Exercises

Review Questions

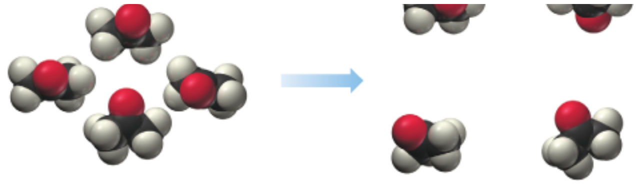
1. What is the greenhouse effect?
2. Why are scientists concerned about increases in atmospheric carbon dioxide? What is the source of the increase?
3. What is the difference between a physical change and a chemical change? List some examples of each.
4. What is the difference between a physical property and a chemical property?
5. What is a balanced chemical equation?
6. Why must chemical equations be balanced?
7. What is reaction stoichiometry? What is the significance of the coefficients in a balanced chemical equation?
8. In a chemical reaction, what is the limiting reactant? What do we mean when we say a reactant is in excess?
9. In a chemical reaction, what is the theoretical yield? The percent yield?
10. We typically calculate the percent yield using the actual yield and theoretical yield in units of mass (g or kg). Would the percent yield be different if the actual yield and theoretical yield were in units of amount (moles)?
11. Where does our society get the majority of its energy?
12. What is a combustion reaction? Why are they important? Give an example.
13. Write a general equation for the reaction of an alkali metal with:
    - **a.** a halogen
    - **b.** water
14. Write a general equation for the reaction of a halogen with:
    - **a.** a metal
    - **b.** hydrogen
    - **c.** another halogen

Problems by Topic

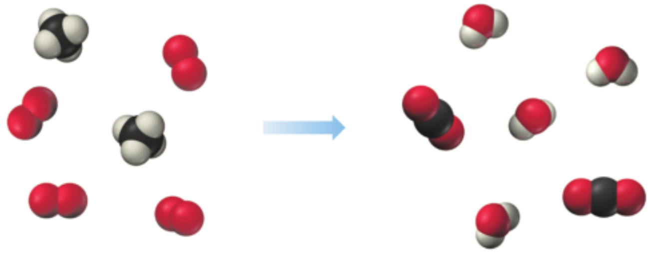
Note: Answers to all odd-numbered Problems can be found in Appendix III. Exercises in the Problems by Topic section are paired, with each odd-numbered problem followed by a similar even-numbered problem. Exercises in the Cumulative Problems section are also paired but more loosely. Because of their nature, Challenge Problems and Conceptual Problems are unpaired.

Chemical and Physical Changes

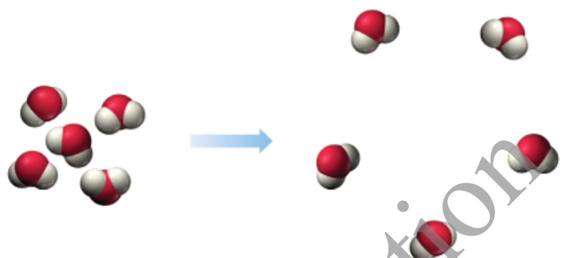
15. Classify each change as physical or chemical.
    - **a.** Natural gas burns in a stove.
    - **b.** The liquid propane in a gas grill evaporates because the valve was left open.
    - **c.** The liquid propane in a gas grill burns in a flame.
    - **d.** A bicycle frame rusts on repeated exposure to air and water.
16. Classify each change as physical or chemical.
    - **a.** Sugar burns when heated on a skillet.
    - **b.** Sugar dissolves in water.
    - **c.** A platinum ring becomes dull because of continued abrasion.
    - **d.** A silver surface becomes tarnished after exposure to air for a long period of time.
17. Based on the molecular diagram, classify each change as physical or chemical.
    - **a.**



b.



c.

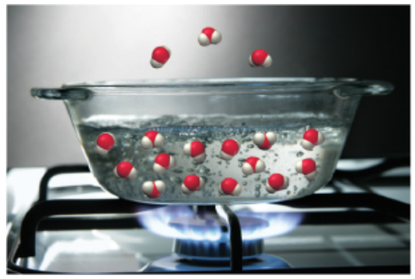


18. Based on the molecular diagram, classify each change as physical or chemical.

a.

b.

c.



