CHAPTER 4 IN REVIEW

TERMS

Section 4.2
chemical reaction (141)
combustion reaction (141)
chemical equation (141)
reactants (141)
products (141)
balanced chemical equation (141)

Section 4.3
stoichiometry (145)

Section 4.4
limiting reactant (150)
reactant in excess (150)
theoretical yield (150)
actual yield (150)
percent yield (150)

CONCEPTS

Climate Change and the Combustion of Fossil Fuels (4.1)

- Greenhouse gases warm Earth by trapping some of the sunlight that penetrates Earth's atmosphere. Global warming, resulting from rising atmospheric carbon dioxide levels, is potentially harmful.
- The largest atmospheric carbon dioxide source is the burning of fossil fuels. This can be verified by reaction stoichiometry.

Writing and Balancing Chemical Equations (4.2)

- In chemistry, we represent chemical reactions with chemical equations. The substances on the left-hand side of a chemical equation are the reactants, and the substances on the right-hand side are the products.
- Chemical equations are balanced when the number of each type of atom on the left side of the equation is equal to the number on the right side.

Reaction Stoichiometry (4.3)

- Reaction stoichiometry refers to the numerical relationships between the reactants and products in a balanced chemical equation.
- Reaction stoichiometry allows us to predict, for example, the amount of product that can be formed for a given amount of reactant, or how much of one reactant is required to react with a given amount of another.

Limiting Reactant, Theoretical Yield, and Percent Yield (4.4)

- When a chemical reaction actually occurs, the reactants are usually not present in the exact stoichiometric ratios specified by the balanced chemical equation. The limiting reactant is the one that is available in the smallest stoichiometric quantity—it will be completely consumed in the reaction, and it limits the amount of product that can be made.
- Any reactant that does not limit the amount of product is in excess.
- The amount of product that can be made from the limiting reactant is the theoretical yield.
- The actual yield—always equal to or less than the theoretical yield—is the amount of product that is actually made when the reaction is carried out.
- The percentage of the theoretical yield that is actually produced when the reaction is carried out is the percent yield.

Combustion, Alkali Metals, and Halogens (4.5)

- In a combustion reaction, a substance reacts with oxygen—emitting heat and forming one or more oxygen-containing products. The alkali metals react with nonmetals, losing electrons in the process.
- The halogens react with many metals to form metal halides. They also react with hydrogen to form hydrogen halides and with one another to form interhalogen compounds.

EQUATIONS AND RELATIONSHIPS

Mass-to-Mass Conversion: Stoichiometry (4.2)

$$\text{mass A} \longrightarrow \text{amount A (in moles)} \longrightarrow \text{amount B (in moles)} \longrightarrow \text{mass B}$$

Percent Yield (4.3)

$$\%\ \text{yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

LEARNING OUTCOMES

Chapter Objectives	Assessment
Balance chemical equations (4.2)	Examples 4.1, 4.2, 4.3 **For Practice** 4.1, 4.2, 4.3 **Exercises** 13–24
Perform calculations involving the stoichiometry of a reaction (4.3)	Examples 4.4, 4.5 **For Practice** 4.4, 4.5 **Exercises** 25–34
Analyze chemical reactions involving a limiting reactant (4.4)	Examples 4.6, 4.7 **For Practice** 4.6, 4.7 **Exercises** 35–50
Write chemical equations for combustion reactions (4.5)	Example 4.8 **For Practice** 4.8 **Exercises** 51–52
Write chemical equations for reactions involving alkali metals and halogens (4.5)	Example 4.9 **For Practice** 4.9 **Exercises** 53–58

EXERCISES

Mastering Chemistry provides end-of-chapter exercises, feedback-enriched tutorial problems, animations, and interactive activities to encourage problem-solving practice and deeper understanding of key concepts and topics.

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 a balanced chemical equation?

