Determine the theoretical yield of the reaction: This calculation is based on the amount of Na_2CO_3, the limiting reactant.

$$?\ g\ NaNO_2 = 0.338\ mol\ Na_2CO_3 \times \frac{4\ mol\ NaNO_2}{2\ mol\ Na_2CO_3} \times \frac{69.00\ g\ NaNO_2}{1\ mol\ NaNO_2} = 46.6\ g\ NaNO_2$$

Determine the actual yield: Use expression (4.6), which relates percent yield (95.0%), theoretical yield (46.6 g $NaNO_2$), and the actual yield.

$$\text{actual yield} = \frac{\text{percent yield} \times \text{theoretical yield}}{100\%} = \frac{95.0\% \times 46.6\ g\ NaNO_2}{100\%} = 44.3\ g\ NaNO_2$$

Assess

After solving a multistep problem, it is important to check over your work. In this example, we should first double-check that the chemical equation is properly balanced. There are 4 Na's on each side, 2 C's, 12 O's, and 4 N's. We can double-check that we correctly identified the limiting reactant by using a different approach. Because 0.338 mol Na_2CO_3 would yield 0.676 mol $NaNO_2$ (in the presence of excess NO and O_2) and 0.736 mol NO would yield 0.736 mol $NaNO_2$ (in the presence of excess Na_2CO_3 and O_2), we conclude that Na_2CO_3 must be the limiting reactant; *the limiting reactant is the one that limits the amount of product obtained.* In checking the calculation of the mass of $NaNO_2$ obtained, we notice that the units work out properly. To check the final step, we can use our final answer to calculate the percent yield for the experiment: $(44.3/46.6) \times 100\% = 95\%$. This is the correct result for the percent yield.

PRACTICE EXAMPLE A: Hexamethylenediamine has the molecular formula $C_6H_{16}N_2$. It is one of the starting materials for the production of nylon. It can be prepared by the following reaction:

$$C_6H_{10}O_4(l) + NH_3(g) + H_2(g) \longrightarrow C_6H_{16}N_2(l) + H_2O(l)\ \text{(not balanced)}$$

A large reaction vessel contains 4.15 kg $C_6H_{10}O_4$, 0.547 kg NH_3, and 0.172 kg H_2. If 1.46 kg $C_6H_{16}N_2$ is obtained, then what is the percent yield for the experiment?

PRACTICE EXAMPLE B: Zinc metal and aqueous hydrochloric acid, HCl(aq), react to give hydrogen gas, $H_2(g)$, and aqueous zinc chloride, $ZnCl_2(aq)$. A 0.4000 g sample of *impure* zinc reacts completely when added to 750.0 mL of 0.0179 M HCl. After the reaction, the molarity of the HCl solution is determined to be 0.00403 M. What is the percent by mass of zinc in the sample?

Exercises

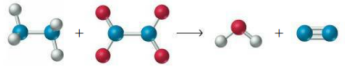
Writing and Balancing Chemical Equations

1. Balance the following equations by inspection.
   (a) $SO_3 \longrightarrow SO_2 + O_2$
   (b) $Cl_2O_7 + H_2O \longrightarrow HClO_4$
   (c) $NO_2 + H_2O \longrightarrow HNO_3 + NO$
   (d) $PCl_3 + H_2O \longrightarrow H_3PO_3 + HCl$
2. Balance the following equations by inspection.
   (a) $P_2H_4 \longrightarrow PH_3 + P_4$
   (b) $P_4 + Cl_2 \longrightarrow PCl_3$
   (c) $FeCl_3 + H_2S \longrightarrow Fe_2S_3 + HCl$
   (d) $Mg_3N_2 + H_2O \longrightarrow Mg(OH)_2 + NH_3$
3. Balance the following equations by inspection.
   (a) $PbO + NH_3 \longrightarrow Pb + N_2 + H_2O$
   (b) $FeSO_4 \longrightarrow Fe_2O_3 + SO_2 + O_2$
   (c) $S_2Cl_2 + NH_3 \longrightarrow N_4S_4 + NH_4Cl + S_8$
   (d) $C_3H_7CHOHCH(C_2H_5)CH_2OH + O_2 \longrightarrow CO_2 + H_2O$
4. Balance the following equations by inspection.
   (a) $SO_2Cl_2 + HI \longrightarrow H_2S + H_2O + HCl + I_2$
   (b) $FeTiO_3 + H_2SO_4 + H_2O \longrightarrow FeSO_4 \cdot 7\,H_2O + TiOSO_4$
   (c) $Fe_3O_4 + HCl + Cl_2 \longrightarrow FeCl_3 + H_2O + O_2$
   (d) $C_6H_5CH_2SSCH_2C_6H_5 + O_2 \longrightarrow CO_2 + SO_2 + H_2O$
5. Write balanced equations based on the information given.
   (a) solid magnesium + oxygen gas ⟶ solid magnesium oxide
   (b) nitrogen monoxide gas + oxygen gas ⟶ nitrogen dioxide gas
   (c) gaseous ethane(C_2H_6) + oxygen gas ⟶ carbon dioxide gas + liquid water
   (d) aqueous silver sulfate + aqueous barium iodide ⟶ solid barium sulfate + solid silver iodide
6. Write balanced equations based on the information given.
   (a) solid magnesium + nitrogen gas ⟶ solid magnesium nitride
   (b) solid potassium chlorate ⟶ solid potassium chloride + oxygen gas
   (c) solid sodium hydroxide + solid ammonium chloride ⟶ solid sodium chloride + gaseous ammonia + water vapor
   (d) solid sodium + liquid water ⟶ aqueous sodium hydroxide + hydrogen gas
7. Write balanced equations to represent the complete combustion of each of the following in excess oxygen: **(a)** butane, $C_4H_{10}(g)$; **(b)** isopropyl alcohol, $CH_3CH(OH)CH_3(l)$; **(c)** lactic acid, $CH_3CH(OH)COOH(s)$.
8. Write balanced equations to represent the complete combustion of each of the following in excess oxygen: **(a)** propylene, $C_3H_6(g)$; **(b)** thiobenzoic acid, $C_6H_5COSH(l)$; **(c)** glycerol, $CH_2(OH)CH(OH)CH_2OH(l)$.

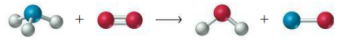
9. Write balanced equations to represent:
(a) the decomposition, by heating, of solid ammonium nitrate to produce dinitrogen monoxide gas (laughing gas) and water vapor
(b) the reaction of aqueous sodium carbonate with hydrochloric acid to produce water, carbon dioxide gas, and aqueous sodium chloride
(c) the reaction of methane (CH_4), ammonia, and oxygen gases to form gaseous hydrogen cyanide (HCN) and water vapor

10. Write balanced equations to represent:
(a) the reaction of sulfur dioxide gas with oxygen gas to produce sulfur trioxide gas (one of the reactions involved in the industrial preparation of sulfuric acid)
(b) the dissolving of limestone (calcium carbonate) in water containing dissolved carbon dioxide to produce calcium hydrogen carbonate (a reaction producing temporary hardness in groundwater)
(c) the reaction of ammonia and nitrogen monoxide to form nitrogen gas and water vapor

11. Write a balanced chemical equation for the reaction depicted below.



12. Write a balanced chemical equation for the reaction depicted below.



Stoichiometry of Chemical Reactions

13. In an experiment, 0.689 g Cr(s) reacts completely with 0.636 g O_2(g) to form a single solid compound. Write a balanced chemical equation for the reaction.