19. Classify each of the listed properties of isopropyl alcohol (also known as rubbing alcohol) as physical or chemical.
    a. colorless
    b. flammable
    c. liquid at room temperature
    d. density = 0.79 g/mL
    e. mixes with water
20. Classify each of the listed properties of ozone (a pollutant in the lower atmosphere, but part of a protective shield against UV light in the upper atmosphere) as physical or chemical.
    a. bluish color
    b. pungent odor
    c. very reactive
    d. decomposes on exposure to ultraviolet light
    e. gas at room temperature
21. Classify each property as physical or chemical.
    a. the tendency of ethyl alcohol to burn
    b. the shine of silver
    c. the odor of paint thinner
    d. the flammability of propane gas
22. Classify each property as physical or chemical.
    a. the boiling point of ethyl alcohol
    b. the temperature at which dry ice evaporates
    c. the tendency of iron to rust
    d. the color of gold

Writing and Balancing Chemical Equations

23. Sulfuric acid (H_2SO_4) is a component of acid rain that forms when gaseous sulfur dioxide pollutant reacts with gaseous oxygen and liquid water to form aqueous sulfuric acid. Write a balanced chemical equation for this reaction. (Note: This is a simplified representation of this reaction.)
24. Nitric acid (HNO_3) is a component of acid rain that forms when gaseous nitrogen dioxide pollutant reacts with gaseous oxygen and liquid water to form aqueous nitric acid. Write a balanced chemical equation for this reaction. (Note: This is a simplified representation of this reaction.)
25. In a popular classroom demonstration, solid sodium is added to liquid water and reacts to produce hydrogen gas and aqueous sodium hydroxide. Write a balanced chemical equation for this reaction.
26. When iron rusts, solid iron reacts with gaseous oxygen to form solid iron(III) oxide. Write a balanced chemical equation for this reaction.
27. Write a balanced chemical equation for the fermentation of sucrose ($C_{12}H_{22}O_{11}$) by yeasts in which the aqueous sugar reacts with liquid water to form aqueous ethyl alcohol (C_2H_5OH) and carbon dioxide gas.
28. Write a balanced equation for the photosynthesis reaction in which gaseous carbon dioxide and liquid water react in the presence of chlorophyll to produce aqueous glucose ($C_6H_{12}O_6$) and oxygen gas.
29. Write a balanced chemical equation for each reaction.

a. Solid lead(II) sulfide reacts with aqueous hydrobromic acid (HBr) to form solid lead(II) bromide and dihydrogen monosulfide gas.
b. Gaseous carbon monoxide reacts with hydrogen gas to form gaseous methane (CH_4) and liquid water.
c. Aqueous hydrochloric acid (HCl) reacts with solid manganese(IV) oxide to form aqueous manganese(II) chloride, liquid water, and chlorine gas.
d. Liquid pentane (C_5H_{12}) reacts with gaseous oxygen to form gaseous carbon dioxide and liquid water.

30. Write a balanced chemical equation for each reaction.
a. Solid copper reacts with solid sulfur to form solid copper(I) sulfide.
b. Solid iron(III) oxide reacts with hydrogen gas to form solid iron and liquid water.
c. Sulfur dioxide gas reacts with oxygen gas to form sulfur trioxide gas.
d. Gaseous ammonia (NH_3) reacts with gaseous oxygen to form gaseous nitrogen monoxide and gaseous water.

31. Write a balanced chemical equation for the reaction of aqueous sodium carbonate with aqueous copper(II) chloride to form solid copper(II) carbonate and aqueous sodium chloride.

32. Write a balanced chemical equation for the reaction of aqueous potassium hydroxide with aqueous iron(III) chloride to form solid iron(III) hydroxide and aqueous potassium chloride.

33. Balance each chemical equation.
a. $CO_2(g) + CaSiO_3(s) + H_2O(l) \rightarrow SiO_2(s) + Ca(HCO_3)_2(aq)$
b. $Co(NO_3)_3(aq) + (NH_4)_2S(aq) \rightarrow Co_2S_3(s) + NH_4NO_3(aq)$
c. $Cu_2O(s) + C(s) \rightarrow Cu(s) + CO(g)$
d. $H_2(g) + Cl_2(g) \rightarrow HCl(g)$

34. Balance each chemical equation.
a. $Na_2S(aq) + Cu(NO_3)_2(aq) \rightarrow NaNO_3(aq) + CuS(s)$
b. $N_2H_4(l) \rightarrow NH_3(g) + N_2(g)$
c. $HCl(aq) + O_2(g) \rightarrow H_2O(l) + Cl_2(g)$
d. $FeS(s) + HCl(aq) \rightarrow FeCl_2(aq) + H_2S(g)$

Reaction Stoichiometry

35. Consider the unbalanced equation for the combustion of hexane:

$$C_6H_{14}(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$

Balance the equation and determine how many moles of O_2 are required to react completely with 7.2 moles C_6H_{14}.