4. Identify the reactants and products in this chemical equation.
$4\,NH_3(g) + 5\,O_2(g) \longrightarrow 4\,NO(g) + 6\,H_2O(g)$

5. Why must chemical equations be balanced?

6. What is reaction stoichiometry? What is the significance of the coefficients in a balanced chemical equation?

7. In a chemical reaction, what is the limiting reactant? What do we mean when we say a reactant is in excess?

8. In a chemical reaction, what is the theoretical yield and the percent yield?

9. We typically calculate the percent yield using the actual yield and theoretical yield in units of mass (grams or kilograms). Would the percent yield be different if the actual yield and theoretical yield were in units of amount (moles)?

10. What is a combustion reaction? Why are combustion reactions important? Give an example.

11. Write a general equation for the reaction of an alkali metal with:
a. a halogen
b. water

12. Write a general equation for the reaction of a halogen with:
a. a metal **b.** hydrogen
c. another halogen

PROBLEMS BY TOPIC

Writing and Balancing Chemical Equations

13. Sulfuric acid is a component of acid rain formed when gaseous sulfur dioxide pollutant reacts with gaseous oxygen and liquid water to form aqueous sulfuric acid. Write the balanced chemical equation for this reaction. (*Note:* This is a simplified representation of this reaction.)
MISSED THIS? *Read Section 4.2; Watch KCV 4.2, IWE 4.2*

14. Nitric acid 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 the balanced chemical equation for this reaction. (*Note:* This is a simplified representation of this reaction.)

15. In a popular classroom demonstration, solid sodium is added to liquid water and reacts to produce hydrogen gas and aqueous sodium hydroxide. Write the balanced chemical equation for this reaction.
MISSED THIS? *Read Sections 4.2, 4.5; Watch KCV 4.2, IWE 4.2*

16. When iron rusts, solid iron reacts with gaseous oxygen to form solid iron(III) oxide. Write the balanced chemical equation for this reaction.

17. Write the balanced chemical equation for the fermentation of sucrose ($C_{12}H_{22}O_{11}$) by yeasts in which the aqueous sugar reacts with water to form aqueous ethanol (C_2H_5OH) and carbon dioxide gas.
MISSED THIS? *Read Section 4.2; Watch KCV 4.2, IWE 4.2*

18. Write the 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.

19. Write the balanced chemical equation for each reaction.
MISSED THIS? *Read Section 4.2; Watch KCV 4.2, IWE 4.2*
a. Solid lead(II) sulfide reacts with aqueous hydrobromic acid 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 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 carbon dioxide and liquid water.

20. Write the 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.

21. Write the 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.
MISSED THIS? *Read Section 4.2; Watch KCV 4.2, IWE 4.3*

22. Write the 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.

23. Balance each chemical equation.
MISSED THIS? *Read Section 4.2; Watch KCV 4.2, IWE 4.2, 4.3*
a. $CO_2(g) + CaSiO_3(s) + H_2O(l) \longrightarrow SiO_2(s) + Ca(HCO_3)_2(aq)$
b. $Co(NO_3)_3(aq) + (NH_4)_2S(aq) \longrightarrow Co_2S_3(s) + NH_4NO_3(aq)$
c. $Cu_2O(s) + C(s) \longrightarrow Cu(s) + CO(g)$
d. $H_2(g) + Cl_2(g) \longrightarrow HCl(g)$

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

Reaction Stoichiometry

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

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

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

MISSED THIS? *Read Section 4.3; Watch KCV 4.3, IWE 4.4*

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

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

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

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

MISSED THIS? *Read Section 4.3; Watch KCV 4.3, IWE 4.4*

$$2\,N_2O_5(g) \longrightarrow 4\,NO_2(g) + O_2(g)$$

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

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

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

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

29. Consider the balanced equation:

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

Complete the 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 forms.

MISSED THIS? *Read Section 4.3; Watch KCV 4.3, IWE 4.4*

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

30. Consider the balanced equation:

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

Complete the 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 forms.