14. A 3.104 g sample of an oxide of manganese contains 1.142 grams of oxygen. Write a balanced chemical equation for the reaction that produces the compound from Mn(s) and O_2(g).

15. Iron metal reacts with chlorine gas. How many grams of $FeCl_3$ are obtained when 515 g Cl_2 reacts with excess Fe?

$$2\,Fe(s) + 3\,Cl_2(g) \longrightarrow 2\,FeCl_3(s)$$

16. If 75.8 g PCl_3 is produced by the reaction

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

how many grams each of Cl_2 and P_4 are consumed?

17. A laboratory method of preparing O_2(g) involves the decomposition of $KClO_3$(s).

$$2\,KClO_3(s) \xrightarrow{\Delta} 2\,KCl(s) + 3\,O_2(g)$$

(a) How many moles of O_2(g) can be produced by the decomposition of 32.8 g $KClO_3$?
(b) How many grams of $KClO_3$ must decompose to produce 50.0 g O_2?
(c) How many grams of KCl are formed, together with 28.3 g O_2, in the decomposition of $KClO_3$?

18. A commercial method of manufacturing hydrogen involves the reaction of iron and steam.

$$3\,Fe(s) + 4\,H_2O(g) \xrightarrow{\Delta} Fe_3O_4(s) + 4\,H_2(g)$$

(a) How many grams of H_2 can be produced from 87.2 g Fe and an excess of H_2O(g) (steam)?
(b) How many grams of H_2O are consumed in the conversion of 25.0 g Fe to Fe_3O_4?
(c) If 29.2 g H_2 is produced, how many grams of Fe_3O_4 must also be produced?

19. How many grams of Ag_2CO_3 are decomposed to yield 75.1 g Ag in this reaction?

$$Ag_2CO_3(s) \xrightarrow{\Delta} Ag(s) + CO_2(g) + O_2(g) \text{ (not balanced)}$$

20. How many kilograms of HNO_3 are consumed to produce 125 kg $Ca(H_2PO_4)_2$ in this reaction?

$$Ca_3(PO_4)_2 + HNO_3 \longrightarrow Ca(H_2PO_4)_2 + Ca(NO_3)_2 \text{ (not balanced)}$$

21. The reaction of calcium hydride with water can be used to prepare small quantities of hydrogen gas, as is done to fill weather-observation balloons.

$$CaH_2(s) + H_2O(l) \longrightarrow Ca(OH)_2(s) + H_2(g) \text{ (not balanced)}$$

(a) How many grams of H_2(g) result from the reaction of 127 g CaH_2 with an excess of water?
(b) How many grams of water are consumed in the reaction of 56.2 g CaH_2?
(c) What mass of CaH_2(s) must react with an excess of water to produce 8.12×10^{24} molecules of H_2?

22. The reaction of potassium superoxide, KO_2, is used in life-support systems to replace CO_2(g) in expired air with O_2(g). The unbalanced chemical equation for the reaction is given below.

$$KO_2(s) + CO_2(g) \longrightarrow K_2CO_3(s) + O_2(g)$$

(a) How many moles of O_2(g) are produced by the reaction of 88.0 g CO_2(g) with excess KO_2(s)?
(b) How many grams of KO_2(s) are consumed per 1.000×10^3 g CO_2(g) removed from expired air?
(c) How many moles of K_2CO_3 are produced per milligram of KO_2 consumed?

23. Iron ore is impure Fe_2O_3. When Fe_2O_3 is heated with an excess of carbon (coke), metallic iron and carbon monoxide gas are produced. From a sample of ore weighing 938 kg, 523 kg of pure iron is obtained. What is the mass percent Fe_2O_3 in the ore sample, assuming that none of the impurities contain Fe?

24. Solid silver oxide, Ag_2O(s), decomposes at temperatures in excess of 300 °C, yielding metallic silver and oxygen gas. A 3.13 g sample of impure silver oxide yields 0.187 g O_2(g). What is the mass percent Ag_2O in the sample? Assume that Ag_2O(s) is the only source of O_2(g). [*Hint:* Write a balanced equation for the reaction.]

25. Decaborane, $B_{10}H_{14}$, was used as a fuel for rockets in the 1950s. It reacts violently with oxygen, O_2, to produce B_2O_3 and water. Calculate the percentage by mass of $B_{10}H_{14}$ in a fuel mixture designed to ensure that $B_{10}H_{14}$ and O_2 run out at exactly the same time. (Such a mixture minimizes the mass of fuel that a rocket must carry.)

26. The rocket boosters of the space shuttle *Discovery*, launched on July 26, 2005, used a fuel mixture containing primarily solid ammonium perchlorate, $NH_4ClO_4(s)$, and aluminum metal. The unbalanced chemical equation for the reaction is given below.

$$Al(s) + NH_4ClO_4(s) \longrightarrow Al_2O_3(s) + AlCl_3(s) + H_2O(l) + N_2(g)$$

What is the minimum mass of NH_4ClO_4 consumed, per kilogram of Al, by the reaction of NH_4ClO_4 and Al? [*Hint*: Balance the elements in the order Cl, H, O, Al, N.]

$2\,Al(s) + 6\,HCl(aq) \rightarrow 2\,AlCl_3(aq) + 3\,H_2(g)$

27. A piece of aluminum foil measuring 10.25 cm × 5.50 cm × 0.601 mm is dissolved in excess HCl(aq). What mass of $H_2(g)$ is produced? Use equation (4.2) and $d = 2.70\ g/cm^3$ for Al.

28. An excess of aluminum foil is allowed to react with 225 mL of an aqueous solution of HCl ($d = 1.088$ g/mL) that contains 18.0% HCl by mass. What mass of $H_2(g)$ is produced? [*Hint:* Use equation (4.2).]

29. *Without performing detailed calculations*, which of the following metals yields the greatest amount of H_2 per gram of metal reacting with HCl(aq)? **(a)** Na, **(b)** Mg, **(c)** Al, **(d)** Zn. [*Hint:* Write equations similar to (4.2).]

30. *Without performing detailed calculations*, which of the following yields the same mass of $CO_2(g)$ per gram of compound as does ethanol, CH_3CH_2OH, when burned in excess oxygen? **(a)** H_2CO; **(b)** $HOCH_2CH_2OH$; **(c)** $HOCH_2CH(OH)CH_2OH$; **(d)** CH_3OCH_3; **(e)** C_6H_5OH.

Molarity

31. What are the molarities of the following solutes when dissolved in water?
(a) 2.92 mol CH_3OH in 7.16 L of solution
(b) 7.69 mmol CH_3CH_2OH in 50.00 mL of solution
(c) 25.2 g $CO(NH_2)_2$ in 275 mL of solution

32. What are the molarities of the following solutes when dissolved in water?
(a) 2.25×10^{-4} mol CH_3CH_2OH in 125 mL of solution
(b) 57.5 g $(CH_3)_2CO$ in 525 mL of solution
(c) 18.5 mL of $C_3H_5(OH)_3$ ($d = 1.26$ g/mL) in 375 mL of solution

33. What are the molarities of the following solutes?
(a) sucrose ($C_{12}H_{22}O_{11}$) if 150.0 g is dissolved per 250.0 mL of water solution
(b) urea, $CO(NH_2)_2$, if 98.3 mg of the 97.9% pure solid is dissolved in 5.00 mL of aqueous solution
(c) methanol, CH_3OH, ($d = 0.792$ g/mL) if 125.0 mL is dissolved in enough water to make 15.0 L of solution

34. What are the molarities of the following solutes?
(a) aspartic acid ($H_2C_4H_5NO_4$) if 0.405 g is dissolved in enough water to make 100.0 mL of solution
(b) acetone, $(CH_3)_2CO$, ($d = 0.790$ g/mL) if 35.0 mL is dissolved in enough water to make 425 mL of solution
(c) diethyl ether, $(C_2H_5)_2O$, if 8.8 mg is dissolved in enough water to make 3.00 L of solution

35. How much
(a) glucose, $C_6H_{12}O_6$, in grams, must be dissolved in water to produce 75.0 mL of 0.350 M $C_6H_{12}O_6$?
(b) methanol, CH_3OH ($d = 0.792$ g/mL), in milliliters, must be dissolved in water to produce 2.25 L of 0.485 M CH_3OH?