36. Consider the unbalanced equation for the neutralization of acetic acid:

$$HC_2H_3O_2(aq) + Ba(OH)_2(aq) \rightarrow H_2O(l) + Ba(C_2H_3O_2)_2(aq)$$

Balance the equation and determine how many moles of $Ba(OH)_2$ are required to completely neutralize 0.461 mole of $HC_2H_3O_2$.

37. Calculate how many moles of NO_2 form when each quantity of reactant completely reacts.

$$2\ N_2O_5(g) \rightarrow 4\ NO_2(g) + O_2(g)$$

a. 2.5 mol N_2O_5
b. 6.8 mol N_2O_5
c. 15.2 g N_2O_5
d. 2.87 kg N_2O_5

38. Calculate how many moles of NH_3 form when each quantity of reactant completely reacts.

$$3\ N_2H_4(l) \rightarrow 4\ NH_3(g) + N_2(g)$$

a. 2.6 mol N_2H_4

b. 3.55 mol N_2H_4

c. 65.3 g N_2H_4

d. 4.88 kg N_2H_4

39. Consider the balanced equation:

$$SiO_2(s) + 3\,C(s) \rightarrow SiC(s) + 2\,CO(g)$$

Complete the following table showing the appropriate number of moles of reactants and products. If the number of moles of a *reactant* is provided, fill in the required amount of the other reactant, as well as the moles of each product that forms. If the number of moles of a *product* is provided, fill in the required amount of each reactant to make that amount of product, as well as the amount of the other product that is made.

Mol SiO_2	Mol C	Mol SiC	Mol CO
3	_____	_____	_____
_____	6	_____	_____
_____	_____	_____	10
2.8	_____	_____	_____
_____	1.55	_____	_____

40. Consider the balanced equation:

$$2\,N_2H_4(g) + N_2O_4(g) \rightarrow 3\,N_2(g) + 4\,H_2O(g)$$

Complete the following table showing the appropriate number of moles of reactants and products. If the number of moles of a *reactant* is provided, fill in the required amount of the other reactant, as well as the moles of each product that forms. If the number of moles of a *product* is provided, fill in the required amount of each reactant to make that amount of product, as well as the amount of the other product that is made.

Mol N_2H_4	Mol N_2O_4	Mol N_2	Mol H_2O
2	_____	_____	_____
_____	5	_____	_____
_____	_____	_____	10
2.5	_____	_____	_____
_____	4.2	_____	_____
_____	_____	11.8	_____

41. Hydrobromic acid (HBr) dissolves solid iron according to the reaction:

$$Fe(s) + 2\,HBr(aq) \rightarrow FeBr_2(aq) + H_2(g)$$

What mass of HBr (in g) do you need to dissolve a 3.2-g pure iron bar on a padlock? What mass of H_2 can the complete reaction of the iron bar produce?

42. Sulfuric acid (H_2SO_4) dissolves aluminum metal according to the reaction:

$$2\,Al(s) + 3\,H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3\,H_2(g)$$

Suppose you want to dissolve an aluminum block with a mass of 15.2 g. What minimum mass of H_2SO_4 (in g) do you need? What mass of H_2 gas (in g) can the complete reaction of the aluminum block produce?

43. For each of the reactions, calculate the mass (in grams) of the product that forms when 3.67 g of the underlined reactant completely reacts. Assume that there is more than enough of the other reactant.

a. $\underline{Ba(s)} + Cl_2(g) \rightarrow BaCl_2(s)$

b. $\underline{CaO(s)} + CO_2(g) \rightarrow CaCO_3(s)$

c. $2\,\underline{Mg(s)} + O_2(g) \rightarrow 2\,MgO(s)$

d. $4\ Al(s)^{-} + 3\ O_2(g) \rightarrow 2\ Al_2O_3(s)$

44. For each of the reactions, calculate the mass (in grams) of the product that forms when 15.39 g of the underlined reactant completely reacts. Assume that there is more than enough of the other reactant.