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

31. Hydrobromic acid dissolves solid iron according to the reaction:

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

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 would the complete reaction of the iron bar produce?

MISSED THIS? *Read Section 4.3; Watch KCV 4.3, IWE 4.4*

32. Sulfuric acid dissolves aluminum metal according to the reaction:

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

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) does the complete reaction of the aluminum block produce?

33. 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.

MISSED THIS? *Read Section 4.3; Watch KCV 4.3, IWE 4.4*

a. $\underline{Ba(s)} + Cl_2(g) \longrightarrow BaCl_2(s)$
b. $\underline{CaO(s)} + CO_2(g) \longrightarrow CaCO_3(s)$
c. $2\,\underline{Mg(s)} + O_2(g) \longrightarrow 2\,MgO(s)$
d. $4\,\underline{Al(s)} + 3\,O_2(g) \longrightarrow 2\,Al_2O_3(s)$

34. 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. $2\,K(s) + \underline{Cl_2(g)} \longrightarrow 2\,KCl(s)$
b. $2\,K(s) + \underline{Br_2(l)} \longrightarrow 2\,KBr(s)$
c. $4\,Cr(s) + 3\,\underline{O_2(g)} \longrightarrow 2\,Cr_2O_3(s)$
d. $2\,\underline{Sr(s)} + O_2(g) \longrightarrow 2\,SrO(s)$

Limiting Reactant, Theoretical Yield, and Percent Yield

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

MISSED THIS? *Read Section 4.4; Watch KCV 4.4, IWE 4.6*

$$2\,Na(s) + Br_2(g) \longrightarrow 2\,NaBr(s)$$

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

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

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

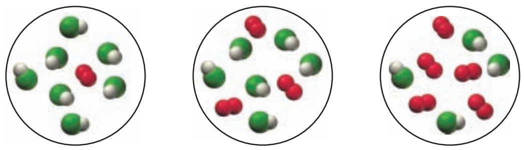
a. 1 mol Al, 1 mol O_2 **b.** 4 mol Al, 2.6 mol O_2
c. 16 mol Al, 13 mol O_2 **d.** 7.4 mol Al, 6.5 mol O_2

37. Consider the reaction:

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

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

MISSED THIS? *Read Section 4.4; Watch KCV 4.4, IWE 4.6*



a. b. c.

38. Consider the reaction:

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

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

a. b. c.

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

MISSED THIS? *Read Section 4.4; Watch KCV 4.4, IWE 4.6*

$$Ti(s) + 2\,Cl_2(g) \longrightarrow TiCl_4(l)$$

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

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

$$3\,Mn(s) + 2\,O_2(g) \longrightarrow Mn_3O_4(s)$$

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

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

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

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?

MISSED THIS? *Read Section 4.4; Watch KCV 4.4, IWE 4.6*

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

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

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 remains?

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

MISSED THIS? *Read Section 4.4; Watch KCV 4.4, IWE 4.6*

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

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

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

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

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

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

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

A reaction mixture initially contains 22.55 g 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?

MISSED THIS? *Read Section 4.4; Watch KCV 4.4, IWE 4.6*

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

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

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?

47. Lead ions can be precipitated from solution with KCl according to the reaction:

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

When 28.5 g KCl is added to a solution containing 25.7 g Pb^{2+}, a $PbCl_2$ precipitate forms. The precipitate 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.

MISSED THIS? *Read Section 4.4; Watch KCV 4.4, IWE 4.6*

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

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

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

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

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

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.

