^- + 2\,K^+ + SO_4^{-2} \rightarrow 2\,K^+ + 2\,Br^- + SrSO_4$; $Sr^{+2} + SO_4^{-2} \rightarrow SrSO_4\downarrow$
   f. $2\,Li^+ + 2\,OH^- + 2\,H^+ + S^{-2} \rightarrow 2\,Li^+ + S^{-2} + 2\,H_2O$; $2\,OH^- + 2\,H^+ \rightarrow 2\,H_2O$
   g. $Al^{+3} + 3\,Cl^- + 3\,H^+ + PO_4^{+3} \rightarrow 3\,H^+ + 3\,Cl^- + AlPO_4\downarrow$; $Al^{+3} + PO_4^{-3} \rightarrow AlPO_4\downarrow$
   h. $Mg^{+2} + 2\,Cl^- + 2\,Ag^+ + NO_3^- \rightarrow Mg^{+2} + 2\,NO_3^- + 2\,AgCl\downarrow$; $2\,Cl^- + 2\,Ag^+ \rightarrow 2\,AgCl\downarrow$

2. a. $H_2SO_4 + 2\,NaCl \rightleftharpoons 2\,HCl + Na_2SO_4$;
$2\,H^+ + SO_4^{-2} + 2\,Na^+ + 2\,Cl \rightarrow 2\,H^+ + 2\,Cl^- +$
$2\,Na^+ + SO_4^{-2}$; NR
b. $KI + NH_4NO_3 \rightleftharpoons KNO_3 + NH_4I$;
$K^+ + I^- + NH_4^+ + I^- \rightarrow K^+ + NO_3^- + NH_4^+ + I^-$; NR
c. $Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4\downarrow + H_2O$;
$Ca^{+2} + 2\,OH^- + 2\,H^+ + SO_4^{-2} \rightarrow CaSO_4 + H_2O$;
net is same
d. $NH_4Cl + KOH \rightarrow KCl + NH_3\uparrow + H_2O$;
$NH_4^+ + Cl^- + K^+ + OH^- \rightarrow K^+ + Cl^- + NH_3\uparrow + H_2O$;
$NH_4^+ + OH^- \rightarrow NH_3\uparrow + H_2O$
e. $AlCl_3 + Fe(NO_3)_3 \rightleftharpoons Al(NO_3)_3 + FeCl_3$;
$Al^{+3} + 3\,Cl^- + Fe^{+3} + 3\,NO_3^- \rightarrow Al^{+3} + 3\,NO_3^- +$
$Fe^{+3} + 3\,Cl^-$; NR

Level 2: 1. a. $Na^+, Cl^- \rightarrow Na^+ + Cl^-$
b. $HCl \rightarrow H^+ + Cl^-$
c. $Ca^{+2}, Br^-_2 \rightarrow Ca^{+2} + 2\,Br^-$
d. $K^+_2SO_4^{-2} \rightarrow 2\,K^+ + SO_4^{-2}$
e. $Al^{+3}(NO_3)^-_3 \rightarrow Al^{+3} + 3\,NO_3^-$
f. $HI \rightarrow H^+ + I^-$
g. $(NH_4)^+_3PO_4^{-3} \rightarrow 3\,NH_4^+ + PO_4^{-3}$
h. $H_2S \rightarrow 2\,H^+ + S^{-2}$

2. a. $CaCl_2 + 2\,NH_4OH \rightleftharpoons Ca(OH)_2 + 2\,NH_4Cl$;
$Ca^{+2} + 2\,Cl^- + 2\,NH_4^+ + 2\,OH^- \rightarrow Ca^{+2} + 2\,OH^- +$
$2\,NH_4^+ + 2\,Cl^-$; NR
b. $2\,KOH + H_2SO_4 \rightarrow K_2SO_4 + 2\,H_2O$
$2\,K^+ + 2\,OH^- + 2\,H^+ + SO_4^{-2} \rightarrow 2\,K^+ + SO_4^{-2} + 2\,H_2O$;
$2\,OH^- + 2\,H^+ \rightarrow 2\,H_2O$
c. $Pb(NO_3)_2 + Na_2S \rightarrow PbS\downarrow + 2\,NaNO_3$;
$Pb^{+2} + 2\,NO_3^- + 2\,Na^+ + S^{-2} \rightarrow PbS\downarrow + 2\,Na^+ +$
$2\,NO_3^-$; $Pb^{+2} + S^{-2} \rightarrow PbS\downarrow$
d. $Li_2CO_3 + 2\,HCl \rightarrow 2\,LiCl + H_2O + CO_2\uparrow$;
$2\,Li^+ + CO_3^{-2} + 2\,H^+ + 2\,Cl^- \rightarrow 2\,Li^+ + 2\,Cl^- + H_2O +$
$CO_2\uparrow$; $CO_3^{-2} + 2\,H^+ \rightarrow H_2O + CO_2\uparrow$
e. $2\,NH_4Br + Sr(OH)_2 \rightarrow SrBr_2 + 2\,NH_3\uparrow + 2\,H_2O$;
$2\,NH_4^+ + 2\,Br^- + Sr^{+2} + 2\,OH^- \rightarrow Sr^{+2} + 2\,Br^- +$
$2\,NH_3\uparrow + 2\,H_2O$; $2\,NH_4^+ + 2\,OH^- \rightarrow 2\,NH_3\uparrow + 2\,H_2O$
f. $CaBr_2 + Li_2SO_4 \rightarrow 2\,LiBr + CaSO_4\downarrow$;
$Ca^{+2} + 2\,Br^- + 2\,Li^+ + SO_4^{-2} \rightarrow 2\,Li^+ + 2\,Br^- +$
$CaSO_4\downarrow$; $Ca^{+2} + SO_4^{-2} \rightarrow CaSO_4\downarrow$
g. $K_2CO_3 + H_2SO_4 \rightarrow K_2SO_4 + H_2O + CO_2\uparrow$;
$2\,K^+ + CO_3^{-2} + 2\,H^+ + SO_4^{-2} \rightarrow 2\,K^+ + SO_4^{-2} + H_2O +$
$CO_2\uparrow$; $CO_3^{-2} + 2\,H^+ \rightarrow H_2O + CO_2\uparrow$

h. $NaClO_3 + NH_4Cl \rightleftharpoons NH_4ClO_3 + NaCl$; $Na^+ + ClO_3^- + NH_4^+ + Cl^- \rightarrow NH_4^+ + ClO_3^- + Na^+ + Cl^-$; NR

Level 3: 1. a. $HBr \rightarrow H^+ + Br^-$

b. $Na^+_3(PO_4^{-3}) \rightarrow 3\ Na^+ + PO_4^{-3}$

c. $Ag^+, Cl^- \rightarrow$ NR

d. $Al^{+3}_2(SO_4^{-2})_3 \rightarrow 2\ Al^{+3} + 3\ SO_4^{-2}$

e. $H_2Se \rightarrow 2\ H^+ + Se^{-2}$

f. $Mg^{+2}_3(PO_4^{-3})_2 \rightarrow 3\ Mg^{+2} + 2\ PO_4^{-3}$

g. $NH_4^+, C_2H_3O_2^- \rightarrow NH_4^+ + C_2H_3O_2^-$

h. $HC_2H_3O_2 \rightarrow H^+ + C_2H_3O_2^-$

2. a. $Na_2SO_3 + 2\ HCl \rightarrow 2\ NaCl + H_2O + SO_2\uparrow$; $2\ Na^+ + SO_3^{-2} + 2\ H^+ + 2\ Cl^- \rightarrow 2\ Na^+ + 2\ Cl^- + H_2O + SO_2\uparrow$; $SO_3^{-2} + 2\ H^+ \rightarrow H_2O + SO_2\uparrow$

b. $2\ NH_4OH + BaCl_2 \rightleftharpoons 2\ NH_4Cl + Ba(OH)_2$; $2\ NH_4^+ + 2\ OH^- + Ba^{+2} + 2\ Cl^- \rightarrow 2\ NH_4^+ + 2\ Cl^- + Ba^{+2} + 2\ OH^-$; NR

c. $2\ HC_2H_3O_2 + Na^2CO^3 \rightarrow 2\ NaC_2H_3O_2 + H_2O + CO_2\uparrow$; $2\ H^+ + 2\ C_2H_3O_2^- + 2\ Na^+ + CO_3^{-2} \rightarrow 2\ Na^+ + 2\ C_2H_3O_2^- + H_2O + CO_2\uparrow$; $2\ H^+ + CO_3^{-2} \rightarrow H_2O + CO_2\uparrow$

d. $3\ ZnCl_2 + 2\ Na_3PO_4 \rightarrow Zn_3(PO_4)_2\downarrow + 6\ NaCl$; $3\ Zn^{+2} + 6\ Cl^- + 6\ Na^+ + 2\ PO_4^{-3} \rightarrow Zn_3(PO_4)_2\downarrow + 6\ Na^+ + 6\ Cl^-$; $3\ Zn^{+2} + 2\ PO_4^{-3} \rightarrow Zn_3(PO_4)_2\downarrow$

e. $2\ FeCl_3 + 3\ Na_2S \rightarrow 6\ NaCl + Fe_2S_3\downarrow$; $2\ Fe^{+3} + 6\ Cl^- + 6\ Na^+ + 3\ S^{-2} \rightarrow 6\ Na^+ + 6\ Cl^- + Fe_2S_3\downarrow$; $2\ Fe^{+3} + 3\ S^{-2} \rightarrow Fe_2S_3\downarrow$

f. $H_3PO_4 + 3\ NH_4OH \rightarrow (NH_4)_3PO_4 + 3\ H_2O$; $3\ H^+ + PO_4^{-3} + 3\ NH_4^+ + 3\ OH^- \rightarrow 3\ NH_4^+ + PO_4^{-3} + 3\ H_2O$; $3\ H^+ + 3\ OH^- \rightarrow 3\ H_2O$

g. $(NH_4)_2CO_3 + 2\ HBr \rightarrow 2\ NH_4Br + H_2O + CO_2\uparrow$; $2\ NH_4^+ + CO_3^{-2} + 2\ H^+ + 2\ Br^- \rightarrow 2\ NH_4^+ + 2\ Br^- + H_2O + CO_2\uparrow$; $CO_3^{-2} + 2\ H^+ \rightarrow H_2O + CO_2\uparrow$

h. $Fe_2(SO_4)_3 + 3\ Pb(ClO_3)_2 \rightleftharpoons 2\ Fe(ClO_3)_3 + 3\ PbSO_4$; $2\ Fe^{+3} + 3\ SO_4^{-2} + 3\ Pb^{+2} + 6\ ClO_3^- \rightarrow 2\ Fe^{+3} + 6\ ClO_3^- + 3\ Pb^{+2} + 3\ SO_4^{-2}$; NR

pH

The acidity of a solution is usually expressed in one of two ways: (1) as the concentration of hydrogen ions, in moles per liter $[H^+]$; or (2) as pH. The quantity known as **pH** is defined as the negative logarithm of the hydrogen ion concentration, or $pH = -\log [H^+]$.

The hydrogen ion concentration in a solution is generally dependent upon two factors: (1) the concentration of the acid itself, and (2) the degree of ionization of the acid. In other words,

$$[H^+] = [HX] \times \text{d.i.}$$

In some situations it is also useful to know the hydroxide ion ($[OH^-]$) and pOH of a solution. These are related to $[H^+]$ and pH as follows:

$$[H^+] \times [OH^-] = 10^{-14} \qquad pH + pOH = 14.$$

Solved Examples

Example 1: Find the hydrogen ion concentration and pH of a 0.010 M solution of hydrochloric acid.

Solution: Since hydrochloric acid is a strong acid, it ionizes almost completely in water solution.

$$[H^+] = [HCl] \times 100\%$$
$$= 10^{-2}\text{ M} \times 1.00 = 10^{-2}\text{ M}$$

Then,

$$pH = -\log [H^+]$$
$$= -\log (10^{-2})$$
$$= -(-2) = +2$$

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Example 2: Find the hydrogen ion concentration and pH of a 0.0010 M solution of acetic acid (HAc) that is 5.0% ionized.

Solution:

$$\begin{aligned}[H^+] &= [HAc] \times 5.0\% \\ &= 1.0 \times 10^{-3}\ M \times 5.0 \times 10^{-2} \\ &= 5.0 \times 10^{-5}\end{aligned}$$

$$\begin{aligned}pH &= -\log(5.0 \times 10^{-5}) \\ &= -(0.699 - 5.000) = 4.3\end{aligned}$$

Example 3: Find the $[H^+]$, $[OH^-]$, pH and pOH of a 0.020 M solution of ammonium hydroxide that is 3.5% ionized. (Refer to Appendix 10, page 198, for logarithms needed in solving this problem.)