36. How much
(a) ethanol, CH_3CH_2OH ($d = 0.789$ g/mL), in liters, must be dissolved in water to produce 200.0 L of 1.65 M CH_3CH_2OH?
(b) concentrated hydrochloric acid solution (36.0% HCl by mass; $d = 1.18$ g/mL), in milliliters, is required to produce 12.0 L of 0.234 M HCl?

37. In the United States, the concentration of glucose, $C_6H_{12}O_6$, in the blood is reported in units of milligrams per deciliter (mg/dL). In Canada, the United Kingdom, and elsewhere, the blood glucose concentration is reported in millimoles per liter (mmol/L), where 1 mmol = 1×10^{-3} mol. If a person has a blood glucose level of 85 mg/dL, then what is **(a)** the blood glucose level in mmol/L; **(b)** the molarity of glucose in the blood?

38. In many communities, water is fluoridated to prevent tooth decay. In the United States, for example, more than half of the population served by public water systems has access to water that is fluoridated at approximately 1 mg F^- per liter. **(a)** What is the molarity of F^- in water if it contains 1.2 mg F^- per liter? **(b)** How many grams of solid KF should be added to a 1.6×10^8 L water reservoir to give a fluoride concentration of 1.2 mg F^- per liter?

39. Which of the following is a 0.500 M KCl solution? **(a)** 0.500 g KCl/mL solution; **(b)** 36.0 g KCl/L solution; **(c)** 7.46 mg KCl/mL solution; **(d)** 373 g KCl in 10.00 L solution.

40. Which two solutions have the same concentration? **(a)** 55.45 g NaCl/L solution; **(b)** 5.545 g NaCl/100 g solution; **(c)** 55.45 g NaCl/kg water; **(d)** 55.45 mg NaCl/1.00 mL solution; **(e)** 5.00 mmol NaCl/5.00 mL solution.

41. Which has the higher concentration of sucrose: a 46% sucrose solution by mass ($d = 1.21$ g/mL), or 1.50 M $C_{12}H_{22}O_{11}$? Explain your reasoning.

42. Which has the greater molarity of ethanol: a white wine ($d = 0.95$ g/mL) with 11% CH_3CH_2OH by mass, or the solution described in Example 4-7? Explain your reasoning.

43. A 10.00 mL sample of 2.05 M KNO_3 is diluted to a volume of 250.0 mL. What is the concentration of the diluted solution?

44. What volume of 2.00 M $AgNO_3$ must be diluted with water to prepare 500.0 mL of 0.350 M $AgNO_3$?

45. Water is evaporated from 125 mL of 0.198 M K_2SO_4 solution until the volume becomes 105 mL. What is the molarity of K_2SO_4 in the remaining solution?

46. A 25.0 mL sample of HCl(aq) is diluted to a volume of 500.0 mL. If the concentration of the diluted solution is found to be 0.085 M HCl, what was the concentration of the original solution?

47. Given a 0.250 M K_2CrO_4 stock solution, describe how you would prepare a solution that is 0.0125 M K_2CrO_4. That is, what combination(s) of pipet and volumetric flask would you use? Typical sizes of volumetric flasks found in a general chemistry laboratory are 100.0, 250.0, 500.0, and 1000.0 mL, and typical sizes of volumetric pipets are 1.00, 5.00, 10.00, 25.00, and 50.00 mL.

48. Given two liters of 0.496 M KCl, describe how you would use this solution to prepare 250.0 mL of 0.175 M KCl. Give sufficient details so that another student could follow your instructions.

Chemical Reactions in Solution

49. Consider the reaction below:

$$2\,AgNO_3(aq) + Na_2S(s) \longrightarrow Ag_2S(s) + 2\,NaNO_3(aq)$$

(a) How many grams of $Na_2S(s)$ are required to react completely with 27.8 mL of 0.163 M $AgNO_3$?
(b) How many grams of $Ag_2S(s)$ are obtained from the reaction in part (a)?

50. Excess $NaHCO_3$ is added to 525 mL of 0.220 M $Cu(NO_3)_2$. These substances react as follows:

$$Cu(NO_3)_2(aq) + 2\,NaHCO_3(s) \longrightarrow CuCO_3(s) + 2\,NaNO_3(aq) + H_2O(l) + CO_2(g)$$

(a) How many grams of the $NaHCO_3(s)$ will be consumed?
(b) How many grams of $CuCO_3(s)$ will be produced?

51. How many milliliters of 0.650 M K_2CrO_4 are needed to precipitate all the silver in 415 mL of 0.186 M $AgNO_3$ as $Ag_2CrO_4(s)$?

$$2\,AgNO_3(aq) + K_2CrO_4(aq) \longrightarrow Ag_2CrO_4(s) + 2\,KNO_3(aq)$$

52. Consider the reaction below.

$$Ca(OH)_2(s) + 2\,HCl(aq) \longrightarrow CaCl_2(aq) + 2\,H_2O(l)$$

(a) How many grams of $Ca(OH)_2$ are required to react completely with 415 mL of 0.477 M HCl?
(b) How many kilograms of $Ca(OH)_2$ are required to react with 324 L of a HCl solution that is 24.28% HCl by mass, and has a density of 1.12 g/mL?

53. Exactly 1.00 mL of an aqueous solution of HNO_3 is diluted to 100.0 mL. It takes 29.78 mL of 0.0142 M $Ca(OH)_2$ to convert all of the HNO_3 to $Ca(NO_3)_2$. The other product of the reaction is water. Calculate the molarity of the undiluted HNO_3 solution.

54. A 5.00 mL sample of an aqueous solution of H_3PO_4 requires 49.1 mL of 0.217 M NaOH to convert all of the H_3PO_4 to Na_2HPO_4. The other product of the reaction is water. Calculate the molarity of the H_3PO_4 solution.

55. Refer to Example 4-6 and equation (4.2). For the conditions stated in Example 4-6, determine **(a)** the number of moles of $AlCl_3$ and **(b)** the molarity of the $AlCl_3(aq)$ if the solution volume is simply the 23.8 mL calculated in the example.

56. Refer to the Integrative Example on page 140. If 138 g Na_2CO_3 in 1.42 L of aqueous solution is treated with an excess of NO(g) and $O_2(g)$, what is the molarity of the $NaNO_2(aq)$ solution that results? (Assume that the reaction goes to completion.)

57. How many grams of Ag_2CrO_4 will precipitate if excess $K_2CrO_4(aq)$ is added to the 415 mL of 0.186 M $AgNO_3$ in Exercise 51?