a. $2\ K(s) + Cl_2(g)^{-} \rightarrow 2\ KCl(s)$

b. $2\ K(s) + Br_2(l)^{-} \rightarrow 2\ KBr(s)$

c. $4\ Cr(s) + 3\ O_2(g)^{-} \rightarrow 2\ Cr_2O_3(s)$

d. $2\ Sr(s)^{-} + O_2(g) \rightarrow 2\ SrO(s)$

Limiting Reactant, Theoretical Yield, Percent Yield, and Reactant in Excess

45. For the following reaction, determine the limiting reactant for each of the initial amounts of reactants.

$$2\ Na(s) + Br_2(g) \rightarrow 2\ NaBr(s)$$

a. 2 mol Na, 2 mol Br_2

b. 1.8 mol Na, 1.4 mol Br_2

c. 2.5 mol Na, 1 mol Br_2

d. 12.6 mol Na, 6.9 mol Br_2

46. Find the limiting reactant for each initial amount of reactants.

$$4\ Al(s) + 3\ O_2(g) \rightarrow 2\ Al_2O_3(s)$$

a. 1 mol Al, 1 mol O_2

b. 4 mol Al, 2.6 mol O_2

c. 16 mol Al, 13 mol O_2

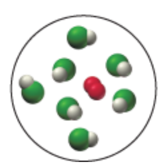
d. 7.4 mol Al, 6.5 mol O_2

47. Consider the reaction:

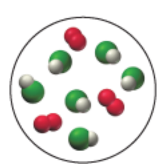
$$4\ HCl(g) + O_2(g) \rightarrow 2\ H_2O(g) + 2\ Cl_2(g)$$

Each molecular diagram represents an initial mixture of the reactants. How many molecules of Cl_2 would form from the reaction mixture that produces the greatest amount of products?

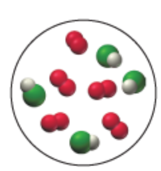
a.



b.



c.

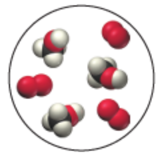


48. Consider the reaction:

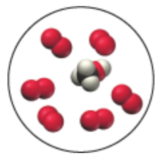
$$2\ CH_3OH(g) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 4\ H_2O(g)$$

Each of the molecular diagrams represents an initial mixture of the reactants. How many CO_2 molecules would form from the reaction mixture that produces the greatest amount of products?

a.



b.



c.

49. Calculate the theoretical yield of the product (in moles) for each initial amount of reactants.

$$Ti(s) + 2\ Cl_2(g) \rightarrow TiCl_4(s)$$

a. 4 mol Ti, 4 mol Cl_2
b. 7 mol Ti, 17 mol Cl_2
c. 12.4 mol Ti, 18.8 mol Cl_2

50. Calculate the theoretical yield of product (in moles) for each initial amount of reactants.

$$2\ Mn(s) + 2\ O_2(g) \rightarrow 2\ MnO_2(s)$$

a. 3 mol Mn, 3 mol O_2
b. 4 mol Mn, 7 mol O_2
c. 27.5 mol Mn, 43.8 mol O_2

51. Zinc sulfide reacts with oxygen according to the reaction:

$$2\ ZnS(s) + 3\ O_2(g) \rightarrow 2\ ZnO(s) + 2\ SO_2(g)$$

A reaction mixture initially contains 4.2 mol ZnS and 6.8 mol O_2. Once the reaction has occurred as completely as possible, what amount (in moles) of the excess reactant remains?

52. Iron(II) sulfide reacts with hydrochloric acid according to the reaction:

$$FeS(s) + 2\ HCl(aq) \rightarrow FeCl_2(s) + H_2S(g)$$

A reaction mixture initially contains 0.223 mol FeS and 0.652 mol HCl. Once the reaction has occurred as completely as possible, what amount (in moles) of the excess reactant is left?

53. For the reaction shown, calculate the theoretical yield of product (in grams) for each initial amount of reactants.

$$2\,Al(s) + 3\,Cl_2(g) \rightarrow 2\,AlCl_3(s)$$

a. 2.0 g Al, 2.0 g Cl_2
b. 7.5 g Al, 24.8 g Cl_2
c. 0.235 g Al, 1.15 g Cl_2

54. For the reaction shown, calculate the theoretical yield of the product (in grams) for each initial amount of reactants.

$$Ti(s) + 2\,F_2(g) \rightarrow TiF_4(s)$$

a. 5.0 g Ti, 5.0 g F_2
b. 2.4 g Ti, 1.6 g F_2
c. 0.233 g Ti, 0.288 g F_2

55. Iron(III) oxide reacts with carbon monoxide according to the equation:

$$Fe_2O_3(s) + 3\,CO(g) \rightarrow 2\,Fe(s) + 3\,CO_2(g)$$

A reaction mixture initially contains 22.55 Fe_2O_3 and 14.78 g CO. Once the reaction has occurred as completely as possible, what mass (in g) of the excess reactant remains?