Solution:

$$\begin{aligned}[OH^-] &= [NH_4OH] \times 3.5\% \\ &= 2.0 \times 10^{-2}\ M \times 3.5 \times 10^{-2} = 7.0 \times 10^{-4}\ M\end{aligned}$$

$$[H^+] = \frac{1.0 \times 10^{-14}}{7.0 \times 10^{-4}} = 1.4 \times 10^{-11}\ M$$

$$\begin{aligned}pOH &= -\log(7.0 \times 10^{-4}) \\ &= -(0.845 - 4.000) = 3.2\end{aligned}$$

$$pH = 14.0 - 3.2 = 10.8$$

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pH

Practice Problems (Level 1)

1. Find the hydrogen ion concentration of each of the following solutions.

- a. 1.0 M acetic acid, 0.10% ionized.
- b. 1.0 M hydrocyanic acid, 0.010% ionized.
- c. 0.100 M acetic acid, 1.0% ionized.
- d. 0.010 M nitrous acid, 1.0% ionized.
- e. 0.0010 M hydrocyanic acid, 1.00% ionized.

2. Find the pH of each of the following solutions.

- a. 1.0 M boric acid, 0.0010% ionized.
- b. 0.010 M hydrocyanic acid, 0.10% ionized.
- c. 0.010 M acetic acid, 10.0% ionized.
- d. 0.00010 M boric acid, 0.10% ionized.
- e. 0.0100 M acetic acid, 0.010% ionized.

3. Find the hydroxide ion concentration of each of the solutions listed in question 1.

4. Find the pOH of each of the solutions listed in question 2.

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pH

Practice Problems (Level 2)

1. Find the hydrogen ion concentration and pH of each of the following solutions.
    - a. hydrocyanic acid: 1.0×10^{-5} M; 10.0% ionized.
    - b. boric acid: 1.0×10^{-5} M; 1.0% ionized.
    - c. acetic acid: 0.050 M; 5.0% ionized.
    - d. tartaric acid: 0.0030 M; 3.0% ionized.
    - e. boric acid: 3.0×10^{-3} M; 4.0% ionized.
    - f. acetic acid: 2.0×10^{-4} M; 3.0% ionized.
    - g. tartaric acid: 4.0×10^{-3} M; 2.3% ionized.
    - h. hydrocyanic acid: 3.5×10^{-2} M; 1.5% ionized.
2. Find the hydroxide ion concentration, hydrogen ion concentration, pH, and pOH for each of the following solutions.
    - a. ammonium hydroxide: 1.0×10^{-3} M; 1.00% ionized.
    - b. ammonium hydroxide: 2.5×10^{-2} M; 2.50% ionized.
    - c. acetic acid: 3.5×10^{-3} M; 3.0% ionized.
    - d. acetic acid: 2.5×10^{-2} M; 2.5% ionized.
    - e. acetic acid: 4.0×10^{-3} M; 2.0% ionized.

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pH

Practice Problems (Level 3)

Find the hydrogen ion concentration, hydroxide ion concentration, pH, and pOH for each of the following solutions.

1. 0.236 M HCl, 100% ionized.

2. 0.084 M HNO_3, 100% ionized.

3. 0.100 M $HC_2H_3O_2$, 5.8% ionized.

4. 0.100 M HNO_2, 0.43% ionized.

5. 0.100 M HNO_2, 0.0674% ionized.

6. 0.058 M $HC_2H_3O_2$, 9.3% ionized.

7. 0.042 M HNO_2, 3.82% ionized.

8. 0.066 M HNO_2, 0.124% ionized.

9. 0.0049 M $HC_2H_3O_2$, 13.4% ionized.

10. 0.00232 M HNO_2, 6.45% ionized.

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pH

Teacher Notes

1. Explanation of Levels

Level 1: $[H^+]$, $[OH^-]$, pH, and pOH for solutions involving exact powers of ten only; log tables not needed for solution.

Level 2: $[H^+]$, $[OH^-]$, pH, and pOH for solutions involving single digit factors other than one times exact powers of ten; log tables required.

Level 3: $[H^+]$, $[OH^-]$, pH, and pOH for solutions of all concentrations and degrees of ionization; log tables required.

2. Answers

(given in sequence of $[H^+]$, $[OH^-]$, pH, pOH where needed)

Level 1:

1. a. 10^{-3}; b. 10^{-4}; c. 10^{-3}; d. 10^{-4}; e. 10^{-5}
2. a. 5; b. 5; c. 3; d. 7; e. 6
3. a. 10^{-11}; b. 10^{-10}; c. 10^{-11}; d. 10^{-10}; e. 10^{-9}
4. a. 9; b. 9; c. 11; d. 7; e. 8

Level 2:

1. a. 10^{-6}; 6; b. 10^{-7}; 7;
   c. 2.5×10^{-3}; 2.6; d. 9×10^{-5}; 4.0;
   e. 1.2×10^{-4}; 3.9; f. 6×10^{-6}; 5.2;
   g. 9.2×10^{-5}; 4.0; h. 5.3×10^{-4}; 3.3

2. a. 1×10^{-9}; 1×10^{-5}; 9; 5
   b. 1.6×10^{-11}; 6.3×10^{-4}; 10.8; 3.2
   c. 1.1×10^{-4}; 9.1×10^{-11}; 4.0; 10.0
   d. 6.3×10^{-4}; 1.6×10^{-11}; 3.2; 10.8
   e. 8.0×10^{-5}; 1.3×10^{-10}; 4.1; 9.9

Level 3:

1. 2.36×10^{-1}; 4.24×10^{-14}; 0.63; 13.37
2. 8.4×10^{-2}; 1.2×10^{-13}; 1.1; 12.9
3. 5.8×10^{-3}; 1.7×10^{-12}; 2.2; 11.8
4. 4.3×10^{-4}; 2.3×10^{-11}; 3.4; 10.6
5. 6.74×10^{-5}; 1.48×10^{-10}; 4.2; 9.8
6. 5.4×10^{-3}; 1.9×10^{-12}; 2.3; 11.7
7. 1.6×10^{-3}; 6.3×10^{-12}; 2.8; 11.2
8. 8.2×10^{-5}; 1.2×10^{-10}; 4.1; 9.9
9. 6.6×10^{-4}; 1.5×10^{-11}; 3.2; 10.8
10. 1.5×10^{-4}; 6.7×10^{-11}; 3.8; 10.2

Standard Solutions

The concentration of a solution can be expressed in many ways: percent (weight/weight, weight/volume, or volume/volume), molarity, and normality are perhaps the most common. In general, the fundamental relationship in any of these solutions is:

$$\text{concentration} = \frac{\text{quantity of solute}}{\text{quantity of solution}}$$

If two of these three variables are known, the third can always be calculated.

Solved Examples

Example 1: How would you make 100 mL of a 2.0% (w/v) solution of sodium chloride?

Solution: Dissolve 2.0 g of sodium chloride in enough water to make 100 mL of solution.

Example 2: How much sucrose is contained in 15.0 mL of a 2.5% (w/v) solution of this substance?

Solution:

$$\text{percent (w/v)} = \frac{\text{weight of solute}}{\text{volume of solution}}$$

or,

$$\begin{aligned} \text{weight of solute} &= \text{percent} \times \text{volume} \\ &= 2.5\ \frac{\text{g}}{100\,\cancel{\text{mL}}} \times 15.0\,\cancel{\text{mL}} \\ &= 0.38\ \text{g} \end{aligned}$$

Example 3: How would you make 250. mL of a 0.050 M solution of barium chloride?

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Solution:

$$0.050 \frac{\cancel{mol}}{\cancel{L}} \times \frac{208.3}{\cancel{mol}} \times \frac{1 \cancel{L}}{1000 \cancel{mL}} \times 250 \cancel{mL} = 2.60 \text{ g}$$

That is, dissolve 2.60 g of barium chloride in enough water to make 250. mL of solution.

Example 4: What volume of a 0.035 N solution of sulfuric acid will contain 18.5 g of the acid?

Solution: From fundamental relationship,

$$\text{volume of solution} = \frac{\text{weight of solute}}{\text{concentration}}$$

$$\text{or,} \quad \text{volume} = \frac{18.5 \cancel{g} \times \frac{1 \cancel{mol}}{98.0 \cancel{g}} \times \frac{2 \cancel{ew}}{1 \cancel{mol}}}{0.035 \frac{\cancel{ew}}{L}} = 10.8 \text{ L}$$

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Standard Solutions

Practice Problems (Level 1)

1. Explain how you would make each of the following solutions.
    a. a 10% (w/v) solution of potassium hydroxide
    b. a 0.1% (w/w) solution of barium hydroxide
    c. a 1.0% (v/v) solution of ethyl alcohol
    d. a 2.4% (w/v) solution of sodium chloride
    e. a 1.0 M solution of silver nitrate ($AgNO_3$)
    f. a 0.010 M solution of acetic acid ($HC_2H_3O_2$)
    g. a 1.0 N solution of sodium sulfate (Na_2SO_4)
    h. 250 mL of a 0.20 N solution of ammonium hydroxide (NH_4OH)

2. What weight of solute is contained in each of the following?
    a. 50.0 mL of a 10% (w/v) solution of ammonium chloride (NH_4Cl)
    b. 25 g of a 2.5% (w/w) solution of sodium chloride
    c. 250 mL of a 0.9% (w/v) solution of sodium chloride
    d. 500.0 mL of a 0.10 M solution of sodium citrate ($Na_3C_6H_5O_7$)
    e. 1.0 L of a 0.010 N solution of magnesium hydroxide ($Mg[OH]_2$)
    f. 400. mL of a 0.10 N solution of barium nitrate ($Ba[NO_3]_2$)

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Standard Solutions

Practice Problems (Level 2)

1. Explain how to make each of the following solutions.
   a. 10.0 g of a 0.10% (w/w) solution of sodium hydroxide
   b. 250. mL of a 1.00% (v/v) ethyl alcohol solution
   c. 1.0 L of a 1×10^{-4} M solution of tartar emetic ($KC_4H_4O_6$)
   d. 750. mL of a 0.050 M solution of potassium permanganate
   e. 250. mL of a 0.010 M solution of sodium hypochlorite (NaClO)
   f. 350. mL of a 0.030 N solution of magnesium chloride
   g. 100.0 mL of a 0.20 N solution of nickel (II) sulfate
   h. 25.0 mL of a 0.80 N solution of aluminum iodide

2. What is the concentration of each of the following solutions, in concentration units requested?
   a. 0.54 g of ammonium chloride in 250. mL of solution (in M)
   b. 492 g of sodium phosphate in 500. mL of solution (in M)
   c. 18.4 g of mercury (II) chloride in 100 mL of solution (in M)
   d. 783 g of potassium sulfate in 750. mL of solution (in M)
   e. 2.29 g of lithium hydroxide in 200. mL of solution (in N)
   f. 42 g of potassium hydroxide in 750 mL of solution (in N)
   g. 1.75 g of ammonium hydroxide in 250. mL of solution (in N)
   h. 0.045 g of lead acetate in 30.0 mL of solution (in N)

3. What weight of solute is contained in each of the following solutions?
   a. 30.0 mL of a 0.030% (v/v) solution of formaldehyde
   b. 10.0 mL of a 4.75% (w/v) solution of glucose
   c. 100.0 mL of a 0.500 M solution of sodium chloride
   d. 350.0 mL of a 2.5 M solution of sodium phosphate
   e. 2.50 L of a 0.500 M solution of potassium permanganate
   f. 300.0 mL of a 0.100 N solution of sulfuric acid
   g. 50.0 mL of a 4.00 N solution of iron (III) nitrate
   h. 50.0 mL of a 2.00 N solution of barium nitrate

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Standard Solutions

Practice Problems (Level 3)

1. What is the molarity and normality of each of the following solutions?

- a. 2.43 g of hydrogen bromide in 1.0 L of solution
- b. 0.60 g of sodium fluoride in 15.0 mL of solution
- c. 1.14 g of aluminum sulfate in 100. mL of solution
- d. 4.5 g of calcium chloride in 125 mL of solution
- e. 2.1 g of manganese (II) chloride in 150. mL of solution
- f. 0.86 g of potassium phosphate in 12.5 mL of solution

2. What weight of solute is contained in each of the following solutions?

- a. 38 mL of 0.17 N strontium hydroxide
- b. 125 mL of 0.015 M iron (III) sulfate
- c. 250. mL of 0.25 N sodium nitrite
- d. 15 mL of 0.017 N calcium nitrate
- e. 250 mL of 0.325 M potassium phosphate
- f. 40.0 mL of 0.90 M aluminum sulfate
- g. 100.0 mL of a sample containing 5.00 ppm of DDT
- h. 25 mL of a sample of air containing 0.015 ppb of lead

3. What volume of solution would be required to deliver each of the following weights of solute?

- a. 3.0 g of a 3.0% (w/v) sodium chloride solution
- b. 0.46 g of 1.3% (w/v) sucrose solution
- c. 0.088 mg carbon monoxide from a sample containing 2.5 ppb
- d. 6.84 g of 0.20 M aluminum sulfate solution
- e. 10.4 g of 0.10 M barium nitrate solution
- f. 2.78 g of 0.10 N calcium chloride solution
- g. 0.500 g of 0.030 N magnesium chloride solution
- h. 0.240 g of 0.020 N copper (II) sulfate solution

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Standard Solutions

Teacher Notes

1. Explanation of Levels

Level 1: Primarily percent solution problems; most problems involve solutions of simple concentration (i.e., no more than one non-zero digit).