58. What volume of 0.0665 M $KMnO_4$ is necessary to convert 12.5 g KI to I_2 in the reaction below? Assume that H_2SO_4 is present in excess.

$$2\,KMnO_4 + 10\,KI + 8\,H_2SO_4 \longrightarrow 6\,K_2SO_4 + 2\,MnSO_4 + 5\,I_2 + 8\,H_2O$$

59. How many grams of sodium must react with 155 mL H_2O to produce a solution that is 0.175 M NaOH? (Assume a final solution volume of 155 mL.)

$$2\,Na(s) + 2\,H_2O(l) \longrightarrow 2\,NaOH(aq) + H_2(g)$$

60. A method of lowering the concentration of HCl(aq) is to allow the solution to react with a small quantity of Mg. How many milligrams of Mg must be added to 250.0 mL of 1.023 M HCl to reduce the solution concentration to exactly 1.000 M HCl?

$$Mg(s) + 2\,HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$$

61. A 0.3126 g sample of oxalic acid, $H_2C_2O_4$, requires 26.21 mL of a particular concentration of NaOH(aq) to complete the following reaction. What is the molarity of the NaOH(aq)?

$$H_2C_2O_4(s) + 2\,NaOH(aq) \longrightarrow Na_2C_2O_4(aq) + 2\,H_2O(l)$$

62. A 25.00 mL sample of HCl(aq) was added to a 0.1000 g sample of $CaCO_3$. All the $CaCO_3$ reacted, leaving some excess HCl(aq).

$$CaCO_3(s) + 2\,HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

The excess HCl(aq) required 43.82 mL of 0.01185 M $Ba(OH)_2$ to complete the following reaction. What was the molarity of the original HCl(aq)?

$$2\,HCl(aq) + Ba(OH)_2(aq) \longrightarrow BaCl_2(aq) + 2\,H_2O(l)$$

Determining the Limiting Reactant

63. How many moles of NO(g) can be produced in the reaction of 3.00 mol $NH_3(g)$ and 4.00 mol $O_2(g)$?

$$4\,NH_3(g) + 5\,O_2(g) \xrightarrow{\Delta} 4\,NO(g) + 6\,H_2O(l)$$

64. The reaction of calcium hydride and water produces calcium hydroxide and hydrogen as products. How many moles of $H_2(g)$ will be formed in the reaction between 0.82 mol $CaH_2(s)$ and 1.54 mol $H_2O(l)$?

65. A 0.696 mol sample of Cu is added to 136 mL of 6.0 M HNO_3. Assuming the following reaction is the only one that occurs, will the Cu react completely?

$$3\,Cu(s) + 8\,HNO_3(aq) \longrightarrow 3\,Cu(NO_3)_2(aq) + 4\,H_2O(l) + 2\,NO(g)$$

66. How many grams of $H_2(g)$ are produced by the reaction of 1.84 g Al with 75.0 mL of 2.95 M HCl? [*Hint:* Recall equation (4.2).]

67. A side reaction in the manufacture of rayon from wood pulp is

$$3\,CS_2 + 6\,NaOH \longrightarrow 2\,Na_2CS_3 + Na_2CO_3 + 3\,H_2O$$

How many grams of Na_2CS_3 are produced in the reaction of 92.5 mL of liquid CS_2 (d = 1.26 g/mL) and 2.78 mol NaOH?

68. Lithopone is a brilliant white pigment used in water-based interior paints. It is a mixture of $BaSO_4$ and ZnS produced by the reaction

$$BaS(aq) + ZnSO_4(aq) \longrightarrow \underset{\text{lithopone}}{ZnS(s) + BaSO_4(s)}$$

How many grams of lithopone are produced in the reaction of 315 mL of 0.275 M $ZnSO_4$ and 285 mL of 0.315 M BaS?

69. Ammonia can be generated by heating together the solids NH_4Cl and $Ca(OH)_2$. $CaCl_2$ and H_2O are also formed. **(a)** If a mixture containing 33.0 g each of NH_4Cl and $Ca(OH)_2$ is heated, how many grams of NH_3 will form? **(b)** Which reactant remains in excess, and in what mass?

70. Chlorine can be generated by heating together calcium hypochlorite and hydrochloric acid. Calcium chloride and water are also formed. **(a)** If 50.0 g $Ca(OCl)_2$ and 275 mL of 6.00 M HCl are allowed to react, how many grams of chlorine gas will form? **(b)** Which reactant, $Ca(OCl)_2$ or HCl, remains in excess, and in what mass?

71. Chromium(II) sulfate, $CrSO_4$, is a reagent that has been used in certain applications to help reduce carbon–carbon double bonds (C═C) in molecules to single bonds (C—C). The reagent can be prepared via the following reaction.

$$4\,Zn(s) + K_2Cr_2O_7(aq) + 7\,H_2SO_4(aq) \longrightarrow 4\,ZnSO_4(aq) + 2\,CrSO_4(aq) + K_2SO_4(aq) + 7\,H_2O(l)$$

What is the maximum number of grams of $CrSO_4$ that can be made from a reaction mixture containing 3.2 mol Zn, 1.7 mol $K_2Cr_2O_7$, and 5.0 mol H_2SO_4?

72. Titanium tetrachloride, $TiCl_4$, is prepared by the reaction below.

$$3\,TiO_2(s) + 4\,C(s) + 6\,Cl_2(g) \longrightarrow 3\,TiCl_4(g) + 2\,CO_2(g) + 2\,CO(g)$$

What is the maximum mass of $TiCl_4$ that can be obtained from 35 g TiO_2, 45 g Cl_2, and 11 g C?

Theoretical, Actual, and Percent Yields

73. In the reaction of 277 g CCl_4 with an excess of HF, 187 g CCl_2F_2 is obtained. What are the **(a)** theoretical, **(b)** actual, and **(c)** percent yields of this reaction?

$$CCl_4 + 2\,HF \longrightarrow CCl_2F_2 + 2\,HCl$$

74. In the reaction shown, 100.0 g $C_6H_{11}OH$ yielded 64.0 g C_6H_{10}. **(a)** What is the theoretical yield of the reaction? **(b)** What is the percent yield? **(c)** What mass of $C_6H_{11}OH$ would produce 100.0 g C_6H_{10} if the percent yield is that determined in part (b)?

$$C_6H_{11}OH \longrightarrow C_6H_{10} + H_2O$$

75. Cryolite, Na_3AlF_6, is an important industrial reagent. It is made by the reaction below.

$$Al_2O_3(s) + 6\,NaOH(aq) + 12\,HF(g) \longrightarrow 2\,Na_3AlF_6(s) + 9\,H_2O(l)$$

In an experiment, 7.81 g Al_2O_3 and excess HF(g) were dissolved in 3.50 L of 0.141 M NaOH. If 28.2 g Na_3AlF_6 was obtained, then what is the percent yield for this experiment?

76. Nitrogen gas, N_2, can be prepared by passing gaseous ammonia over solid copper(II) oxide, CuO, at high temperatures. The other products of the reaction are solid copper, Cu, and water vapor. In a certain experiment, a reaction mixture containing 18.1 g NH_3 and 90.4 g CuO yields 6.63 g N_2. Calculate the percent yield for this experiment.