MISSED THIS? *Read Section 4.4; Watch KCV 4.4, IWE 4.6*

50. 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

51. Complete and balance each combustion reaction equation.

MISSED THIS? *Read Section 4.5*

a. $S(s) + O_2(g) \longrightarrow$
b. $C_3H_6(g) + O_2(g) \longrightarrow$
c. $Ca(s) + O_2(g) \longrightarrow$
d. $C_5H_{12}S(l) + O_2(g) \longrightarrow$

52. Complete and balance each combustion reaction equation:

a. $C_4H_6(g) + O_2(g) \longrightarrow$
b. $C(s) + O_2(g) \longrightarrow$
c. $CS_2(s) + O_2(g) \longrightarrow$
d. $C_3H_8O(l) + O_2(g) \longrightarrow$

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

MISSED THIS? *Read Section 4.5*

54. Write a balanced chemical equation for the reaction between lithium metal and chlorine gas.

55. Write a balanced chemical equation for the reaction of solid lithium with liquid water. **MISSED THIS?** *Read Section 4.5*

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

57. Write a balanced equation for the reaction of hydrogen gas with bromine gas. **MISSED THIS?** *Read Section 4.5*

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

CUMULATIVE PROBLEMS

59. 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.)

60. Many home barbeques are fueled with propane gas (C_3H_8). What mass of carbon dioxide (in kg) is produced 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.)

61. 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:

$$C_4H_6O_3 + C_7H_6O_3 \longrightarrow C_9H_8O_4 + C_2H_4O_2$$

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.

62. The combustion of liquid ethanol (C_2H_5OH) produces carbon dioxide and water. After 4.62 mL of ethanol (density = 0.789 g/mL) is allowed to burn 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.)

63. 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?

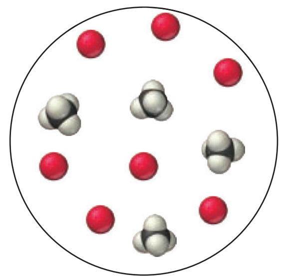

a.

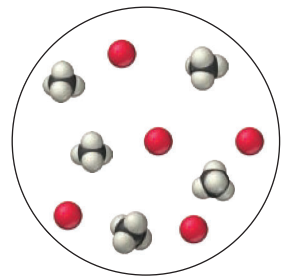

b.


c.


d.

64. Gaseous methane reacts with oxygen to form carbon dioxide and water vapor. Write a balanced equation for the combustion reaction and determine which mixture has neither reactant in excess.


a.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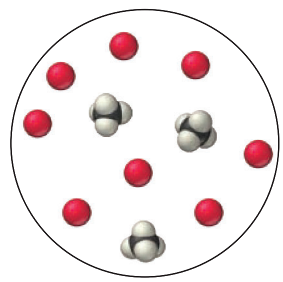
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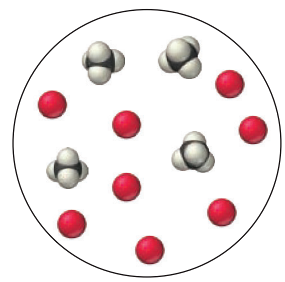

d.

65. 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 of NH_3.

66. 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.

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

68. 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:

$$FeTiO_3(s) + 3\,Cl_2(g) + 3\,C(s) \longrightarrow 3\,CO(g) + FeCl_2(s) + TiCl_4(g)$$
$$TiCl_4(g) + 2\,Mg(s) \longrightarrow 2\,MgCl_2(l) + Ti(s)$$

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 be obtained from 1.00 kg of the ilmenite–sand mixture?

CHALLENGE PROBLEMS

69. 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.

70. A mixture of 20.6 g of P and 79.4 g of Cl_2 reacts completely to form PCl_3 and PCl_5 as the only products. Find the mass of PCl_3 that forms.

71. A mixture of A and B contains a total of 5.3 mols. Both A and B react with Z according to the following equations:

$$A + Z \longrightarrow AZ$$
$$B + 2\,Z \longrightarrow BZ_2$$

The reaction of the mixture of A and B with Z consumes 7.8 mol Z. Assuming the reactions go to completion, how many moles of A does the mixture contain?

72. 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:

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

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 given 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.)

73. 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. Find the theoretical yield (in grams) of manganese from the reaction of 250 g of this mixture.