Level 2: Fewer percent and more molar and normal solutions; more difficult solutions to make; determination of concentration of solutions; calculating amount of solute present.

Level 3: Determination of more advanced normal and molar solutions; calculation of both solute and solution amounts needed to deliver given quantities; introduction of parts per million and parts per billion concentrations.

2. Answers

Level 1:

1. Amount of solute per amount of solution is given in each case.
   a. 10 g/100 mL
   b. 0.1 g/100 g
   c. 1.0 mL/100 mL
   d. 2.4 g/100 mL
   e. 169.9 g/1.0 L
   f. 0.60 g/1.0 L
   g. 71.0 g/1.0 L
   h. 1.8 g/250. mL

2. a. 5 g
   b. 0.63 g
   c. 2.3 g
   d. 12.9 g
   e. 0.292 g
   f. 5.22 g

Level 2:

1. Amount of solute per amount of solution is given in each case.
   a. 0.010 g/10.0 g
   b. 2.50 mL/250. mL
   c. 0.01881 g/1.0 L
   d. 5.9 g/750. mL
   e. 0.18 g/250. mL
   f. 0.50 g/350. mL
   g. 1.54 g/100. mL
   h. 2.72 g/25 mL

2. a. 0.040 M
   b. 6.0 M
   c. 0.50 M
   d. 6.0 M
   e. 0.50 N
   f. 1.00 N
   g. 0.20 N
   h. 0.010 N

Level 3:

1. a. 0.030 M; 0.030 N
   b. 0.095 M; 0.095 N
   c. 0.033 M; 0.20 N
   d. 3.24 M; 6.48 N
   e. 0.11 M; 0.22 N
   f. 0.33 M; 0.99 N

2. a. 0.40 g
   b. 2.9 g
   c. 4.3 g
   d. 0.021 g
   e. 17.2 g
   f. 1.23 g
   g. 0.500 mg
   h. 3.75×10^{-7} mg

3. a. 100. mL
   b. 35.5 mL
   c. 35.0 L
   d. 100. mL
   e. 400. mL
   f. 500. mL
   g. 350. mL
   h. 150. mL

Oxidation-Reduction Reactions

Some chemical changes involve an exchange of electrons as well as a rearrangement of atoms. Such changes are known as **oxidation-reduction (redox) reactions**. Balancing an equation that represents a redox reaction requires balancing both atoms (as is usually done in equation balancing) and electron loss and gain.

A variety of methods are available for balancing redox equations. Two are illustrated in the solved examples that follow.

Solved Examples

Example 1: Balance the following redox reaction:

$$HNO_3 + H_2S \rightarrow NO + S + H_2O$$

Solution: Oxidation state method: Determine the two elements which have changed oxidation state in the reaction. Record the changes these two have undergone:

$$N^{+5} \rightarrow N^{+2} \therefore \text{ N gains 3 } e^-$$

$$S^{-2} \rightarrow S^{0} \therefore \text{ S loses 2 } e^-$$

Find the least common multiple that will balance electron gain with electron loss: $3 \times 2 = 6$

$$2\ N^{+5} \rightarrow 2\ N^{+2} \therefore \text{ N gains 6 } e^-$$

$$3\ S^{-2} \rightarrow 3\ S^{0} \therefore \text{ S gains 6 } e^-$$

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Insert these coefficients into equation:

$$2\ HNO_3 + 3\ H_2S \rightarrow 2\ NO + 3\ S + H_2O$$

Finally, balance other atoms for which there was no electron change.

$$2\ HNO_3 + 3\ H_2S \rightarrow 2\ NO + 3\ S + 4\ H_2O$$

Example 2: Balance the following redox reaction:

$$MnO_4^- + H^+ + Cl^- \rightarrow Mn^{+2} + Cl_2 + H_2O$$

Solution: Half-reaction method: Identify the oxidizing agent and reducing agent and write half-reactions for each of these changes.

Oxidation: $2\ Cl^- \rightarrow Cl_2 + 2\ e^-$

Reduction: $MnO_4^- + 8\ H^+ + 5\ e^- \rightarrow Mn^{+2} + 4\ H_2O$

Now balance these two half-reactions by multiplying by some factor which will make the number of electrons lost equal to the number gained.

5 × oxidation: $10\ Cl^- \rightarrow 5\ Cl_2 + 10\ e^-$

2 × reduction: $2\ MnO_4^- + 16\ H^+ + 10\ e^- \rightarrow 2\ Mn^{+2} + 8\ H_2O$

Finally, add the two half-reactions:

$$10\ Cl^- + 2\ MnO_4^- + 16\ H^+ \rightarrow 5\ Cl_2 + 2\ Mn^{+2} + 8\ H_2O$$

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Oxidation-Reduction Reactions

Practice Problems (Level 1)

Balance each of the following redox equations by the method you prefer or are instructed to use.

1. $Cu + AgNO_3 \rightarrow Ag + Cu(NO_3)_2$

2. $CdS + I_2 + HCl \rightarrow CdCl_2 + HI + S$

3. $I_2 + Na_2S_2O_3 \rightarrow NaI + Na_2S_4O_6$

4. $K_2Cr_2O_7 + SnCl_2 + HCl \rightarrow CrCl_3 + SnCl_4 + KCl + H_2O$

5. $SnCl_2 + HgCl_2 \rightarrow SnCl_4 + HgCl$

6. $NaClO + H_2S \rightarrow NaCl + H_2SO_4$

7. $FeCl_2 + HCl + HNO_3 \rightarrow FeCl_3 + NO + H_2O$

8. $H_2O_2 + Ce(SO_4)_2 \rightarrow Ce_2(SO_4)_3 + H_2SO_4 + O_2$

9. $Sn + HNO_3 + H_2O \rightarrow H_2SnO_3 + NO$

10. $KBr + Fe_2(SO_4)_3 \rightarrow Br_2 + K_2SO_4 + FeSO_4$

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Oxidation-Reduction Reactions

Practice Problems (Level 2)

Balance each of the following redox equations by the method you prefer or are instructed to use.

1. $Ca(OH)_2 + Cl_2 \rightarrow CaCl_2 + Ca(ClO_3)_2 + H_2O$
2. $Ti_2(SO_4)_3 + Fe_2(SO_4)_3 \rightarrow Ti(SO_4)_2 + FeSO_4$
3. $Hg_2I_2 + HCl + HNO_3 \rightarrow HgCl_2 + HIO_3 + NO + H_2O$
4. $H_2C_2O_4 + Ce(SO_4)_2 \rightarrow CO_2 + \cancel{H_2SO_4} + Ce_2(SO_4)_3$
5. $Mn(NO_3)_2 + Pb_3O_4 + \cancel{HNO_3} \rightarrow HMnO_4 + Pb(NO_3)_2 + \cancel{H_2O}$
6. $MnO_2 + FeSO_4 + H_2SO_4 \rightarrow MnSO_4 + Fe_2(SO_4)_3 + \cancel{H_2O}$
7. $MnCl_2 + NaOH + Br_2 \rightarrow MnO_2 + NaCl + NaBr + H_2O$
8. $AgNO_3 + NaClO \rightarrow AgCl + AgClO_3 + NaNO_3$
9. $K_2Cr_2O_7 + HCl + H_2S \rightarrow KCl + CrCl_3 + S + H_2O$
10. $Ag + HNO_3 \rightarrow AgNO_3 + NO + H_2O$

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Oxidation-Reduction Reactions

Practice Problems (Level 3)

Balance each of the following redox equations by the method you prefer or are instructed to use.

1. $Ag_2S + HNO_3 \rightarrow AgNO_3 + NO + S + H_2O$
2. $Bi(NO_3)_3 + Al + NaOH \rightarrow Bi + NH_3 + NaAlO_2$
3. $HMnO_4 + HNO_3 \rightarrow Mn(NO_3)_2 + H_2O + O_2$
4. $FeS_2 + Na_2O_2 \rightarrow Fe_2O_3 + Na_2SO_4 + Na_2O$
5. $Ca(IO_3)_2 + KI + HCl \rightarrow CaCl_2 + KCl + I_2 + H_2O$
6. $Sb_2S_5 + HCl \rightarrow SbCl_3 + S + H_2S$
7. $ZnSO_4 + KI + KIO_3 + H_2O \rightarrow Zn_5(OH)_8SO_4 + K_2SO_4 + I_2$
8. $MoO_3 + KI + HCl \rightarrow MoO_2I + KCl + I_2 + H_2O$
9. $H_2C_2O_4 + KMnO_4 + HNO_3 \rightarrow CO_2 + Mn(NO_3)_2 + KNO_3 + H_2O$
10. $NaCrO_2 + NaOH + H_2O_2 \rightarrow Na_2CrO_4 + H_2O$

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Oxidation-Reduction Reactions

Teacher Notes

1. Explanation of Levels

Level 1: Relatively simple reactions; few products and reactants involved; one element is oxidized and a second element reduced.

Level 2: Somewhat more complicated reactions; more products and reactants involved; one element may be both oxidized and reduced; one element may be either oxidized or reduced and also retain original oxidation state.

Level 3: Still more complicated reactions; any number of elements may be oxidized and/or reduced and/or retain original oxidation state.

2. Answers

Coefficients of correctly balanced equation are given in same order as species in equation.

Level 1:

1. 1 - 2 - 2 - 1
2. 1 - 1 - 2 - 1 - 2 - 1
3. 1 - 2 - 2 - 1
4. 1 - 3 - 14 - 2 - 3 - 2 - 7
5. 1 - 2 - 1 - 2
6. 4 - 1 - 4 - 1
7. 3 - 3 - 1 - 3 - 1 - 2
8. 1 - 2 - 1 - 1 - 1
9. 3 - 4 - 1 - 3 - 4
10. 2 - 1 - 1 - 1 - 2

Level 2:

1. 6 - 6 - 5 - 1 - 6
2. 1 - 1 - 2 - 2
3. 3 - 12 - 14 - 6 - 6 - 14 - 10
4. 1 - 2 - 2 - 1 - 1
5. 2 - 5 - 26 - 2 - 15 - 12
6. 1 - 2 - 2 - 1 - 1 - 2
7. 1 - 4 - 1 - 1 - 2 - 2 - 2
8. 3 - 3 - 2 - 1 - 3
9. 1 - 8 - 3 - 2 - 2 - 3 - 7
10. 3 - 4 - 3 - 1 - 2

Level 3:

1. 3 - 8 - 6 - 2 - 3 - 4
2. 1 - 9 - 9 - 1 - 3 - 9
3. 4 - 8 - 4 - 6 - 5
4. 2 - 15 - 1 - 4 - 11
5. 1 - 10 - 12 - 1 - 10 - 6 - 6
6. 1 - 6 - 2 - 2 - 3
7. 15 - 20 - 4 - 12 - 3 - 12 - 12
8. 2 - 4 - 4 - 2 - 4 - 1 - 2
9. 5 - 2 - 6 - 10 - 2 - 2 - 8
10. 2 - 2 - 3 - 2 - 4

Colligative Properties

The term **colligative property** refers to a solution effect which depends solely on the **number** of solute particles present, and not on the **type** of solute. For example, when one mole of a great many different substances is added to a kilogram of water, the boiling point of the solution is raised by 0.52°C, no matter what the substance is. Similar effects are observed for freezing point changes and changes in osmotic pressure.

The amount by which the boiling point is raised or the freezing point depressed is characteristic of the solvent used and is called the **molal boiling point elevation** or **molal freezing point depression**. Values for various solvents for these quantities are given in Appendix 11, page 199.

Solved Examples

Example 1: What would be the boiling point of a solution containing 30.0 g of isopropyl alcohol (C_3H_7OH) in 500 g of water?

Solution: The boiling point elevation is given by:

$$\Delta T = K_{bp} \times m$$

where **m** is the **molality** of the solution. The molality is defined as the number of moles of solute per kilogram of solvent. In this example,

$$m = \frac{30.0\,\cancel{g} \times \dfrac{1\text{ mol}}{60.1\,\cancel{g}}}{0.500\text{ kg water}} = .998\text{ m}$$

Then,

$$= 0.52°\text{C}/\cancel{m} \times 1.00\,\cancel{m} = 0.52°\text{C}$$

The boiling point would be 100.00°C + 0.52°C = 100.52°C.

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Example 2: What is the molecular weight of a substance if 85 g of the compound dissolved in 350. g of chloroform has a freezing point of -70.4° C?