77. The reaction of 15.0 g C_4H_9OH, 22.4 g NaBr, and 32.7 g H_2SO_4 yields 17.1 g C_4H_9Br in the reaction shown. What are the **(a)** theoretical yield, **(b)** actual yield, and **(c)** percent yield of this reaction?

$$C_4H_9OH + NaBr + H_2SO_4 \longrightarrow C_4H_9Br + NaHSO_4 + H_2O$$

78. Azobenzene, an intermediate in the manufacture of dyes, can be prepared from nitrobenzene by reaction with triethylene glycol in the presence of Zn and KOH. In one reaction, 0.10 L of nitrobenzene (d = 1.20 g/mL) and 0.30 L of triethylene glycol (d = 1.12 g/mL) yields 55 g azobenzene. What are the **(a)** theoretical yield, **(b)** actual yield, and **(c)** percent yield of this reaction?

$$\underset{\text{nitrobenzene}}{2\,C_6H_5NO_2} + \underset{\text{triethylene glycol}}{4\,C_6H_{14}O_4} \xrightarrow[\text{KOH}]{\text{Zn}} \underset{\text{azobenzene}}{(C_6H_5N)_2} + 4\,C_6H_{12}O_4 + 4\,H_2O$$

79. How many grams of commercial acetic acid (97% CH_3COOH by mass) must be allowed to react with an excess of PCl_3 to produce 75 g of acetyl chloride (CH_3COCl), if the reaction has a 78.2% yield?

$$CH_3COOH + PCl_3 \longrightarrow CH_3COCl + H_3PO_3 \text{ (not balanced)}$$

80. Suppose that reactions **(a)** and **(b)** each have a 92% yield. Starting with 112 g CH_4 in reaction **(a)** and an excess of Cl_2(g), how many grams of CH_2Cl_2 are formed in reaction **(b)**?

(a) $CH_4 + Cl_2 \longrightarrow CH_3Cl + HCl$

(b) $CH_3Cl + Cl_2 \longrightarrow CH_2Cl_2 + HCl$

81. An essentially 100% yield is necessary for a chemical reaction used to *analyze* a compound, but it is almost never expected for a reaction that is used to *synthesize* a compound. Explain this difference.

82. Suppose we carry out the precipitation of $Ag_2CrO_4(s)$ described in Example 4-10. If we obtain 2.058 g of precipitate, we might conclude that it is nearly pure $Ag_2CrO_4(s)$, but if we obtain 2.112 g, we can be quite sure that the precipitate is not pure. Explain this difference.

Consecutive Reactions, Simultaneous Reactions

83. How many grams of HCl are consumed in the reaction of 425 g of a mixture containing 35.2% $MgCO_3$ and 64.8% $Mg(OH)_2$, by mass?

$$Mg(OH)_2 + 2\,HCl \longrightarrow MgCl_2 + 2\,H_2O$$
$$MgCO_3 + 2\,HCl \longrightarrow MgCl_2 + H_2O + CO_2$$

84. How many grams of CO_2 are produced in the complete combustion of 406 g of a bottled gas that consists of 72.7% propane (C_3H_8) and 27.3% butane (C_4H_{10}), by mass?

85. Dichlorodifluoromethane, once widely used as a refrigerant, can be prepared by the reactions shown. How many moles of Cl_2 must be consumed in the first reaction to produce 2.25 kg CCl_2F_2 in the second? Assume that all the CCl_4 produced in the first reaction is consumed in the second.

$$CH_4 + Cl_2 \longrightarrow CCl_4 + HCl \text{ (not balanced)}$$
$$CCl_4 + HF \longrightarrow CCl_2F_2 + HCl \text{ (not balanced)}$$

86. Carbon dioxide gas, $CO_2(g)$, produced in the combustion of a sample of ethane is absorbed in $Ba(OH)_2(aq)$, producing 0.506 g $BaCO_3(s)$. How many grams of ethane (C_2H_6) must have been burned?

$$C_2H_6(g) + O_2(g) \longrightarrow CO_2(g) + H_2O(l) \text{ (not balanced)}$$
$$CO_2(g) + Ba(OH)_2(aq) \longrightarrow BaCO_3(s) + H_2O(l)$$

87. The following process has been used to obtain iodine from oil-field brines in California. How many kilograms of silver nitrate are required in the first step for every kilogram of iodine produced in the third step?

sodium iodide + silver nitrate ⟶ silver iodide + sodium nitrate

silver iodide + iron ⟶ iron(II) iodide + silver

iron(II) iodide + chlorine gas ⟶ iron(III) chloride + solid iodine

88. Sodium bromide, used to produce silver bromide for use in photography, can be prepared as shown. How many kilograms of iron are consumed to produce 2.50×10^3 kg NaBr?

$$Fe + Br_2 \longrightarrow FeBr_2$$
$$FeBr_2 + Br_2 \longrightarrow Fe_3Br_8 \text{ (not balanced)}$$
$$Fe_3Br_8 + Na_2CO_3 \longrightarrow NaBr + CO_2 + Fe_3O_4 \text{ (not balanced)}$$

89. High-purity silicon is obtained using a three-step process. The first step involves heating solid silicon dioxide, SiO_2, with solid carbon to give solid silicon and carbon monoxide gas. In the second step, solid silicon is converted into liquid silicon tetrachloride, $SiCl_4$, by treating it with chlorine gas. In the last step, $SiCl_4$ is treated with hydrogen gas to give ultrapure solid silicon and hydrogen chloride gas.
(a) Write balanced chemical equations for the steps involved in this three-step process.
(b) Calculate the masses of carbon, chlorine, and hydrogen required per kilogram of silicon.

90. The following set of reactions is to be used as the basis of a method for producing nitric acid, HNO_3. Calculate the minimum masses of N_2, H_2, and O_2 required per kilogram of HNO_3.

$$N_2(g) + 3\,H_2(g) \longrightarrow 2\,NH_3(g)$$
$$4\,NH_3(g) + 5\,O_2(g) \longrightarrow 4\,NO(g) + 6\,H_2O(g)$$
$$2\,NO(g) + O_2(g) \longrightarrow 2\,NO_2(g)$$
$$3\,NO_2(g) + H_2O(l) \longrightarrow 2\,HNO_3(aq) + NO(g)$$

91. When a solid mixture of $MgCO_3$ and $CaCO_3$ is heated strongly, carbon dioxide gas is given off and a solid mixture of MgO and CaO is obtained. If a 24.00 g sample of a mixture of $MgCO_3$ and $CaCO_3$ produces 12.00 g CO_2, then what is the percentage by mass of $MgCO_3$ in the original mixture?

92. A mixture of Fe_2O_3 and FeO was analyzed and found to be 72.0% Fe by mass. What is the percentage by mass of Fe_2O_3 in the mixture?

Integrative and Advanced Exercises

93. Write chemical equations to represent the following reactions.
(a) Limestone rock (calcium carbonate) is heated (calcined) and decomposes to calcium oxide and carbon dioxide gas.
(b) Zinc sulfide ore is heated in air (roasted) and is converted to zinc oxide and sulfur dioxide gas. (Note that oxygen gas in the air is also a reactant.)
(c) Propane gas reacts with gaseous water to produce a mixture of carbon monoxide and hydrogen gases. (This mixture, called *synthesis gas*, is used to produce a variety of organic chemicals.)
(d) Sulfur dioxide gas is passed into an aqueous solution containing sodium sulfide and sodium carbonate. The reaction products are carbon dioxide and an aqueous solution of sodium thiosulfate.

94. Write chemical equations to represent the following reactions.
(a) Calcium phosphate is heated with silicon dioxide and carbon, producing calcium silicate ($CaSiO_3$), phosphorus (P_4), and carbon monoxide. The phosphorus and chlorine react to form phosphorus trichloride, and the phosphorus trichloride and water react to form phosphorous acid.
(b) Copper metal reacts with gaseous oxygen, carbon dioxide, and water to form green basic copper carbonate, $Cu_2(OH)_2CO_3$ (a reaction responsible for the formation of the green patina, or coating, often seen on outdoor bronze statues).
(c) White phosphorus and oxygen gas react to form tetraphosphorus decoxide. The tetraphosphorus decoxide reacts with water to form an aqueous solution of phosphoric acid.
(d) Calcium dihydrogen phosphate reacts with sodium hydrogen carbonate (bicarbonate), producing calcium phosphate, sodium hydrogen phosphate, carbon dioxide, and water (the principal reaction occurring when ordinary baking powder is added to cakes, bread, and biscuits).