56. Elemental phosphorus reacts with chlorine gas according to the equation:

$$P_4(s) + 6\,Cl_2(g) \rightarrow 4\,PCl_3(l)$$

A reaction mixture initially contains 45.69 g P_4 and 131.3 g Cl_2. Once the reaction has occurred as completely as possible, what mass (in g) of the excess reactant remains?

57. Lead(II) ions can be removed from solution with KCl according to the reaction:

$$Pb^{2+}(aq) + 2\,KCl(aq) \rightarrow PbCl_2(s) + 2\,K^+(aq)$$

When 28.5 g KCl is added to a solution containing 25.7 g Pb^{2+}, a $PbCl_2(s)$ forms. The solid is filtered and dried and found to have a mass of 29.4 g. Determine the limiting reactant, theoretical yield of $PbCl_2$, and percent yield for the reaction.

58. Magnesium oxide can be made by heating magnesium metal in the presence of oxygen. The balanced equation for the reaction is:

$$2\,Mg(s) + O_2(g) \rightarrow 2\,MgO(s)$$

When 10.1 g of Mg reacts with 10.5 g O_2, 11.9 g MgO forms. Determine the limiting reactant, theoretical yield, and percent yield for the reaction.

59. Urea (CH_4N_2O) is a common fertilizer that is synthesized by the reaction of ammonia (NH_3) with carbon dioxide:

$$2\,NH_3(aq) + CO_2(aq) \rightarrow CH_4N_2O(aq) + H_2O(l)$$

In an industrial synthesis of urea, a chemist combines 136.4 kg of ammonia with 211.4 kg of carbon dioxide and obtains 168.4 kg of urea. Determine the limiting reactant, theoretical yield of urea, and percent yield for the reaction.

60. Many computer chips are manufactured from silicon, which occurs in nature as SiO_2. When SiO_2 is heated to melting, it reacts with solid carbon to form liquid silicon and carbon monoxide gas. In an industrial preparation of silicon, 155.8 kg of SiO_2 reacts with 78.3 kg of carbon to produce 66.1 kg of silicon. Determine the limiting reactant, theoretical yield, and percent yield for the reaction.

Combustion, Alkali Metal, and Halogen Reactions

61. Complete and balance each combustion reaction equation.

61. Complete and balance each combustion reaction equation:

a. $S(s) + O_2(g) \rightarrow$

b. $C_3H_6(g) + O_2(g) \rightarrow$

c. $Ca(s) + O_2(g) \rightarrow$

d. $C_5H_{12}S(l) + O_2(g) \rightarrow$

62. Complete and balance each combustion reaction equation:

a. $C_4H_6(g) + O_2(g) \rightarrow$

b. $C(s) + O_2(g) \rightarrow$

c. $CS_2(s) + O_2(g) \rightarrow$

d. $C_3H_8O(l) + O_2(g) \rightarrow$

63. Write a balanced chemical equation for the reaction of solid strontium with iodine gas.

64. Based on the ionization energies of the alkali metals , which alkali metal would you expect to undergo the most exothermic reaction with chlorine gas? Write a balanced chemical equation for the reaction.

65. Write a balanced chemical equation for the reaction of solid lithium with liquid water.

66. Write a balanced chemical equation for the reaction of solid potassium with liquid water.

67. Write a balanced equation for the reaction of hydrogen gas with bromine gas.

68. Write a balanced equation for the reaction of chlorine gas with fluorine gas.

Cumulative Problems

69. The combustion of gasoline produces carbon dioxide and water. Assume gasoline to be pure octane (C_8H_{18}) and calculate the mass (in kg) of carbon dioxide that is added to the atmosphere per 1.0 kg of octane burned. (*Hint*: Begin by writing a balanced equation for the combustion reaction.)

70. Many home barbeques are fueled with propane gas (C_3H_8). What mass of carbon dioxide (in kg) forms upon the complete combustion of 18.9 L of propane (approximate contents of one 5-gallon tank)? Assume that the density of the liquid propane in the tank is 0.621 g/mL. (*Hint*: Begin by writing a balanced equation for the combustion reaction.)