Solution: Freezing point depression = Observed temperature − Normal freezing point

$$\Delta T = -70.4°C - (-63.5°C) = -6.9°C$$

$$\text{molality of solution} = \frac{\Delta T}{K_{f_p}} = \frac{6.9°\cancel{C}}{4.68°\cancel{C}/m} = 1.5\ m$$

molality (m) =

$$\frac{\text{number of moles}}{\text{kg of solvent}} = \frac{\text{g/molecular weight (mw)}}{\text{kg of solvent}}$$

or,

$$m = \frac{g/mw}{kg}\text{; thus,}\quad mw = \frac{g}{m \times kg}$$

or,

$$mw = \frac{85\ \cancel{g}}{1.5\ \cancel{g}/\cancel{kg} \times 0.350\ \cancel{kg}} = 162$$

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Colligative Properties

Practice Problems (Level 1)

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1. What is the boiling point of a solution that contains 30.0 g of sucrose ($C_{12}H_{22}O_{11}$) dissolved in 1000 g of water?

2. What is the boiling point of a solution that contains 45.0 g of p-dichlorobenzene ($C_6H_4Cl_2$) in 500 g of carbon tetrachloride?

3. What is the freezing point of a solution that contains 20.0 g of phenol (C_6H_5OH) dissolved in 250 g of water?

4. What is the freezing point of a solution that contains 35 g of aniline ($C_6H_5NH_2$) in 500 g of benzene?

5. What is the boiling point of a solution containing 85.6 g of sucrose dissolved in 500 g of water?

6. What is the boiling point of a solution that contains 9.2 g of p-dichlorobenzene dissolved in 250 g of carbon tetrachloride?

7. What is the freezing point of a solution containing 29 g of acetone (CH_3COCH_3) in 250 g of water?

8. What will be the freezing point of a solution of 20. g of naphthalene ($C_{10}H_8$) dissolved in 200. g of benzene?

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Colligative Properties

Practice Problems (Level 2)

1. A solution containing 180. g of glucose dissolved in 1000 g of water has a boiling point of 100.52° C. What is the molecular weight of glucose?

2. 23.0 g of ethyl alcohol dissolved in 1000 g of water has a boiling point of 100.26° C. What is the molecular weight of ethyl alcohol from this information?

3. 10.8 g of a compound dissolved in 400 g of water has a boiling point of 100.13° C. What is the molecular weight of this compound?

4. Glucose ($C_6H_{12}O_6$) is dissolved in 600 g of ethyl alcohol. The resulting solution boils at 78.9° C. How much glucose was dissolved in the alcohol?

5. 24 g of a non-volatile, non-ionic substance dissolved in 100 g of water results in a solution that has a freezing point of -3.72° C. What is the molecular weight of the substance?

6. A non-volatile, non-ionic compound whose molecular weight is 140 is dissolved in 1000 g of cyclohexane. The freezing point of this solution is 4.75° C. How much of the compound was dissolved in the cyclohexane?

7. What weight of phenol (C_6H_5OH) would have to be added to 1000 g of ethyl alcohol in order to produce a solution that freezes at -126.6° C?

8. A solution containing glycerol [$C_3H_5(OH)_3$] in 350 g of chloroform freezes at -64.9° C. How many grams of glycerol are present in this solution?

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Colligative Properties

Practice Problems (Level 3)

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1. What is the boiling point of a solution that contains 13.85 g of glucose ($C_6H_{12}O_6$) dissolved in 30.8 g of water?

2. How much aniline ($C_6H_5NH_2$) would you need to dissolve in 250 g of benzene to produce a solution with a boiling point of 80.9° C?

3. How much ethylene glycol ($C_2H_6O_2$) was dissolved in 400 g of ethyl alcohol if the resulting solution freezes at -123.8° C?

4. 25.0 g of a non-volatile, non-ionic compound is dissolved in 250 g of benzene. The boiling point of this solution is 80.66° C. What is the molecular weight of the solute?

5. 85 g of a non-ionic compound is dissolved in 350 g of chloroform. The freezing point of the resulting solution is -70.4° C. What is the molecular weight of the solute?

6. How much ethylene glycol [$C_2H_4(OH)_2$] has to be added to 6.0 L of water in order to have a freezing point of -32° C?

7. How much p-dichlorobenzene is present in a benzene solution of this compound that contains 450 g of benzene and has a boiling point of 86.6° C?

8. Calculate the molecular weight of a compound from the information that 1.58 g of this compound dissolved in 316.5 g of water has a boiling point of 100.0176° C.

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Colligative Properties

Teacher Notes

1. Explanation of Levels

Level 1: Calculation of boiling point elevation or freezing point depression only. Simple values for weight of solvent and whole-number multiples of temperature changes used in most problems.

Level 2: Calculation of molecular weight and mass of dissolved solute predominate. Somewhat less simple values for given quantities are used.

Level 3: Calculation of molecular weight and mass of dissolved solute only. More complex values for variables given.

2. Answers

Level 1:	1. 100.05°C	3. -1.57°C	5. 100.26°C	7. -3.7°C
	2. 79.5°C	4. 1.65°C	6. 78°C	8. 1.5°C
Level 2:	1. 180	3. 108	5. 120	7. 567 g
	2. 46	4. 47 g	6. 39 g	8. 9.6 g
Level 3:	1. 101.°C	3. 115 g	5. 165	7. 170 g
	2. 5.5 g	4. 422	6. 6410 g	8. 147

Nuclear Equations

Nuclear reactions can be represented by nuclear equations in much the same way that chemical reactions can be represented by chemical equations. In the case of nuclear equations, however, the problem is not to balance the number of atoms involved in the change. It is to balance the number of nuclear particles and charges involved in the reaction.

The customary designation for a radioactive isotope (radioisotope) shows its atomic number and mass number. For example, the designation of one isotope of carbon is:

$$\begin{array}{r} \text{mass number} \rightarrow \\ \text{atomic number} \rightarrow \end{array} {}^{14}_{6}\mathrm{C}$$

The mass number indicates the number of protons and number of neutrons in the nucleus of this isotope. The atomic number represents the number of protons or the positive charge on the nucleus. Since the atomic number is redundant when the symbol of the isotope is shown, it may be omitted in some cases.

Solved Examples

Example 1: What is the second product of the reaction shown below?

$${}^{23}_{11}\mathrm{Na} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{1}_{1}\mathrm{H} + ?$$

Solution: The total number of mass particles must be the same on both sides of the equation. So,

$$23 + 4 = 1 + x$$

$$x = 26$$

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The total number of positive charges must also be the same on both sides of the equation. So,

$$11 + 2 = 1 + x$$

$$x = 12$$

So the second product has a nuclear charge of +12, making it an isotope of magnesium. Specifically, the isotope is:

$${}^{26}_{12}\text{Mg}$$

Example 2: What is the second product in the reaction:

$${}^{10}\text{B}(\alpha,\quad){}^{13}\text{N}\ ?$$

Solution: This shorthand method shows the two reacting particles (^{10}B and an alpha particle) and the two product particles (the blank space represents the unknown particle and ^{13}N). Writing this as a complete equation:

$${}^{10}_{5}\text{B} + {}^{4}_{2}\text{He} \rightarrow {}^{13}_{7}\text{N} + ?$$

Notice that the alpha particle (α) must be written as a helium nucleus in order to balance the equation. The mass number of the missing particle is 1 (10 + 4 − 13) and the charge number is 0 (5 + 2 − 7). The particle with a mass of 1 and a charge of 0 is the neutron. So the second product particle is: ${}^{1}_{0}$n, the neutron.

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Nuclear Equations

Practice Problems (Level 1)

Balance each of the nuclear equations shown below by determining the missing particle in each case.

1. ${}^{14}_{7}N + {}^{1}_{0}n \rightarrow {}^{14}_{6}C + ?$

2. ${}^{54}_{24}Cr + {}^{1}_{1}H \rightarrow {}^{54}_{25}Mn + ?$

3. ${}^{125}_{52}Te + {}^{1}_{1}H \rightarrow {}^{1}_{0}n + ?$

4. ${}^{11}_{5}B + {}^{4}_{2}He \rightarrow {}^{1}_{0}n + ?$

5. ${}^{31}_{15}P + ? \rightarrow {}^{28}_{14}Si + {}^{4}_{2}He$

6. ${}^{37}_{17}Cl + ? \rightarrow {}^{35}_{16}S + {}^{4}_{2}He$

7. ${}^{9}_{4}Be + {}^{1}_{1}H \rightarrow {}^{6}_{3}Li + ?$

8. $? + {}^{2}_{1}H \rightarrow {}^{61}_{28}Ni + {}^{4}_{2}He$

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Nuclear Equations

Practice Problems (Level 2)

Balance each of the nuclear equations shown below by determining the missing particle in each case.

1. ${}^{6}_{3}\mathrm{Li} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{4}_{2}\mathrm{He} + ?$

2. ${}^{12}_{6}\mathrm{C} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{13}_{7}\mathrm{N} + ?$

3. ${}^{10}_{5}\mathrm{B} + \alpha \rightarrow ? + {}^{13}_{7}\mathrm{N}$

4. ${}^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + ?$

5. ${}^{214}_{82}\mathrm{Pb} \rightarrow {}^{214}_{83}\mathrm{Bi} + ?$

6. ${}^{64}_{30}\mathrm{Zn} + \beta \rightarrow {}^{63}_{29}\mathrm{Cu} + ?$

7. ${}^{7}_{3}\mathrm{Li} + \mathrm{p} \rightarrow {}^{1}_{0}\mathrm{n} + ?$

8. $? + \mathrm{d} \rightarrow {}^{3}_{2}\mathrm{He} + \mathrm{n}$

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Nuclear Equations

Practice Problems (Level 3)

Balance each of the nuclear equations indicated below. For those shown in shorthand method, write out the full equation before balancing.

1. $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{1}_{1}H + ?$
2. $^{2}_{1}H + ? \rightarrow ^{1}_{1}H + ^{1}_{0}n$
3. $^{63}Cu + ^{1}H \rightarrow ? + ^{1}n + ^{25}Al$
4. $^{209}Bi + \alpha \rightarrow ^{211}At + ?$
5. $^{238}U + ^{12}C \rightarrow 4\,n + ?$
6. $^{235}U + n \rightarrow ^{138}Ba + 3\,n + ?$
7. $^{2}H + ^{2}H \rightarrow ^{3}He + ?$
8. $? + n \rightarrow ^{95}Br + ^{139}La + 2\,n$
9. $^{29}Si(d, n)?$
10. $^{6}Li(?, \alpha)^{3}He$
11. $^{238}U(\alpha, ?)^{240}Pu$
12. $^{237}Np(?, 3n)^{238}Am$
13. $^{33}Cl(n, ?)^{31}P$
14. $?(^{11}B, 4n)^{257}Lr$

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Nuclear Equations

Teacher Notes

1. Explanation of Levels

Level 1:	Simple equations in which all information for three of four species is given. All subatomic particles given in complete form.
Level 2:	More complex equations in which abbreviations are used for some subatomic particles.
Level 3:	Still more complex reactions in which all types of shorthand are used for subatomic particles and for reactions. Some exotic reactions (more than two reactants and/or products involved) and less familiar particles (e.g., positron) are included.

2. Answers

In all of the following answers, the following abbreviations are used:

α = alpha = $^4_2$He; β = beta = e^-; p = proton = $^1_1$H

γ = gamma ray; d = deuteron = $^2_1$H; t = triton = $^3_1$H

Level 1: 1. p; 2. n; 3. ^{125}I; 4. ^{14}N; 5. p; 6. d; 7. α; 8. ^{63}Cu

Level 2: 1. t; 2. γ; 3. n; 4. α; 5. β; 6. n; 7. ^{7}Be; 8. d

Level 3: 1. t; 2. γ; 3. ^{38}Cl; 4. 2n; 5. ^{246}Cf; 6. ^{95}Kr; 7. n;

8. ^{235}U; 9. ^{30}P; 10. p; 11. 2n; 12. α; 13. ^{3}He;

14. ^{250}Cf

Half Life

The **half life** of a radioactive substance is defined as the time it takes for one half of a given sample of that substance to undergo radioactive decay. Half lives range greatly from a few microseconds to billions of years. The half lives of some isotopes are given in Appendix 12, page 200.

Calculations involving half life may require higher order mathematics. In many cases, however, methods are available for solving such problems more simply. The solved examples that follow illustrate one of these methods.

Solved Examples

Example 1: A laboratory has purchased a 10.0 g sample of radioactive tungsten 187. How much of the sample would be left at the end of one day? At the end of two days? At the end of one week?

Solution: One approach to this kind of problem is to construct a table such as the one shown below. Continue making entries until the result desired has been reached. (From Appendix 12, page 200, we learn that the half life of tungsten 187 is 24 hours.)

At the end of	***or***	***there will remain***
0 half life	00 hrs	10.0 g (original amount)
1 half life	24 hrs	5.0 g ← FIRST ANSWER
2 half lives	48 hrs	2.5 g ← SECOND ANSWER
3 half lives	3 days	1.25 g
4 half lives	4 days	0.625 g
5 half lives	5 days	0.3125 g
6 half lives	6 days	0.156 g
7 half lives	7 days	0.078 g ← THIRD ANSWER

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Example 2: A 100.0 g sample of platinum 197 has just been produced in the laboratory. How long will it be before only 50.0 g of the ^{197}Pt remains? Before only 1.0 g of the isotope remains? (From Appendix 12, page 200, the half life of platinum 197 is found to be 18 hours.)