95. The three astronauts aboard *Apollo 13*, which was launched in 1970 on April 11 and returned to Earth on April 17, were kept alive during their mission, in part, because of lithium hydroxide (LiOH) canisters that were designed to remove exhaled CO_2 from the air. Solid lithium hydroxide reacts with $CO_2(g)$ to give solid Li_2CO_3 and water. With the assumption that an astronaut exhales approximately 1.00 kg CO_2 per day, what mass of LiOH was required to remove all of the CO_2 exhaled by the three-member crew on their six-day mission?

96. Chalkboard chalk is made from calcium carbonate and calcium sulfate, with minor impurities such as SiO_2. Only the $CaCO_3$ reacts with dilute HCl(aq). What is the mass percent $CaCO_3$ in a piece of chalk if a 3.28 g sample yields 0.981 g $CO_2(g)$?

$$CaCO_3(s) + 2\,HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

97. Hydrogen gas, $H_2(g)$, is passed over $Fe_2O_3(s)$ at 400 °C. Water vapor is formed together with a black residue—a compound consisting of 72.3% Fe and 27.7% O. Write a balanced equation for this reaction.

98. A sulfide of iron, containing 36.5% S by mass, is heated in $O_2(g)$, and the products are sulfur dioxide and an oxide of iron containing 27.6% O, by mass. Write a balanced chemical equation for this reaction.

99. Water and ethanol, $CH_3CH_2OH(l)$, are miscible, that is, they can be mixed in all proportions. However, when these liquids are mixed, the total volume of the resulting solution is not equal to the sum of the pure liquid volumes, and we say that the volumes are not additive. For example, when 50.0 mL of water and 50.0 mL of $CH_3CH_2OH(l)$, are mixed at 20 °C, the total volume of the solution is 96.5 mL, not 100.0 mL. (The volumes are not additive because the interactions and packing of water molecules are slightly different from the interactions and packing of CH_3CH_2OH molecules.) Calculate the molarity of CH_3CH_2OH in a solution prepared by mixing 50.0 mL of water and 50.0 mL of $CH_3CH_2OH(l)$ at 20 °C. At this temperature, the densities of water and ethanol are 0.99821 g/mL and 0.7893 g/mL, respectively.

100. When water and methanol, $CH_3OH(l)$, are mixed, the total volume of the resulting solution is not equal to the sum of the pure liquid volumes. (Refer to Exercise 99 for an explanation.) When 72.061 g H_2O and 192.25 g CH_3OH are mixed at 25 °C, the resulting solution has a density of 0.86070 g/mL. At 25 °C, the densities of water and methanol are 0.99705 g/mL and 0.78706 g/mL, respectively.
(a) Calculate the volumes of the pure liquid samples and the solution, and show that the pure liquid volumes are not additive. [*Hint*: Although the volumes are not additive, the masses are.]
(b) Calculate the molarity of CH_3OH in this solution.

101. What volume of 0.149 M HCl must be added to 1.00×10^2 mL of 0.285 M HCl so that the resulting solution has a molarity of 0.205 M? Assume that the volumes are additive.

102. What volume of 0.0175 M CH_3OH must be added to 50.0 mL of 0.0248 M CH_3OH so that the resulting solution has a molarity of exactly 0.0200 M? Assume that the volumes are additive.

103. What is the molarity of NaCl(aq) if a solution has 1.52 ppm Na? Assume that NaCl is the only source of Na and that the solution density is 1.00 g/mL. (The unit *ppm* is parts per million; here it can be taken to mean g Na per million grams of solution.)

104. How many milligrams $Ca(NO_3)_2$ must be present in 50.0 L of a solution containing 2.35 ppm Ca? [*Hint:* See also Exercise 103.]

105. A drop (0.05 mL) of 12.0 M HCl is spread over a sheet of thin aluminum foil. Assume that all the acid reacts with, and thus dissolves through, the foil. What will be the area, in cm^2, of the cylindrical hole produced? (Density of Al = 2.70 g/cm^3; foil thickness = 0.10 mm.)

$$2\,Al(s) + 6\,HCl(aq) \longrightarrow 2\,AlCl_3(aq) + 3\,H_2(g)$$

106. A small piece of zinc is dissolved in 50.00 mL of 1.035 M HCl. At the conclusion of the reaction, the concentration of the 50.00 mL sample is redetermined and found to be 0.812 M HCl. What must have been the mass of the piece of zinc that dissolved?

$$Zn(s) + 2\,HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$$

107. How many milliliters of 0.715 M NH_4NO_3 solution must be diluted with water to produce 1.00 L of a solution with a concentration of 2.37 mg N/mL?

108. A seawater sample has a density of 1.03 g/mL and 2.8% NaCl by mass. A saturated solution of NaCl in water is 5.45 M NaCl. How many liters of water would have to be evaporated from 1.00×10^6 L of the seawater before NaCl would begin to crystallize? (A saturated solution contains the maximum amount of dissolved solute possible.)

109. A 99.8 mL sample of a solution that is 12.0% KI by mass (d = 1.093 g/mL) is added to 96.7 mL of another solution that is 14.0% $Pb(NO_3)_2$ by mass (d = 1.134 g/mL). How many grams of PbI_2 should form?

$$Pb(NO_3)_2(aq) + 2\,KI(aq) \longrightarrow PbI_2(s) + 2\,KNO_3(aq)$$

110. Solid calcium carbonate, $CaCO_3(s)$, reacts with HCl(aq) to form H_2O, $CaCl_2(aq)$, and $CO_2(g)$. If a 45.0 g sample of $CaCO_3(s)$ is added to 1.25 L of HCl(aq) that is 25.7% HCl by mass (d = 1.13 g/mL), what will be the molarity of HCl in the solution after the reaction is completed? Assume that the solution volume remains constant.

111. A 2.05 g sample of an iron–aluminum alloy (ferroaluminum) is dissolved in excess HCl(aq) to produce 0.105 g $H_2(g)$. What is the percent composition, by mass, of the ferroaluminum?

$$Fe(s) + 2\,HCl(aq) \longrightarrow FeCl_2(aq) + H_2(g)$$
$$2\,Al(s) + 6\,HCl(aq) \longrightarrow 2\,AlCl_3(aq) + 3\,H_2(g)$$

112. A 0.155 g sample of an Al–Mg alloy reacts with an excess of HCl(aq) to produce 0.0163 g H_2. What is the percent Mg in the alloy?
[*Hint:* Write equations similar to (4.2).]

113. In a dilute nitric acid solution, copper reacts to form copper nitrate, nitrogen monoxide, and water according to the following equation:

$$3\,Cu(s) + 8\,HNO_3(aq) \longrightarrow 3\,Cu(NO_3)_2(aq) + 2\,NO(g) + 4\,H_2O(l)$$

In a vessel, 800.0 mL of 0.500 M HNO_3 is added to 3.177 g of copper, and the vessel is then sealed. After an hour, the vessel is opened and drained, and the remaining copper rinsed, dried, and weighed. The remaining mass of the copper was 0.0739 g.
(a) Calculate the extent of the reaction.
(b) Calculate the moles of NO generated by the reaction and the moles of HNO_3 remaining.

114. The following chemical equation represents the decomposition of hydrogen peroxide, H_2O_2.

$$2\,H_2O_2 \longrightarrow O_2 + 2\,H_2O$$

If the reaction started with 8.67 g of pure H_2O_2 and produced 3.74 g of O_2, what is the extent of reaction, ξ, and what percentage of the H_2O_2 reacted?