71. Aspirin can be made in the laboratory by reacting acetic anhydride ($C_4H_6O_3$) with salicylic acid ($C_7H_6O_3$) to form aspirin ($C_9H_8O_4$) and acetic acid ($C_2H_4O_2$). The balanced equation is:

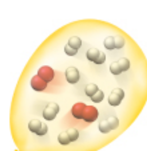
$$C_4H_6O_3 + C_7H_6O_3 \rightarrow C_9H_8O_4 + C_2H_4O_2$$

In a laboratory synthesis, a student begins with 3.00 mL of acetic anhydride (density = 1.08 g/mL) and 1.25 g of salicylic acid. Once the reaction is complete, the student collects 1.22 g of aspirin. Determine the limiting reactant, theoretical yield of aspirin, and percent yield for the reaction.

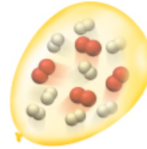
72. The combustion of liquid ethanol (C_2H_5OH) produces carbon dioxide and water. After 4.62 mL of ethanol (density = 0.789 g/mL) burns in the presence of 15.55 g of oxygen gas, 3.72 mL of water (density = 1.00 g/mL) is collected. Determine the limiting reactant, theoretical yield of H_2O, and percent yield for the reaction. (*Hint*: Write a balanced equation for the combustion of ethanol.)

73. A loud classroom demonstration involves igniting a hydrogen-filled balloon. The hydrogen within the balloon reacts explosively with oxygen in the air to form water. If the balloon is filled with a mixture of hydrogen and oxygen, the explosion is even louder than if the balloon is filled only with hydrogen—the intensity of the explosion depends on the relative amounts of oxygen and hydrogen within the balloon. Look at the molecular views representing different amounts of hydrogen and oxygen in four different balloons. Based on the balanced chemical equation, which balloon will make the loudest explosion? (Hint: Write a balanced equation for the chemical reaction first.)

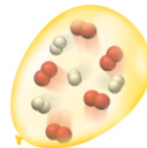
a.



b.



c.



d.

74. The nitrogen in sodium nitrate and in ammonium sulfate is available to plants as fertilizer. Which is the more economical source of nitrogen, a fertilizer containing 30.0% sodium nitrate by weight and costing $9.00 per 100 lb or one containing 20.0% ammonium sulfate by weight and costing $8.10 per 100 lb?

75. The reaction of NH_3 and O_2 forms NO and water. The NO can be used to convert P_4 to P_4O_6, forming N_2 in the process. The P_4O_6 can be treated with water to form H_3PO_3, which forms PH_3 and H_3PO_4 when heated. Find the mass of PH_3 that forms from the reaction of 1.00 g NH_3.

76. An important reaction that takes place in a blast furnace during the production of iron is the formation of iron metal and CO_2 from Fe_2O_3 and CO. Determine the mass of Fe_2O_3 required to form 910 kg of iron. Determine the amount of CO_2 that forms in this process.

77. A liquid fuel mixture contains 30.35% hexane (C_6H_{14}) and 15.85% heptane (C_7H_{16}). The remainder is octane (C_8H_{18}). What maximum mass of carbon dioxide is produced by the complete combustion of 10.0 kg of this fuel mixture?

78. Titanium occurs in the magnetic mineral ilmenite ($FeTiO_3$), which is often found mixed with sand. The ilmenite can be separated from the sand with magnets. The titanium can then be extracted from the ilmenite by the following set of reactions:

$$\mathrm{FeTiO_3}(s) + 3\,\mathrm{Cl_2}(g) + 3\,\mathrm{C}(s) \rightarrow 3\,\mathrm{CO}(g) + \mathrm{FeCl_2}(s) + \mathrm{TiCl_4}(g)$$

$$\mathrm{TiCl_4}(g) + 2\,\mathrm{Mg}(s) \rightarrow 2\,\mathrm{MgCl_2}(l) + \mathrm{Ti}(s)$$

Suppose that an ilmenite–sand mixture contains 22.8% ilmenite by mass and that the first reaction is carried out with a 90.8% yield. If the second reaction is carried out with an 85.9% yield, what mass of titanium can we obtain from 1.00 kg of the ilmenite–sand mixture?

Challenge Problems

79. A mixture of C_3H_8 and C_2H_2 has a mass of 2.0 g. It is burned in excess O_2 to form a mixture of water and carbon dioxide that contains 1.5 times as many moles of CO_2 as of water. Find the mass of C_2H_2 in the original mixture.