Solution: Construct a chart like the one on page 161.

At the end of	***or***	***there will remain***	
0 half life	00 hrs	100.0 g (original amount)	
1 half life	18 hrs	50.0 g	← FIRST ANSWER
2 half lives	36 hrs	25.0 g	
3 half lives	54 hrs	12.5 g	
4 half lives	72 hrs	6.25 g	
5 half lives	90 hrs	3.12 g	
6 half lives	108 hrs	1.56 g	
7 half lives	126 hrs	0.78 g	← SECOND ANSWER

Sometime between 108 and 126 hours there will be only 1.0 g of the isotope left.

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Half Life

Practice Problems (Level 1)

Refer to half lives listed in Appendix 12, page 200, for the solution of the following problems.

1. A piece of uranium 238 weighs 1.000 kg. How much of this isotope will remain about 36 × 10^9 years?
2. Polonium 218 has a half life of 3.0 m. A sample weighing 50.0 g is stored on a laboratory shelf. How much of the isotope will remain after 15 minutes have passed?
3. A certain rock sample is found to contain 35 g of the radioactive isotope, technetium 99. How much of the isotope will remain in the rock after a period of 1,000,000 years?
4. A block of radium 226 weighs 1.0 × 10^4 kg. How much of this radioisotope will remain after 6500 years have passed?
5. How long will it take a piece of strontium 90, weighing exactly 1.000 kg, to be reduced to only 10.0 g?
6. A sample of cesium 138 is produced in a laboratory. The sample weighs 100.0 g at the time it is produced. How long will it take before this sample is reduced to only 20.0 g? The half life of cesium 138 is 32.2 m.
7. A hospital purchases 80.0 kg of cobalt 60 to use in cancer therapy. How long will it be before there remains only 15 kg of this radioisotope?
8. A sample of oxygen gas contained within a glass tube includes 7.4 g of the radioisotope oxygen 15. At what later time will the amount of oxygen 15 be reduced to only 0.5 g?

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Half Life

Practice Problems (Level 2)

Refer to Appendix 12, page 200, for half lives needed for the solution of the following problems.

1. A meteorite strikes the earth in western Wyoming. Chemical analysis shows that it contains 44.62 kg of radioactive iron 59. How much of this isotope will remain in the meteorite after 220 days?
2. A sample of gallium 67 was ordered by a research laboratory sometime ago. When received in the lab, it weighed 492 g. Today it weighs only 15 g. How long ago was the gallium 67 received in the laboratory?
3. A 100.0 g sample of radiophosphorus (^{32}P) was ordered and received at the same time as the gallium 67 (problem 2). When its weight is reduced to 20.0 g, a new sample must be ordered. How long after the radiophosphorus was received will a new order have to be placed?
4. How much time will be required for a sample of radioactive tritium to lose 75% of its radioactivity?
5. A sample of pure radium 226 is donated to a museum in the year 1990. The sample weighs 5.0 mg. The museum decides to replace the sample after it has been reduced in weight to 0.62 mg. In what year will the sample have to be replaced?
6. A radioactive isotope of radon has a half life of 3.8 days. How long will it be be before only 1/16 of the original sample of radon remains?
7. A piece of wood is known to be 34,320 years old. At the present time, the wood contains 4.0 g of radiocarbon (^{14}C). How much carbon 14 was in the wood originally?
8. The decay of a sample of tritium gas has been carefully monitored for just slightly more than 37 years. The weight of the tritium in the sample today is 6.4 g. What was the weight of the tritium in the sample originally?

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Half Life

Practice Problems (Level 3)

Refer to Appendix 12, page 200, for half lives needed for the solution of the following problems.

1. What fraction of the uranium 235 originally present at the creation of the universe is still in existence today? Use a value of 8.0×10^9 years for the age of the universe.

2. You plan on using radioactive sulfur 38 in an experiment in your laboratory. It will take 15 hours to ship the sulfur 38 from the producer to your lab. If you want to have 5 g of the isotope to use in the experiment, how much should you order from the producer? The half life of sulfur 38 is 3.0 hr.

3. A sample of sodium 24 was received in your laboratory 1 day 22 hours after being shipped from the producer. The weight of the sample when it reached you was 2.0 g. Did the producer ship the 24.0 g of sodium 24 you had requested?

4. A radioactive isotope decays to one eighth of its original activity in 60 years. What is the half life of this isotope?

5. A sample of selenium 83 registers 10^{12} disintegrations per second when it is first tested in a laboratory. What rate of disintegration would you predict for this isotope 12 hours later? The half life of selenium 83 is 25 minutes.

6. An order for phosphorus 32 has been placed for some studies on plant growth. How much of the isotope will remain one month after it has been produced? Six months later? (Express your answers as percents of the original amount.)

7. In studies to determine the half life of an isotope, 10.0 g of the isotope is found to decay to 0.625 g over a period of 6.0 hours. From this information, calculate the half life of the isotope.

8. In an experiment to determine the half life of an isotope, a very precise clock is set at $00^h\ 00^m\ 00.000^s$ the moment the isotope is produced. At the instant the clock reads $00^h\ 00^m\ 14.846^s$, 8.0% of the isotope remains unchanged. From this information, calculate the half life of the isotope.

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Half Life

Teacher Notes

1. Explanation of Levels

Level 1: Relatively simple problems that require the calculation of amount remaining after a certain number of half lives or the time required to reach a certain sample size.

Level 2: Somewhat more complex problems that require calculation of amount remaining after a given time, time needed to reach certain sample size, or original quantity of sample.

Level 3: Somewhat more complex problems that require calculations like those for Level 2 plus the calculation of half life.

2. Answers

Note: Students who are familiar with the expression

$$t = 3.32(t_{1/2}) \log \frac{N_0}{N_t}$$

may use that formula to solve these problems.

Level 1: 1. 0.0040 kg; 2. 1.6 g; 3. 1.1 g; 4. about 625 g;
5. between 173 and 202 yr; 6. between 64 and 96 min;
7. between 10.5 - 15.8 yr; 8. about 7.9 min

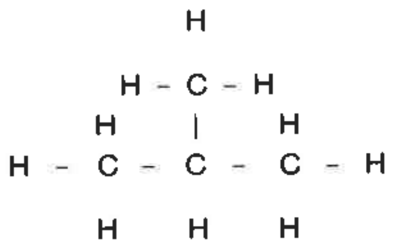
Level 2: 1. 1.4 kg; 2. about 375 h (nearly 16 d); 3. about 28.6 d;
4. about 24.6 y; 5. 6850; 6. 15.2 d; 7. about 250 g;
8. about 51.2 g

Level 3: 1. about 5×10^{4} of original amount; 2. 160 g; 3. no; 17 g
was shipped; 4. 20 y; 5. about 2.5×10^{3} cps;
6. about 25%; 102%; 7. 90 m; 8. 4.08 s

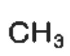
Organic Chemistry: Nomenclature

Organic compounds are named according to the family to which they belong. Compounds are assigned to families on the basis of characteristic groupings of atoms (**functional groups**) which they contain.

Formulas for organic compounds can be written in a variety of ways. **Molecular formulas**, most common in writing the structures of inorganic compounds, are usually not very helpful with organic compounds because of the possibility of isomers. **Structural formulas** are by far more commonly used with organic compounds. Although **expanded structural formulas**, like the one shown below, are sometimes useful, they require a lot of time and space to write. In most cases, **condensed** or **semi-condensed** formulas are more helpful and easier to write. Shown below are three ways of writing the structure of methylpropane.



$$\begin{array}{ccccccc} & & & H & & & \\ & & H - & C & - H & & \\ & H & & | & & H & \\ H - & C & - & C & - & C & - H \\ & H & & H & & H & \end{array}$$



$$\begin{array}{ccccc} & & CH_3 & & \\ & & | & & \\ CH_3 & - & CH & - & CH_3 \end{array}$$

Semi-condensed formula

$CH_3CH(CH_3)CH_3$

Condensed formula

Solved Examples

Example 1: To what family does the following compound belong?

$CH_3CH_2NH_2$

Solution: To answer this question, we must first identify any and all functional groups present in the molecule. In this case, the

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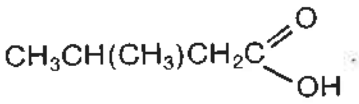
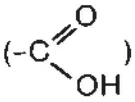
only functional group present is the $-NH_2$ (amino) group. The presence of this group makes the compound a member of the **amine** family.

Example 2: Name the following compound:  $CH_3CH(CH_3)CH_2C\genfrac{}{}{0pt}{}{/\!\!/O}{\diagdown OH}$

Solution: First, it is necessary to identify the family to which the compound belongs. The presence of the carboxyl ( $-C\genfrac{}{}{0pt}{}{/\!\!/O}{\diagdown OH}$) group makes this a carboxylic acid. The longest chain containing the carboxyl group includes four atoms, so the stem name of the compound is **butanoic acid**. Attached to the main chain is a methyl group on the #3 carbon atom. So the complete name of the compound is: 3-methylbutanoic acid.

Example 3: Draw the structure of 2-chloropentane.

Solution: Draw the structure of the parent compound (pentane): $CH_3CH_2CH_2CH_2CH_3$. Then, insert a chlorine atom on the #2 carbon atom: $CH_3CHClCH_2CH_2CH_3$.

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Organic Chemistry: Nomenclature

Practice Problems (Level 1)

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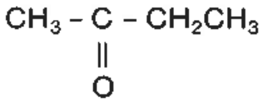
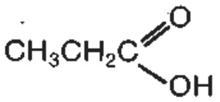
1. Tell what family to which each of the following compounds belong. Identify the functional group in each compound.

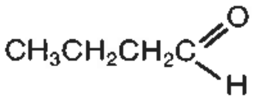
a. $CH_3CH = CHCH_2CH_3$

b. 
$CH_3 - \underset{\underset{O}{||}}{C} - CH_2CH_3$

c. $CH_3CH_2CHOHCH_2CH_3$

d. $CH_3CH_2CH_2CH_2CH_3$

e. 

f. 

2. Give the correct IUPAC name for each of the following compounds.

a. $CH_3CH_2CH_2CH_2CH_3$

b. $CH_3CH_2CH(CH_2CH_3)CH(CH_3)CH_2CH_3$

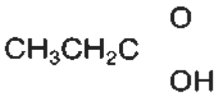
c. $CH_2 = CHCH_2CH_2CH_2CH_3$

d. 

e. $CH_3CH_2CHOHCH_2CH_2CH_3$

f. CH_2O

g. $CH \equiv CH$

h. 
$CH_3CH_2\overset{O}{\underset{OH}{C}}$

i. 

j. $CH_3 - O - CH_3$

3. Write the correct structural formula for each of the following compounds.

a. 2,3-dimethylbutane
b. methylethylether
c. 2-methyl-2-butene
d. butanal
e. 2-pentanone
f. ethanol
g. acetic acid (ethanoic acid)
h. urea

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Organic Chemistry: Nomenclature

Practice Problems (Level 2)

---

1. Tell what family to which each of the following compounds belong. Identify the functional group in each compound.

a. $CH_3CH_2 - O - CH_2CH_3$

b. CH_3NHCH_3

c. $CH \equiv CCH_2CH_3$

d. $CH_3CHBrCH_2CH_3$

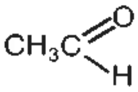
2. Give the correct IUPAC name for each of the following compounds.

a. $CH_3C(CH_3)_2CH(CH_3)CH_2CH_3$

b. $CH_3CBr_2CBr_2C(CH_3)_2CH_3$

c. $CH_3C(OH)(CH_3)CH_2CHBrCH_2CH_3$

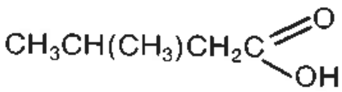
d.



$CH_3C{\genfrac{}{}{0pt}{}{=O}{-H}}$

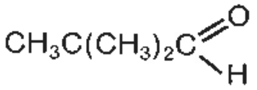
e. $CH_3CH = C(CH_3)CH_2CH_2CH_3$

f.



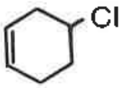
$CH_3CH(CH_3)CH_2C{\genfrac{}{}{0pt}{}{=O}{-OH}}$

g.



$CH_3C(CH_3)_2C{\genfrac{}{}{0pt}{}{=O}{-H}}$

h.