115. An organic liquid is either methyl alcohol (CH_3OH), ethyl alcohol (CH_3CH_2OH), or a mixture of the two. A 0.220 g sample of the liquid is burned in an excess of $O_2(g)$ and yields 0.352 g $CO_2(g)$. Is the liquid a pure alcohol or a mixture of the two?

116. The manufacture of ethyl alcohol, CH_3CH_2OH, yields diethyl ether, $(C_2H_5)_2O$ as a by-product. The complete combustion of a 1.005 g sample of the product of this process yields 1.963 g CO_2. What must be the mass percents of CH_3CH_2OH and of $(C_2H_5)_2O$ in this sample?

117. A mixture contains only $CuCl_2$ and $FeCl_3$. A 0.7391 g sample of the mixture is completely dissolved in water and then treated with $AgNO_3(aq)$. The following reactions occur.

$$CuCl_2(aq) + 2\,AgNO_3(aq) \longrightarrow 2\,AgCl(s) + Cu(NO_3)_2(aq)$$
$$FeCl_3(aq) + 3\,AgNO_3(aq) \longrightarrow 3\,AgCl(s) + Fe(NO_3)_3(aq)$$

If it takes 86.91 mL of 0.1463 M $AgNO_3$ solution to precipitate all the chloride as AgCl, then what is the percentage by mass of copper in the mixture?

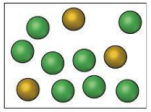
118. Under appropriate conditions, copper sulfate, potassium chromate, and water react to form a product containing Cu^{2+}, CrO_4^{2-}, and OH^- ions. Analysis of the compound yields 48.7% Cu^{2+}, 35.6% CrO_4^{2-}, and 15.7% OH^-.
(a) Determine the empirical formula of the compound.
(b) Write a plausible equation for the reaction.

119. Write a chemical equation to represent the complete combustion of malonic acid, a compound with 34.62% C, 3.88% H, and 61.50% O, by mass.

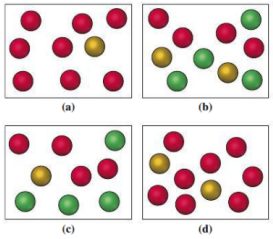
120. Aluminum metal and iron(III) oxide react to give aluminum oxide and iron metal. What is the maximum mass of iron that can be obtained from a reaction mixture containing 2.5 g of aluminum and 9.5 g of iron(III) oxide. What mass of the excess reactant remains?

121. Silver nitrate is a very expensive chemical. For a particular experiment, you need 100.0 mL of 0.0750 M $AgNO_3$, but only 60 mL of 0.0500 M $AgNO_3$ is available. You decide to pipet exactly 50.00 mL of the solution into a 100.0 mL flask, add an appropriate mass of $AgNO_3$, and then dilute the resulting solution to exactly 100.0 mL. What mass of $AgNO_3$ must you use?

122. When sulfur (S_8) and chlorine are mixed in a reaction vessel, disulfur dichloride is the sole product. The starting mixture below is represented by yellow spheres for the S_8 molecules and green spheres for the chlorine molecules.



Which of the following is (are) a valid representation(s) of the contents of the reaction vessel after some disulfur dichloride (represented by red spheres) has formed?



123. A method for eliminating oxides of nitrogen (e.g., NO_2) from automobile exhaust gases is to pass the exhaust gases over solid cyanuric acid, $C_3N_3(OH)_3$. When the hot exhaust gases come in contact with cyanuric acid, solid $C_3N_3(OH)_3$ decomposes into

isocyanic acid vapor, HNCO(g), which then reacts with NO_2 in the exhaust gases to give N_2, CO_2, and H_2O. How many grams of $C_3N_3(OH)_3$ are needed per gram of NO_2 in this method?
[*Hint*: To balance the equation for reaction between HNCO and NO_2, balance with respect to each kind of atom in this order: H, C, O, and N.]

124. For a specific reaction, ammonium dichromate is the only reactant and chromium(III) oxide and water are two of the three products. The third product contains only one type of atom. What is the third product and how many grams of this product are produced per kilogram of ammonium dichromate decomposed?

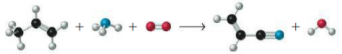
125. It is desired to produce as large a volume of 1.25 M urea [$CO(NH_2)_2(aq)$] as possible from these three sources: 345 mL of 1.29 M $CO(NH_2)_2$, 485 mL of 0.653 M $CO(NH_2)_2$, and 835 mL of 0.775 M $CO(NH_2)_2$. How can this be done? What is the maximum volume of this solution obtainable?

126. The mineral ilmenite, $FeTiO_3$, is an important source of titanium dioxide for use as a white pigment. In the first step in its conversion to titanium dioxide, ilmenite is treated with sulfuric acid and water to form $TiOSO_4$ and iron(II) sulfate heptahydrate. Titanium dioxide is obtained in two subsequent steps. How many kilograms of iron(II) sulfate heptahydrate are produced for every 1.00×10^3 kg of ilmenite processed?

127. Refer to Exercise 126. Iron(II) sulfate heptahydrate formed in the processing of ilmenite ore cannot be released into the environment. Its further treatment involves dehydration by heating to produce anhydrous iron(II) sulfate. Upon further heating, the iron(II) sulfate decomposes to iron(III) oxide, and sulfur dioxide and oxygen gases. The iron(III) oxide is used in the production of iron and steel. How many kilograms of iron(III) oxide are obtained for every 1.00×10^3 kg of iron(II) sulfate heptahydrate?

128. Melamine, $C_3N_3(NH_2)_3$, is used in adhesives and resins. It is manufactured in a two-step process in which urea, $CO(NH_2)_2$, is the sole starting material, isocyanic acid (HNCO) is an intermediate, and ammonia and carbon dioxide gases are by-products.
(a) Write a balanced equation for the overall reaction.
(b) What mass of melamine will be obtained from 100.0 kg of urea if the yield of the overall reaction is 84%?

129. Acrylonitrile is used in the production of synthetic fibers, plastics, and rubber goods. It can be prepared from propylene (propene), ammonia, and oxygen in the reaction illustrated below.
(a) Write a balanced chemical equation for this reaction.
(b) The actual yield of the reaction is 0.73 kg acrylonitrile per kilogram of propylene. What is the minimum mass of ammonia required to produce 1.00 metric ton (1000 kg) of acrylonitrile?



130. A fundamental principle in *green chemistry* is atom economy (AE). AE is a measure of how many atoms from the starting materials are incorporated into the desired product. For example, if a reaction incorporates all the reactant atoms into the product of interest, the reaction has a percent AE of 100%. To obtain percent AE for a reaction, we calculate the mass of the desired product that can be formed from a stoichiometric mixture of reactants, and compare this mass with the total mass of that reaction mixture. (In a stoichiometric mixture of reactants, none of the reactants are present in excess; the mole amounts are in the same ratio as the stoichiometric coefficients).

$$\%\ \text{AE} = \frac{\text{mass } (m'_p) \text{ of the desired product P}}{\text{total mass of a stoichiometric mixture of reactants}} \times 100$$

The prime (′) on the symbol for the mass of the desired product serves to remind us that this mass is calculated for a stoichiometric mixture of reactants. Use the definition above to calculate the percent AE for the following reactions, both of which can be used to make $C_6H_5NH_2$, the desired product.

$$C_6H_6 + (CH_3)_3SiN_3 + 2\,F_3CSO_3H + NaOH \longrightarrow C_6H_5NH_2 + N_2 + (CH_3)_3SiOSO_2CF_3 + NaF_3CSO_3 + H_2O$$

$$C_6H_6 + HNO_3 + 3\,H_2 \longrightarrow C_6H_5NH_2 + 3\,H_2O$$

131. The industrial production of hydrazine (N_2H_4) by the Raschig process is the topic of the Focus On feature for Chapter 4 on www.masteringchemistry.com. The following chemical equation represents the overall process, which actually involves three consecutive reactions.

$$2\,NH_3(aq) + Cl_2(g) + 2\,NaOH(aq) \longrightarrow N_2H_4(aq) + 2\,NaCl(aq) + 2\,H_2O(l)$$

(a) Use the definition of percent atom economy (AE) from exercise 130 to calculate, to the nearest percent, the percent AE for the Raschig process.
(b) Propose a reaction for the synthesis of N_2H_4 that has percent AE of 100%.