74. 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

75. Consider the reaction:

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

The molar mass of K is 39.10 g/mol, and that of O_2 is 32.00 g/mol. Without doing any calculations, pick 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

76. Consider the reaction:

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

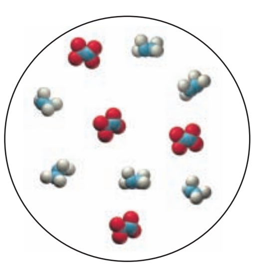
A reaction mixture initially contains 5 moles of NO and 10 moles of H_2. Without doing any calculations, determine which set of amounts best represents the mixture after the reactants have reacted as completely as possible. Explain your reasoning.

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

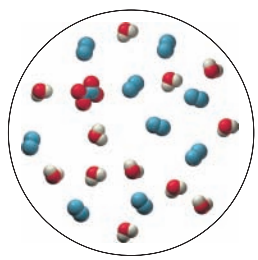
77. Consider the reaction:

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

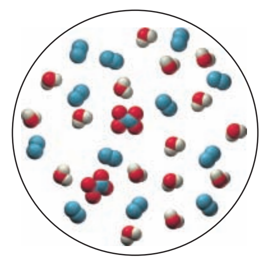
Consider also this representation of an initial mixture of N_2H_4 and N_2O_4:



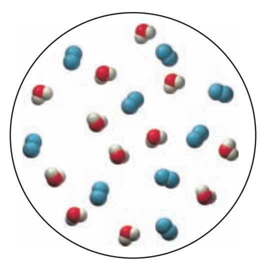
Which diagram best represents the reaction mixture after the reactants have reacted as completely as possible?



a.



b.



c.

QUESTIONS FOR GROUP WORK

Active Classroom Learning

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

78. Octane (C_8H_{18}), 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 each member completes his or her step, explain your reasoning to the group.

79. 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 vapor forms.

a. Write the balanced chemical reaction for the combustion of methane.

b. Depict the process that occurred using circles to represent atoms. Represent carbon with black circles, hydrogen with white circles, and oxygen with gray 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? If so, how much?

e. Identify the following: limiting reagent, excess reagent, and theoretical yield.

80. Explain the problem with the following statement to your group and correct it. "When a chemical equation is balanced, the number of molecules of each type on both sides of the equation is equal."

DATA INTERPRETATION AND ANALYSIS

Limiting Reactant and Percent Yield

81. 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 coeffecients 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 coeffecients 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.

Cc ANSWERS TO CONCEPTUAL CONNECTIONS

Counting Atoms in a Chemical Equation

4.1 **(d)** The number of oxygen atoms in 2 Fe_2O_3 is 6, and the number in 4 CO_2 is 8, for a total of 14.

Balanced Chemical Equations

4.2 **(a)** When the equation is balanced, the number of atoms of each type is the same on both sides of the equation. Since molecules change during a chemical reaction, the number of molecules is not the same on both sides, nor is the number of moles of each molecule necessarily the same.

Stoichiometry I

4.3 **(d)** $22.0\ \cancel{\text{mol } C_8H_{18}} \times \dfrac{18\ \text{mol } H_2O}{2\ \cancel{\text{mol } C_8H_{18}}} = 198\ \text{mol } H_2O$

Stoichiometry II

4.4 **(c)** Since each O_2 molecule reacts with 4 Na atoms, 12 Na atoms are required to react with 3 O_2 molecules.

Stoichiometry III

4.5 **(a)** Since the balanced equation indicates that one A reacts with three B, and since the diagram in the question includes 12 B available to react, the amount of A necessary is four A.

Limiting Reactant and Theoretical Yield

4.6 **(c)** Nitrogen is the limiting reactant, and there is enough nitrogen to make four NH_3 molecules. Hydrogen is in excess, and two hydrogen molecules remain after the reactants have reacted as completely as possible.

Reactant in Excess

4.7 **(c)** The limiting reactant is the 1 mol 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.