3. Draw all isomers represented by each of the following molecular formulas:

a. C_5H_{12}

b. C_4H_9Br

c. C_4H_8

4. Write the correct structural formula for each of the following compounds.

a. 3-bromo-2, 5-dimethylhexane

b. 2,4,4-trimethyl-2-pentene

c. 3,4,5-trichloro-2-pentanol

d. p-chlorophenol

e. 2-methyl-3-pentanone

f. isopropyl alcohol

g. glycerol

h. formic acid

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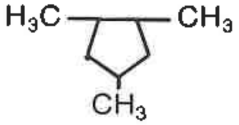
Organic Chemistry: Nomenclature

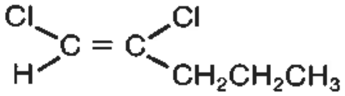
Practice Problems (Level 3)

1. Give the correct IUPAC name for each of the following compounds.

a.



b.

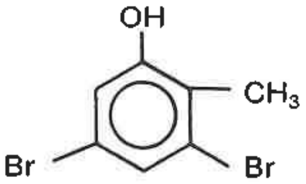


c. $CH_3C(CH_2CH_3)_2CH_2OH$

d. $CH_3CHOHCH(CH_3)CH(CH_3)CH(CH_3)CH_3$

e. $CH_3CHOHCHOHCH_3$

f.



g. $CH_3CH_2CF_2CH(CH_3)CHO$

h. $CH_3CH_2CH_2CH(NH_2)COOH$

i. $CH_3CH(CH_3)CH(CH_2CH_3)CHICOOH$

j. $CH_3CH(CH_3)COCH(CH_3)CH_2CH_3$

2. Write the correct structural formula for each of the following compounds.

a. 2-methyl-3-n-propylhexane

b. 2,3-dibromo-4,4-dimethyl-2-pentene

c. 2,3,4-trichlorophenol

d. 2-methyl-3,4,5-tribromocyclopentanol

e. 3,3-pentanediol

f. o-methylphenol

g. cyclohexanone

h. 4,4,5-tribromohexanoic acid

i. trichloroacetic acid

j. trimethylamine

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Organic Chemistry: Nomenclature

Teacher Notes

1. Explanation of Levels

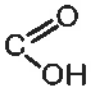
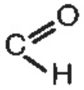
Level 1: Identification of functional groups and families; simple naming and formula-writing exercises.

Level 2: Less identification of functional groups and families; writing of isomers; somewhat more difficult naming and formula-writing exercises.

Level 3: Still more difficult naming and formula-writing exercises.

2. Answers

Level 1:

1. a. alkene - $C = C$ -
   b. ketone - $C = O$
   c. alcohol - $C - OH$
   d. alkane; none
   e. carboxylic acid 
   f. aldehyde 

2. a. pentane
   b. 3-ethyl-4-methylhexane
   c. 1-hexene
   d. cyclopentene
   e. 3-hexanol
   f. formaldehyde (methanal)
   g. acethylene (ethyne)
   h. propanoic acid
   i. benzene
   j. methylether

3. a. $CH_3CH(CH_3)CH(CH_3)CH_3$
   b. $CH_3CH_2 - O - CH_3$
   c. $CH_3C(CH_3) = CHCH_3$
   d. $CH_3CH_2CH_2CHO$

e. $CH_3COCH_2CH_2CH_3$
f. CH_3CH_2OH
g. CH_3COOH; $(NH_2)_2CO$

Level 2: 1. a. ether; b. amine; c. alkyne; d. alkyl halide

2. a. 2,2,3-trimethylpentane
b. 2,2,3,3-tetrabromo-4,4-dimethylpentane
c. 2-methyl-4-bromo-2-hexanol
d. ethanal (acetaldehyde)
e. 3-methyl-2-hexene
f. 3-methylbutanoic acid
g. 2,2-dimethylpropanal
h. 3-chlorocyclohexene

3. Names of isomers are:

a. pentane; 2-methylbutane; 2,2-dimethylpropane
b. 1-bromo-butane; 2-bromobutane; 2-bromo-2-methylpropane; 1-bromo-2-methylpropane
c. 1-butene; 2-butene; 2-methyl-1-propene; cyclobutane; methylcyclopropane

4. a. $CH_3CH(CH_3)CHBrCH_2CH(CH_3)CH_3$
b. $CH_3C(CH_3) = CHC(CH_3)_2CH_3$
c. $CH_3CHOHCHClCHClCH_2Cl$
d. $C_6H_4OH(p)Cl$
e. $CH_3CH(CH_3)COCH_2Ch_3$
f. $CH_3CHOHCH_3$
g. $CH_2OHCHOHCH_2OH$
h. $HCOOH$

Level 3: 1. a. 1,2,4-trimethylcyclopentane
b. cis-1,2-dichloro-2-pentene
c. 2-methyl-2-ethyl-1-butanol
d. 3,4,5-trimethyl-2-hexanol
e. 2,3-butanediol
f. 2-methyl-3,5-dibromophenol
g. 2-methyl-3,3-difluoropentanal
h. 2-aminopentanoic acid
i. 2-iodo-3-ethyl-4-methylpentanoic acid
j. 2,4-dimethyl-3-hexanone

2. a. $CH_3CH(CH_3)CH(CH_2CH_2CH_3)CH_2 \rightarrow CH_2CH_3$
   b. $CH_3CBr = CBrC(CH_3)_2CH_3$
   c. $C_6H_2Cl_3OH$
   d. $C_5H_5OH(CH_3)Br_3$
   e. $CH_3CH_2C(OH)_2CH_2CH_3$
   f. $C_6H_4OH(o)CH_3$
   g. $C_6H_{11}CO$
   h. $CH_3CHBrCBr_2CH_2CH_2COOH$
   i. CCl_3COOH
   j. $N(CH_3)_3$

Organic Chemistry: Reactions

Organic reactions differ from inorganic reactions in a number of ways. For one thing, organic reactions typically do not proceed stoichiometrically, as do inorganic reactions. We can predict with some confidence, for example, that sodium chloride and silver nitrate will react with each other to produce predictable amounts of silver chloride and sodium nitrate. Compare the reaction between ethyl alcohol and acetic acid. We anticipate that ethyl acetate and water will be produced in this reaction. And they are. However, a number of byproducts are also produced. And, depending upon the conditions under which the reaction takes place, the ratio of byproducts to major products may be greater or less than unity. As a consequence, the balancing of organic reactions tends to be of somewhat lesser significance than the ability to predict the most likely products.

Solved Examples

Example 1: Predict the reaction between propane and oxygen, at elevated temperatures.

Solution: Rapid oxidation (combustion) is a reaction typical of many organic compounds. Under the proper conditions, the complete combustion of any organic compound produces only carbon dioxide and water.

$$CH_3CH_2CH_3 + 5\,O_2 \xrightarrow{\Delta} 3\,CO_2\uparrow + 4\,H_2O\uparrow$$

Notice that this is a reaction in which it **is** possible to balance the equation with little difficulty.

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Example 2: Predict the reaction that will occur between butane and bromine.

Solution: This problem illustrates the importance of conditions in an organic reaction. If the butane and bromine are kept in the dark, no reaction will occur:

$$CH_3CH_2CH_2CH_3 + Br_2 \rightarrow NR$$

However, if light or some other source of energy is available, a substitution reaction takes place:

$$CH_3CH_2CH_2CH_3 + Br_2 \xrightarrow{energy} CH_2BrCH_2CH_2CH_3 + HBr$$

Notice that a second reaction is also possible:

$$CH_3CH_2CH_2CH_3 + Br_2 \xrightarrow{energy} CH_3CHBrCH_2CH_3 + HBr$$

In many cases, the beginning student has no way of predicting which of these reactions, if either, will predominate.

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Organic Chemistry: Reactions

Practice Problems (Level 1)

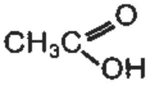
Using the formulas with which you are most comfortable, write equations representing the reactions you would expect in each of the following cases.

1. $C_6H_{14} + Br_2 \xrightarrow{\text{light}}$
hexane bromine

2. $C_6H_{14} + O_2 \xrightarrow{\text{heat}}$
hexane oxygen

3. $CH_2 = CHCH_2CH_3 + H_2 \longrightarrow$
1-butene hydrogen

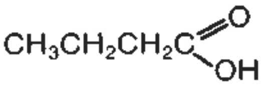
4.



$CH_3CH_2CH_2OH + CH_3C{\overset{\displaystyle O}{\diagup\!\!\!\!=}}\!\diagdown OH \xrightarrow{H^+}$
1-propanol ethanoic acid

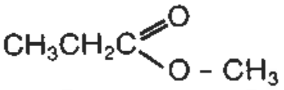
5. $CH_3CH_2CH_2OH + (O) \xrightarrow{Cr_2O_7^{=}}$
1-propanol oxygen (mild conditions)

6.



$CH_3CH_2CH_2C(=O)OH + NaOH \longrightarrow$
butanoic acid sodium hydroxide

7.



$CH_3CH_2C(=O)O - CH_3 + HOH \xrightarrow{NaOH}$
methyl propanoate water (basic solution + heat)

8. $CH_2 = CHCH_2CH_3 + Cl_2 \longrightarrow$
1-butene chlorine

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Organic Chemistry: Reactions

Practice Problems (Level 2)

Use condensed or semi-condensed structural formulas for organic compounds to show the reaction you would expect to occur in each of the following situations. Insert any conditions which may be necessary to make the reaction occur.

1. hexane + fluorine (1 mole)

2. 2-pentene + bromine (1 mole)

3. benzene + bromine (1 mole)

4. 3-pentanol + phosphorus tribromide

5. t-butyl alcohol + hydrochloric acid (conc)

6. 1-butanol + oxygen (mild conditions)

7. glycerol + nitric acid (one mole)

8. glyceryl tristearate + water (with heat in basic solution)

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Organic Chemistry: Reactions

Practice Problems (Level 3)

Use condensed or semi-condensed structural formulas for organic compounds to show the reaction you would expect to occur in each of the following situations. Insert any conditions which may be necessary to make the reaction occur.

1. hexane + one mole of fluorine + one mole of bromine
2. 2-butyne + one mole of hydrogen
3. product of reaction in #2 + one mole of hydrogen bromide
4. 2-butyne + 2 moles of hydrogen chloride
5. glyceryl stearatedipalmitate (hydrolyzed)
6. 2-methylbutanal + Benedict's reagent (Cu^{+2})
7. propanoic acid + 1-butanol
8. ethene (polymerized; 2 steps)
9. glycine + glycine
10. ammonia + 1-bromopropane

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Organic Chemistry: Reactions

Teacher Notes

1. Explanation of Levels

Level 1: Simple reactions used; reactants given with both formula and name; necessary conditions included in all cases.

Level 2: Somewhat more difficult reactions; reactants given by name only; necessary conditions to be inserted by student.

Level 3: More difficult reactions; reactants given by name only; necessary conditions to be inserted by student.

2. Answers

Level 1:

1. $C_6H_{14} + Br_2 \xrightarrow{\text{energy}} C_6H_{13}Br + HBr$
2. $2\ C_6H_{14} + 19\ O_2 \xrightarrow{\Delta} 12\ CO_2\uparrow + 14\ H_2O\uparrow$
3. $CH_2 = CHCH_2CH_3 + H_2 \rightarrow CH_3CH_2CH_2CH_3$
4. $CH_3CH_2CH_2OH + CH_3COOH \quad H^{+}$
   $CH_3COOCH_2CH_2CH_3 + HOH$
5. $CH_3CH_2CH_2OH + (O) \xrightarrow{Cr_2O_7{}^{2}} CH_3CH_2CHO + H_2O$
6. $CH_3CH_2CH_2COOH + NaOH \rightarrow CH_3CH_2CH_2CONa$
   $+ HOH$
7. $CH_3CH_2COOCH_3 + HOH \xrightarrow[\Delta]{NaOH} CH_3CH_2COOH +$
   CH_3OH
8. $CH_2 = CHCH_2CH_3 + Cl_2 \rightarrow CH_2ClCHClCH_2CH_3$

Level 2:

1. $CH_3CH_2CH_2CH_2CH_2CH_3 + F_2 \xrightarrow{\text{energy}}$
   $CH_2FCH_2CH_2CH_2CH_2CH_3 + HF$
2. $CH_3CH = CHCH_2CH_3 + Br_2 \rightarrow CH_3CHCHBrCH_2CH_3$

3. $C_6H_6 + Br_2 \xrightarrow{FeBr_3} C_6H_5Br + HBr$
4. $3\ CH_3CH_2CHOHCH_2CH_3 + PBr_3 \rightarrow 3\ CH_3CH_2CHBrCH_2CH_3 + H_3PO_3$
5. $(CH_3)_3COH + HCl$ (conc) $\xrightarrow{ZnCl_2} (CH_3)_3CCl + HOH$
6. $CH_2OHCH_2CH_2CH_3 + (O) \xrightarrow{MnO_4} CH_3CH_2CH_2CHO + HOH$
7. $CH_2OHCHOHCH_2OH + HNO_3 \rightarrow CH_2ONO_2CHOHCH_2OH + HOH$
8. $C_3H_5[OCO(CH_2)_{16}CH_3]_3 + 3\ HOH \xrightarrow{NaOH\ +\ \Delta} CH_3(CH_2)_{16}COOH + C_3H_5(OH)_3$