80. A mixture of 20.6 g of P and 79.4 g Cl_2 reacts completely to form PCl_3 and PCl_5, which are the only products. Determine the mass of PCl_3 that forms.

81. Lead poisoning is a serious condition resulting from the ingestion of lead in food, water, or other environmental sources. It affects the central nervous system, leading to a variety of symptoms such as distractibility, lethargy, and loss of motor coordination. Lead poisoning is treated with chelating agents, substances that bind to metal ions, allowing them to be eliminated in the urine. A modern chelating agent used for this purpose is succimer ($C_4H_6O_4S_2$). Suppose you are trying to determine the appropriate dose for succimer treatment of lead poisoning. What minimum mass of succimer (in mg) is needed to bind all of the lead in a patient's bloodstream? Assume that patient blood lead levels are 45 μg/dL, that total blood volume is 5.0 L, and that one mole of succimer binds one mole of lead.

82. A particular kind of emergency breathing apparatus—often placed in mines, caves, or other places where oxygen might become depleted or where the air might become poisoned—works via the following chemical reaction:

$$4\,KO_2(s) + 2\,CO_2(g) \rightarrow 2\,K_2CO_3(s) + 3\,O_2(g)$$

Notice that the reaction produces O_2, which can be breathed, and absorbs CO_2, a product of respiration. Suppose you work for a company interested in producing a self-rescue breathing apparatus (based on the above reaction) that would allow the user to survive for 10 minutes in an emergency situation. What are the important chemical considerations in designing such a unit? Estimate how much KO_2 would be required for the apparatus. (Find any necessary additional information—such as human breathing rates—from appropriate sources. Assume that normal air is 20% oxygen.)

83. Metallic aluminum reacts with MnO_2 at elevated temperatures to form manganese metal and aluminum oxide. A mixture of the two reactants is 67.2% mole percent Al. Determine the theoretical yield (in grams) of manganese from the reaction of 250 g of this mixture.

84. Hydrolysis of the compound B_5H_9 forms boric acid, H_3BO_3. Fusion of boric acid with sodium oxide forms a borate salt, $Na_2B_4O_7$. Without writing complete equations, find the mass (in grams) of B_5H_9 required to form 151 g of the borate salt by this reaction sequence.

Conceptual Problems

85. Consider the reaction:

$$4\,K(s) + O_2(g) \rightarrow 2\,K_2O(s)$$

The molar mass of K is 39.09 g/mol and that of O_2 is 32.00 g/mol. Without doing any calculations, choose the conditions under which potassium is the limiting reactant and explain your reasoning.

a. 170 g K, 31 g O_2
b. 16 g K, 2.5 g O_2
c. 165 kg K, 28 kg O_2
d. 1.5 g K, 0.38 g O_2

86. Consider the reaction:

$$2\,NO(g) + 5\,H_2(g) \rightarrow 2\,NH_3(g) + 2\,H_2O(g)$$

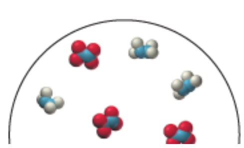
A reaction mixture initially contains 5 moles of NO and 10 moles of H_2. Without doing any calculations, determine which set of amounts best represents the mixture after the reactants have reacted as completely as possible. Explain your reasoning.

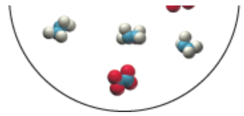
a. 1 mol NO, 0 mol H_2, 4 mol NH_3, 4 mol H_2O
b. 0 mol NO, 1 mol H_2, 5 mol NH_3, 5 mol H_2O
c. 3 mol NO, 5 mol H_2, 2 mol NH_3, 2 mol H_2O
d. 0 mol NO, 0 mol H_2, 4 mol NH_3, 4 mol H_2O

87. Consider the reaction:

$$2\,N_2H_4(g) + N_2O_4(g) \rightarrow 3\,N_2(g) + 4\,H_2O(g)$$

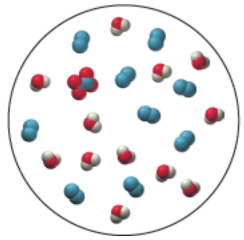
Consider also this representation of an initial mixture of N_2H_4 and N_2O_4:



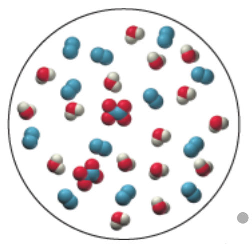


Which diagram best represents the reaction mixture after the reactants have reacted as completely as possible? (Hint: Begin by determining the limiting reactant.)

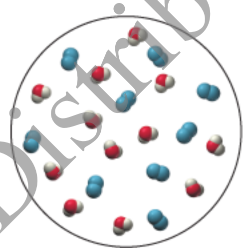
a.



b.



c.



Questions for Group Work

Active Classroom Learning

Discuss these questions with the group and record your consensus answer.

88. Octane (C_8H_8), a component of gasoline, reacts with oxygen to form carbon dioxide and water. Write the balanced chemical reaction for this process by passing a single piece of paper around your group and asking each group member to complete the next logical step. As you each complete your step, explain your reasoning to the group.

89. Imagine you mix 16.05 g of methane (CH_4) gas and 96.00 g of oxygen (O_2) gas and then ignite the mixture. After a bright flash and a loud bang, some water droplets form on the inside of the reaction vessel.

- **a.** Write the balanced chemical reaction for the combustion of methane.
- **b.** Sketch the process that occurred in the vessel using circles to represent atoms. Represent carbon with black circles, hydrogen with white circles, and oxygen with red circles. Let one circle (or one molecule made of circles bonded together) represent exactly one mole.
- **c.** How many moles of water can you make? How many moles of carbon dioxide?
- **d.** Will anything be left over? What? How much?
- **e.** Identify the following: limiting reactant, reactant in excess, and theoretical yield.

Data Interpretation and Analysis

90. A chemical reaction in which reactants A and B form the product C is studied in the laboratory. The researcher carries out the reaction with differing relative amounts of reactants and measures the amount of product produced. Examine the given tabulated data from the experiment and answer the questions.

Experiment #	Mass A (*g*)	Mass B (*g*)	Mass C Obtained (*g*)
1	2.51	7.54	3.76
2	5.03	7.51	7.43
3	7.55	7.52	11.13
4	12.53	7.49	14.84
5	15.04	7.47	14.94
6	19.98	7.51	15.17
7	20.04	9.95	19.31
8	20.02	12.55	24.69

a. For which experiments is A the limiting reactant?

b. For which experiments is B the limiting reactant?

c. The molar mass of A is 50.0 g/mol, and the molar mass of B is 75.0 g/mol. What are the coefficients of A and B in the balanced chemical equation?

d. For each of the experiments in which A is the limiting reactant, calculate the mass of B remaining after the reaction has gone to completion. Use the molar masses and coefficients from part c.

e. The molar mass of C is 88.0 g/mol. What is the coefficient of C in the balanced chemical equation?

f. Calculate an average percent yield for the reaction.

Answers to Conceptual Connections

Cc 7.1 (**b**) The burning of lamp oil is like the burning of gasoline. The lamp oil is transformed into other substances (primarily carbon dioxide and water). The evaporation of rubbing alcohol and the formation of frost are both changes of state and therefore physical changes.

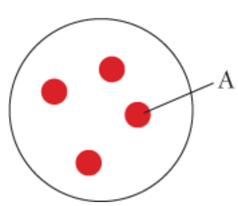
Cc 7.2 View (**a**) best represents the water after vaporization. Vaporization is a physical change, so the molecules remain the same before and after the change.

Cc 7.3 Both (**a**) and (**d**) are correct. When the number of atoms of each type is balanced, the sum of the masses of the substances involved will be the same on both sides of the equation. Since molecules change during a chemical reaction, their number is not the same on both sides, nor is the number of moles necessarily the same.

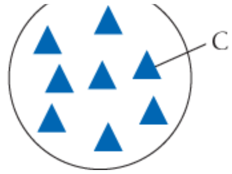
Cc 7.4 Image (**c**) is the best representation because each O_2 molecule reacts with 4 Na atoms; 12 Na atoms are required to react with 3 O_2 molecules.

Cc 7.5

a.



b.



Cc 7.6 Image (**c**) best represents the mixture. Nitrogen is the limiting reactant, and there is enough nitrogen to make 4 NH_3 molecules. Hydrogen is in excess, and 2 hydrogen molecules remain after the reactants have reacted as completely as possible.

Cc 7.7 The limiting reactant is the H_2O, which is completely consumed. The 1 mol of H_2O requires 3 mol of NO_2 to completely react; therefore, 2 mol NO_2 remain after the reaction is complete.