Level 3:

1. $CH_3CH_2CH_2CH_2CH_2CH_3 + F_2 + Br_2$ (two steps; with energy) $\rightarrow CH_2FCHBrCH_2CH_2CH_2CH_3$ (many isomers possible)
2. $CH_3C \equiv CCH_3 + H_2 \rightarrow CH_3CH = CHCH_3$
3. $CH_3CH = CHCH_3 + H_2 \rightarrow CH_3CH_2CH_2CH_3$
4. $CH_3C \equiv CCH_3 + 2\ HCl$ (two steps) $\rightarrow CH_3CH_2CCl_2CH_3$
5. $C_3H_5[OCO(CH_2)_{16}CH_3][OCO(CH_2)_{14}CH_3]_2 + 3\ HOH$ (OH^- or H^+ with heat) $\rightarrow CH_3(CH_2)_{16}COOH + 2\ CH_3(CH_2)_{14}COOH + C_3H_5(OH)_3$
6. $CH_3CH_2CH(CH_3)CHO + (O)$ (via Benedict's) $\rightarrow CH_3CH_2CH(CH_3)COOH + Cu^0$
7. $CH_3CH_2COOH + CH_3CH_2CH_2CH_2OH$ (with H^+ and heat) $\rightarrow CH_3CH_2COOCH_2CH_2CH_2CH_3 + HOH$
8. $CH_2 = CH_2 + CH_2 = CH_2 \xrightarrow{H^+} CH_3CH_2CH = CH_2 + CH_2 = CH_2 \xrightarrow{H^+} CH_3CH_2CH_2CH_2CH = CH_2$ (isomers possible)
9. $CH_2NH_2COOH + CH_2NH_2COOH \rightarrow HOH + CH_2NH_2CONH(CH_2COOH)$
10. $NH_3 + CH_2BrCH_2CH_3 \rightarrow HBr + NH_2CH_2CH_2CH_3$

Equilibria

Some chemical reactions are such that, after a period of time, all of the substances originally involved in the reaction (the **reactants**) have been converted to new substances (the **products**). Such reactions are said to **go to completion**. Other reactions do not fit this pattern. Instead, after some period of time, the reaction mixture consists of both **products and reactants**. Such a reaction is said to be **in equilibrium** if the rate at which reactants combine to form products is the same as the rate at which products combine to form reactants.

For a system in equilibrium, the relative quantities of products and reactants can be expressed by The Law of Mass Action. For the reaction:

$$m\,A + n\,B \rightleftharpoons p\,C + q\,D,$$

the law says that

$$\frac{[C]^p \times [D]^q}{[A]^m \times [B]^n} = \text{a constant, generally referred to as } K_{eq}.$$

The concept of equilibrium can be applied to a wide variety of situations. Two instances in which it is particularly useful are in describing the ionization of weak electrolytes (ionic equilibrium) and the solubility of slightly soluble substances (solubility product).

Solved Examples

Example 1: At equilibrium in the reaction $H_2 + I_2 \rightleftharpoons 2\,HI$, the concentration of each species was found to be: $[H_2] = 1.14 \times 10^{-3}$; $[I_2] = 1.14 \times 10^{-3}$; $[HI] = 8.41 \times 10^{-3}$. From these data, calculate the value of K_{eq} for the reaction.

Solution: For this reaction, $K_{eq} = \dfrac{[HI]^2}{[H_2] \times [I_2]}$

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$$= \frac{(8.41 \times 10^{-3}\ \text{mol/L})^2}{(1.14 \times 10^{-3}\ \text{mol/L})(1.14 \times 10^{-3}\ \text{mol/L})}$$

$$= 54.4$$

Example 2: The solubility product ($K_{eq} = K_{sp}$) for the reaction shown below is 1.0×10^{-6}. What is the concentration of barium ions in g/100 mL for this compound in a saturated solution of barium fluoride? $BaF_2 \rightleftharpoons Ba^{+2} + 2\ F^-$

Solution: K_{sp} for this reaction is:

$$K_{sp} = [Ba^{+2}] \times [F^-]^2$$

$$\text{Let } x = [Ba^{+2}]\text{; then } 2x = [F^-]\text{, and}$$

$$(x) \cdot (2x)^2 = 1.0 \times 10^{-6}$$

$$4x^3 = 1.0 \times 10^{-6}$$

$$x = 6.3 \times 10^{-3} = [Ba^{+2}]$$

$$6.3 \times 10^{-3}\ \frac{\cancel{\text{mol}}}{\cancel{\text{L}}} \times \frac{175.3\ \text{g}}{\cancel{\text{mol}}} \times \frac{1\ \cancel{\text{L}}}{1000\ \cancel{\text{mL}}} \times 100\ \cancel{\text{mL}} = 0.11\ \text{g}$$

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Equilibria

Practice Problems (Level 1)

---

1. Write the expression for the equilibrium constant for each of the following reactions.

a. $H_2 + Cl_2 \rightleftharpoons 2\,HCl$

b. $2\,SO_2 + O_2 \rightleftharpoons 2\,SO_3$

c. $N_2 + 3\,H_2 \rightleftharpoons 2\,NH_3$

d. $2\,CO + O_2 \rightleftharpoons 2\,CO_2$

e. $CaCO_3 \rightleftharpoons CaO + CO_2$

f. $HCN \rightleftharpoons H^+ + CN^-$

g. $H_2SO_4 \rightleftharpoons H^+ + HSO_4^-$

h. $H_2CO_3 \rightleftharpoons 2\,H^+ + CO_3^{-2}$

i. $AgCl \rightleftharpoons Ag^+ + Cl^-$

j. $PbF_2 \rightleftharpoons Pb^{+2} + 2\,F^-$

2. From the data provided below, calculate the value of the equilibrium constant for the conditions under which the reaction took place.

a. Reaction 1a above: $[H_2] = [Cl_2] = [HCl] = 1.0 \times 10^{-2}$

b. Reaction 1b above: $[SO_2] = 1.0 \times 10^{-3}$; $[O_2] = 2.0 \times 10^{-3}$; $[SO_3] = 3.0 \times 10^{-3}$

c. Reaction 1c above: $[N_2] = 4.4 \times 10^{-2}$; $[H_2] = 1.2 \times 10^{-1}$; $[NH_3] = 3.4 \times 10^{-3}$

d. Reaction 1d above: $[CO] = 2.5 \times 10^{-3}$; $[O_2] = 1.6 \times 10^{-3}$; $[CO_2] = 3.2 \times 10^{-2}$

e. For the reaction, $2\,NO_2 \rightleftharpoons N_2O_4$, the equilibrium concentrations are: $[NO_2] = 3.1 \times 10^{-2}$ and $[N_2O_4] = 4.5 \times 10^{-3}$. From these data, calculate K_{eq} for the reaction at this temperature.

f. In reaction 1a above, assume the equilibrium constant to be 55.0. During one experiment, the equilibrium concentrations of hydrogen and chlorine were measured to be 4.8×10^{-3} M and 2.1×10^{-3} M respectively. What was the concentration of the hydrogen chloride at this point?

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Equilibria

Practice Problems (Level 2)

1. Determine the hydrogen ion concentration in a solution of formic acid, HCOOH ($K_a = 1.8 \times 10^{-5}$), when the concentration of acid and formate ion at equilibrium are 0.090 M and 0.110 M respectively.
2. A solution of acetic acid, $HC_2H_3O_2$, with $K_a = 1.8 \times 10^{-5}$ contains equal concentrations of hydrogen and acetate ions, namely 1.33×10^{-3} M. What is the concentration of acid at equilibrium?
3. What is the hydrogen ion concentration in a solution of hydrocyanic acid ($K_a = 4.9 \times 10^{-10}$) when the concentration of acid is 0.20 M?
4. What is the concentration of hypochlorous acid in a solution where the concentration of hydrogen and hypochlorite ions are both equal to 5.8×10^{-3} M? K_a for this acid is 1.7×10^{-4}.
5. What is the cyanide ion concentration in a 0.100 M solution of the acid? K_a under these conditions is 7.2×10^{-10}.
6. The silver ion concentration in a saturated solution of silver chloride is found to be 0.0010 M. What is the concentration of the chloride ion? K_{sp} for silver chloride is 1.6×10^{-10}.
7. In a saturated solution of magnesium fluoride, the magnesium ion concentration is found to be 0.100 M. What is the molar concentration of the fluoride ion if the solubility product constant for this salt is 3.3×10^{-9}?
8. The solubility of barium sulfate is 2.4×10^{-4} g/100 mL. From this information, calculate the solubility product constant for barium sulfate.
9. Enough sulfide ion is added to a saturated solution of silver sulfide to make the anion's concentration 0.100 M. What is the concentration of the silver ion in this solution?
10. The solubility product constant of aluminum fluoride is 5.3×10^{-4}. From this information, calculate the solubility of this salt in grams per 100 mL of solution.

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Equilibria

Practice Problems (Level 3)

---

1. Calculate the acid ionization constant for acetic acid, $HC_2H_3O_2$, which is 0.010 M in concentration and 4.2% ionized.

2. What is the degree of ionization of hypochlorous acid in a 0.10 M solution, if the acid ionization constant for this situation is 1.4×10^{-3}?

3. A 0.20 M acetic acid solution has been made 0.10 M with respect to sodium acetate also. What is the concentration of hydrogen ion in this solution if K_a for acetic acid is taken to be 1.8×10^{-5}?

4. Find the pH of a 0.12 M solution of hydrocyanic acid if the K_a at this temperature is 2.1×10^{-9}.

5. What is the pH of a solution of acetic acid that is 0.100 M? For this situation, take K_a for the acid as 7.2×10^{-4}.

6. The concentration of calcium phosphate in a solution is 3.1×10^{-3} g/100 mL. What is the solubility product constant for this slightly soluble salt?

7. Given that the solubility of magnesium hydroxide is 9.6×10^{-4} g/100 mL, what do you calculate for the solubility product of this compound?

8. The solubility product constant for calcium sulfate is 2.36×10^{-4}. From this, determine the solubility of this salt in g/100 mL of solution.

9. The solubility product constant for silver carbonate is 6.3×10^{-12}. What solubility, in g/100 mL, does this give for silver carbonate in a saturated solution?

10. What concentration of sulfide ion will be needed to begin the precipitation of copper (I) sulfide from a 0.100 M solution of copper (I) nitrate? K_{sp} for copper (I) sulfide is 3.0×10^{-48}.

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Equilibria

Teacher Notes

1. Explanation of Levels

Level 1: General problems on equilibrium constant; calculation of K_{eq} primarily.

Level 2: Problems on ionization constant and solubility product constant; relatively simple problems.

Level 3: Problems on ionization constant and solubility product constant; slightly more difficult problems.

2. Answers

Level 1:

1. a. $\dfrac{[HCl]^2}{[H_2] \times [Cl_2]}$

   b. $\dfrac{[SO_3]^2}{[SO_2]^2 \times [O_2]}$

   c. $\dfrac{[NH_3]^2}{[N_2] \times [H_2]^3}$

   d. $\dfrac{[CO_2]^2}{[CO]^2 \times [O_2]}$

   e. $\dfrac{[CaO] \times [CO_2]}{[CaCO_3]}$

   f. $\dfrac{[H^+] \times [CN^-]}{[HCN]}$

   g. $\dfrac{[H^+] \times [HSO_4^-]}{[H_2SO_4]}$

   h. $\dfrac{[H^+]^2 \times [CO_3^{-2}]}{[H_2CO_3]}$

   i. $\dfrac{[Ag^+] \times [Cl^-]}{[AgCl]}$

   j. $\dfrac{[Pb^{+2}] \times [F^-]^2}{[PbF_2]}$

2. a. 1.0
   b. 4.5×10^3
   c. 0.150
   d. 1.0×10^5
   e. 4.7
   f. 0.024

Level 2:

1. 1.5×10^{-5} M
2. 9.9×10^{-2} M
3. 9.9×10^{-6} M
4. 0.20 M
5. 8.5×10^{-6} M
6. 1.6×10^{-7} M
7. 1.8×10^{-4} M
8. 1.1×10^{-10}
9. 1.3×10^{-24} M
10. 0.56 g/100 mL

Level 3:

1. 1.8×10^{-5}
2. 11%
3. 3.6×10^{-5} M
4. 4.8
5. 2.1
6. 1.1×10^{-18}
7. 1.8×10^{-11}
8. 0.21 g/100 mL
9. 3.2×10^{-3}g/100 mL
10. 3.0×10^{-46} M

Appendix 1:
The Systēme Internationale (SI)

Basic Units

Quantity	Name of Unit	Symbol
length	meter	m
mass	gram	kg
time	second	s
temperature	kelvin	K
electric current	ampere	A
amount of substance	mole	mol
luminous intensity	candela	cd
*(volume	liter	L)

---

*Volume is not a basic unit since it is derived from length. Because of its common use, however, we include it here.

Prefixes

Prefix	Meaning	Symbol	Prefix	Meaning	Symbol
tera	10^{12}	T	deci	10^{-1}	d
giga	10^{9}	G	centi	10^{-2}	c
mega	10^{6}	M	milli	10^{-3}	m
kilo	10^{3}	k	micro	10^{-6}	μ
hecto	10^{2}	h	nano	10^{-9}	n
deka	10^{1}	da	pico	10^{-12}	p
			femto	10^{-15}	f
			atto	10^{-18}	a

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Appendix 2:
Metric-English Conversion Factors

Length

1 in = 2.54 cm
1 km = 0.621 mi

Mass

1 g = 0.03527 oz
1 lb = 0.4536 kg

Volume

1 L = 1.057 qt (US liquid)
1 ft^3 = 28.32 L

Temperature

K = °C + 273.15
°C = 5/9 (°F − 32)
°F = 9/5 (°C) + 32

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Appendix 3:
The Periodic Table

Periodic Chart of the Elements

I A	II A	III B	IV B	V B	VI B	VII B	VIII B			I B	II B	III A	IV A	V A	VI A	VII A	VIII A
1 H 1.0080																1 H 1.0080	2 He 4.003
3 Li 6.940	4 Be 9.013											5 B 10.82	6 C 12.011	7 N 14.008	8 O 16.000	9 F 19.00	10 Ne 20.183
11 Na 22.991	12 Mg 24.32											13 Al 26.98	14 Si 28.09	15 P 30.975	16 S 32.066	17 Cl 35.457	18 Ar 39.944
19 K 39.100	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.95	24 Cr 52.01	25 Mn 54.94	26 Fe 55.85	27 Co 58.94	28 Ni 58.71	29 Cu 63.54	30 Zn 65.38	31 Ga 69.72	32 Ge 72.60	33 As 74.91	34 Se 78.96	35 Br 79.916	36 Kr 83.80
37 Rb 85.48	38 Sr 87.63	39 Y 88.92	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc (99)	44 Ru 101.1	45 Rh 102.91	46 Pd 106.4	47 Ag 107.880	48 Cd 112.41	49 In 114.82	50 Sn 118.70	51 Sb 121.87	52 Te 127.61	53 I 126.91	54 Xe 131.30
55 Cs 132.91	56 Ba 137.36	57 •La 138.92	72 Hf 178.50	73 Ta 180.95	74 W 183.86	75 Re 186.22	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 197.0	80 Hg 200.61	81 Tl 204.39	82 Pb 207.21	83 Bi 209.00	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 †Ac (227)	104 Ku (261)	105 Ha (260)	106 ? (263)	107	108	109	110	111	112	113	114	115	116	117	118

•LANTHANUM SERIES	58 Ce 140.13	59 Pr 140.92	60 Nd 144.27	61 Pm (147)	62 Sm 150.35	63 Eu 152.0	64 Gd 157.26	65 Tb 158.93	66 Dy 162.51	67 Ho 164.94	68 Er 167.27	69 Tm 168.94	70 Yb 173.04	71 Lu 174.99
†ACTINIUM SERIES	90 Th (232)	91 Pa (231)	92 U 238.07	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (249)	98 Cf (251)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (253)	103 Lw (257)

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Appendix 4:

Electronegativities of the Elements

As a generalization, a difference of less than 0.5 in electronegativities represents a nonpolar bond. A difference of 0.5 to about 1.7 represents a polar covalent bond. A difference greater than 1.7 represents an ionic bond.

1 **H** 2.1																		2 **He**
3 **Li** 1.0	4 **Be** 1.5												5 **B** 2.0	6 **C** 2.5	7 **N** 3.0	8 **O** 3.5	9 **F** 4.0	10 **Ne**
11 **Na** 0.9	12 **Mg** 1.2												13 **Al** 1.5	14 **Si** 1.8	15 **P** 2.1	16 **S** 2.5	17 **Cl** 3.0	18 **Ar**
19 **K** 0.8	20 **Ca** 1.0	21 **Sc** 1.3		22 **Ti** 1.5	23 **V** 1.6	24 **Cr** 1.6	25 **Mn** 1.5	26 **Fe** 1.8	27 **Co** 1.8	28 **Ni** 1.8	29 **Cu** 1.9	30 **Zn** 1.6	31 **Ga** 1.6	32 **Ge** 1.8	33 **As** 2.0	34 **Se** 2.4	35 **Br** 2.8	36 **Kr**
37 **Rb** 0.8	38 **Sr** 1.0	39 **Y** 1.3		40 **Zr** 1.4	41 **Nb** 1.6	42 **Mo** 1.8	43 **Tc** 1.9	44 **Ru** 2.2	45 **Rh** 2.2	46 **Pd** 2.2	47 **Ag** 1.9	48 **Cd** 1.7	49 **In** 1.7	50 **Sn** 1.8	51 **Sb** 1.9	52 **Te** 2.1	53 **I** 2.5	54 **Xe**
55 **Cs** 0.7	56 **Ba** 0.9	57 **La** 1.1	58 71 **Ce→Lu**	72 **Hf** 1.3	73 **Ta** 1.5	74 **W** 1.7	75 **Re** 1.9	76 **Os** 2.2	77 **Ir** 2.2	78 **Pt** 2.2	79 **Au** 2.4	80 **Hg** 1.9	81 **Tl** 1.8	82 **Pb** 1.8	83 **Bi** 1.9	84 **Po** 2.0	85 **At** 2.2	86 **Rn**
87 **Fr** 0.7	88 **Ra** 0.9	89 **Ac** 1.1	90 103 **Th→Lr**	104 **Ku**	105 **Ha**													

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Appendix 5:
Some Common Polyatomic Ions

Formula	Name
HCO_3^-	bicarbonate
CO_3^{2-}	carbonate
$C_2H_3O_2^-$	acetate
CN^-	cyanide
NO_3^-	nitrate
NO_2^-	nitrite
$H_2PO_4^-$	dihydrogen phosphate
HPO_4^{2-}	hydrogen phosphate
PO_4^{3-}	phosphate
OH^-	hydroxide
HSO_4^-	hydrogen sulfate (bisulfate)
SO_4^{2-}	sulfate
$S_2O_3^{2-}$	thiosulfate
HSO_3^-	hydrogen sulfite (bisulfite)
SO_3^{2-}	sulfite
ClO_4^-	perchlorate
ClO_3^-	chlorate
ClO_2^-	chlorite
ClO^-	hypochlorite
CrO_4^{2-}	chromate
$Cr_2O_7^{2-}$	dichromate
MnO_4^-	permanganate
NH_4^+	ammonium

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Appendix 6:
Some Common Multivalenced Cations

Element	Name	Symbol
chromium	chromous or chromium (II)	Cr^{+2}
	chromic or chromium (III)	Cr^{+3}
cobalt	cobaltous or cobalt (II)	Co^{+2}
	cobaltic or cobalt (III)	Co^{+3}
copper	cuprous or copper (I)	Cu^{+1}
	cupric or copper (II)	Cu^{+2}
iron	ferrous or iron (II)	Fe^{+2}
	ferric or iron (III)	Fe^{+3}
lead	plumbous or lead (II)	Pb^{+2}
	plumbic or lead (IV)	Pb^{+4}
mercury	mercurous or mercury (I)	Hg^{+1}*
	mercuric or mercury (II)	Hg^{+2}
nickel	nickelous or nickel (II)	Ni^{+2}
	nickelic or nickel (IV)	Ni^{+4}
tin	stannous or tin (II)	Sn^{+2}
	stannic or tin (IV)	Sn^{+4}

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*Mercury (I) occurs as two univalent atoms joined together, Hg_2^{+2}.

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Appendix 7:
Activity Series of the Elements

Metals

lithium
rubidium
potassium
sodium
strontium
barium
calcium
magnesium
aluminum
manganese
zinc
chromium
iron
cadmium
cobalt
nickel
tin
lead
HYDROGEN
antimony
bismuth
arsenic
copper
mercury
silver
platinum
gold

Non-metals

fluorine
chlorine
bromine
iodine
sulfur

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Appendix 8:
Solubility Chart

Initial note: All common compounds containing sodium or potassium or the ammonium, chlorate, or nitrate radical are soluble in water and are not listed in the following table.

S = soluble in water

P = partially soluble in water

I = insoluble in water and in dilute acids

A = insoluble in water, soluble in dilute acids

a = partially soluble in dilute acids; insoluble in water

X = does not exist or decompose in water

	acetate	bromide	carbonate	chloride	chromate	hydroxide	iodide	oxide	phosphate	silicate	sulfate	sulfide
aluminum	S	S	X	S	X	A	S	a	A	I	S	X
barium	S	S	P	S	A	S	S	S	A	S	a	X
calcium	S	S	P	S	S	S	S	P	P	P	P	P
cupric	S	S	X	S	X	A	X	A	A	A	S	A
ferrous	S	S	P	S	X	A	S	A	A	X	S	A
ferric	S	S	X	S	A	A	S	A	P	X	P	X
lead	S	S	A	S	A	P	S	P	A	A	P	A
magnesium	S	S	P	S	S	A	S	A	P	A	S	X
manganese	S	S	P	S	X	A	S	A	P	I	S	A
mercurous	P	A	A	a	P	X	A	A	A	X	P	I
mercuric	S	S	X	S	P	A	P	P	A	X	X	I
silver	P	a	A	a	P	X	I	P	A	X	P	A
stannous	X	S	X	S	A	A	S	A	A	X	S	A
stannic	S	S	X	X	S	P	X	A	X	X	S	A
strontium	S	S	P	S	P	S	S	S	A	A	P	S
zinc	S	S	P	S	P	A	S	P	A	A	S	A

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Appendix 9:
Water Vapor Pressure

Water Vapor Pressure
(in millimeters of mercury)

temperature (°C)	pressure (mmHg)	temperature (°C)	pressure (mmHg)	temperature (°C)	pressure (mmHg)
1	4.9	21	18.6	41	58.3
2	5.3	22	19.8	42	61.5
3	5.7	23	21.1	43	64.8
4	6.1	24	22.4	44	68.3
5	6.5	25	23.8	45	71.9
6	7.0	26	25.2	46	75.6
7	7.5	27	26.7	47	79.6
8	8.0	28	28.3	48	83.7
9	8.6	29	30.0	49	88.0
10	9.2	30	31.8	50	92.5
11	9.8	31	33.7	55	118.0
12	10.5	32	35.7	60	149.4
13	11.2	33	37.7	65	187.5
14	12.0	34	39.9	70	233.7
15	12.8	35	42.2	75	289.1
16	13.6	36	44.6	80	355.1
17	14.5	37	47.1	85	433.6
18	15.5	38	49.7	90	525.8
19	16.5	39	52.4	95	633.9
20	17.5	40	55.3	100	760.0

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Appendix 10:
A Table of Common Logarithms

Number	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	.00	.04	.08	.11	.15	.18	.20	.23	.26	.28
2	.30	.32	.34	.36	.38	.40	.42	.43	.45	.46
3	.48	.49	.51	.52	.53	.54	.56	.57	.58	.59
4	.60	.61	.62	.63	.64	.65	.66	.67	.68	.69
5	.70	.71	.72	.72	.73	.74	.75	.76	.76	.77
6	.78	.79	.79	.80	.81	.81	.82	.83	.83	.84
7	.85	.85	.86	.86	.87	.88	.88	.89	.89	.90
8	.90	.91	.91	.92	.92	.93	.93	.94	.94	.95
9	.95	.96	.96	.97	.97	.98	.98	.99	.99	1.00

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Appendix 11:

Boiling Point Elevation and Freezing Point Depression Constants

(All temperatures in °C)

Substance	Normal Boiling Point	Boiling Point Elevation	Normal Freezing Point	Freezing Point Depression
acetic acid	118.1	2.53	16.6	3.90
benzene	80.1	2.53	5.5	5.12
camphor	207.4	5.61	179.5	37.7
carbon tetrachloride	76.8	4.48	-23.0	29.8
chloroform	61.2	3.62	-63.5	4.68
cyclohexane	80.7	2.75	6.5	6.54
1,2-dibromoethane	131.7	6.61	10	12.5
ethyl alcohol	78.4	1.16	-114.6	1.99
napththalene	218.0	5.80	80.2	6.94
water	100.0	0.52	0.0	1.86

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Appendix 12:
Half Lives of Some Selected Isotopes

Isotope	**Half Life**
carbon 14	5720 y
cobalt 60	5.26 y
gallium 67	75 h
gold 198	2.69 d
hydrogen 3	12.5 y
iron 59	44.3 d
iodine 131	8.0 d
oxygen 15	1.97 m
phosphorus 32	14.3 d
plutonium 239	24,360 y
potassium 40	9.9×10^{8} y
radium 226	1620 y
sodium 24	15.0 h
strontium 90	28.8 yr
technetium 99	2×10^{5} y
thorium 232	1.4×10^{10} y
uranium 235	7.1×10^{8} y
uranium 238	4.5×10^{9} y
tungsten 187	24 h
platinum 197	18 h

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