132. It is often difficult to determine the concentration of a species in solution, particularly if it is a biological species that takes part in complex reaction pathways. One way to do this is through a dilution experiment with labeled molecules. Instead of molecules, however, we will use fish.

An angler wants to know the number of fish in a particular pond, and so puts an indelible mark on 100 fish and adds them to the pond's existing population. After waiting for the fish to spread throughout the pond, the angler starts fishing, eventually catching 18 fish. Of these, five are marked. What is the total number of fish in the pond?

Feature Problems

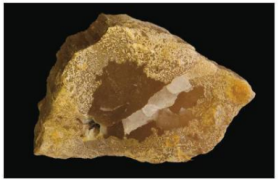
133. Lead nitrate and potassium iodide react in aqueous solution to form a yellow precipitate of lead iodide. In one series of experiments, the masses of the two reactants were varied, but the *total* mass of the two was held constant at 5.000 g. The lead iodide formed was filtered from solution, washed, dried, and weighed. The table gives data for a series of reactions.

Experiment	Mass of Lead Nitrate, *g*	Mass of Lead Iodide, *g*
1	0.500	0.692
2	1.000	1.388
3	1.500	2.093
4	3.000	2.778
5	4.000	1.391

(a) Plot the data in a graph of mass of lead iodide versus mass of lead nitrate, and draw the appropriate curve(s) connecting the data points. What is the maximum mass of precipitate that can be obtained? **(b)** Explain why the maximum mass of precipitate is obtained when the reactants are in their stoichiometric proportions. What are these stoichiometric proportions expressed as a mass ratio, and as a mole ratio? **(c)** Show how the stoichiometric proportions determined in part (b) are related to the balanced equation for the reaction.

134. Baking soda, $NaHCO_3$, is made from soda ash, a common name for sodium carbonate. The soda ash is obtained in two ways. It can be manufactured in a process in which carbon dioxide, ammonia, sodium chloride, and water are the starting materials. Alternatively, it is mined as a mineral called *trona* (top photo). Whether the soda ash is mined or manufactured, it is dissolved in water and carbon dioxide is bubbled through the solution. Sodium bicarbonate precipitates from the solution.

As a chemical analyst you are presented with two samples of sodium bicarbonate—one from the manufacturing process and the other derived from trona. You are asked to determine which is purer and are told that the impurity is sodium carbonate. You decide to treat the samples with just sufficient hydrochloric acid to convert all the sodium carbonate and bicarbonate to sodium chloride, carbon dioxide, and water. You then precipitate silver chloride in the reaction of sodium chloride with silver nitrate. A 6.93 g sample of baking soda derived from trona gave 11.89 g of silver chloride. A 6.78 g sample from manufactured sodium carbonate gave 11.77 g of silver chloride. Which sample is purer, that is, which has the greater mass percent $NaHCO_3$?



John Cancalosi/National Geographic Society/Corbis

Trona $Na_2CO_3 \cdot NaHCO_3 \cdot 2\,H_2O$

Robert Matheny/Fundamental Photographs

Baking soda $NaHCO_3$

Self-Assessment Exercises

135. In your own words, define or explain these terms or symbols.

(a) $\xrightarrow{\Delta}$ **(b)** (aq)

(c) stoichiometric coefficient **(d)** overall equation

136. Briefly describe **(a)** balancing a chemical equation; **(b)** preparing a solution by dilution; **(c)** determining the limiting reactant in a reaction.

137. Explain the important distinctions between **(a)** chemical formula and chemical equation; **(b)** stoichiometric coefficient and stoichiometric factor; **(c)** solute and solvent; **(d)** actual yield and percent yield; **(e)** consecutive and simultaneous reactions.

138 When the equation below is balanced, the correct set of stoichiometric coefficients is **(a)** 1, 6 ⟶ 1, 3, 4; **(b)** 1, 4 ⟶ 1, 2, 2; **(c)** 2, 6 ⟶ 2, 3, 2; **(d)** 3, 8 ⟶ 3, 4, 2.

$$? Cu(s) + ? HNO_3(aq) \longrightarrow ? Cu(NO_3)_2(aq) + ? H_2O(l) + ? NO(g)$$

139 A reaction mixture contains 1.0 mol $CaCN_2$ (calcium cyanamide) and 1.0 mol H_2O. The maximum number of moles of NH_3 produced is **(a)** 3.0; **(b)** 2.0; **(c)** between 1.0 and 2.0; **(d)** less than 1.0.

$$CaCN_2(s) + 3\,H_2O(l) \longrightarrow CaCO_3(s) + 2\,NH_3(g)$$

140. Consider the chemical equation below. What is the maximum number of moles of K_2SO_4 that can be obtained from a reaction mixture containing 5.0 moles each of $KMnO_4$, KI, and H_2SO_4? **(a)** 3.0 mol; **(b)** 3.8 mol; **(c)** 5.0 mol; **(d)** 6.0 mol; **(e)** 15 mol.

$$2\,KMnO_4 + 10\,KI + 8\,H_2SO_4 \longrightarrow 6\,K_2SO_4 + 2\,MnSO_4 + 5\,I_2 + 8\,H_2O$$

141. In the decomposition of silver carbonate to form metallic silver, carbon dioxide gas, and oxygen gas, **(a)** one mol of oxygen gas is formed for every 2 mol of carbon dioxide gas; **(b)** 2 mol of silver metal is formed for every 1 mol of oxygen gas; **(c)** equal numbers of moles of carbon dioxide and oxygen gases are produced; **(d)** the same number of moles of silver metal are formed as of the silver carbonate decomposed.

142. To obtain a solution that is 1.00 M $NaNO_3$, you should prepare **(a)** 1.00 L of aqueous solution containing 100 g $NaNO_3$; **(b)** 1 kg of aqueous solution containing 85.0 g $NaNO_3$; **(c)** 5.00 L of aqueous solution containing 425 g $NaNO_3$; **(d)** an aqueous solution containing 8.5 mg $NaNO_3$/mL.

143. What is the volume (in mL) of 0.160 M KNO_3 that must be added to 200.0 mL of 0.240 M K_2SO_4 to produce a solution having $[K^+] = 0.400$ M?

144. To prepare a solution that is 0.50 M KCl starting with 100.0 mL of 0.40 M KCl, you should **(a)** add 20.0 mL of water; **(b)** add 0.075 g KCl; **(c)** add 0.10 mol KCl; **(d)** evaporate 20.0 mL of water.

145. An aqueous solution that is 5.30% LiBr by mass has a density of 1.040 g/mL. What is the molarity of this solution? **(a)** 0.563 M; **(b)** 0.635 M; **(c)** 0.0635 M; **(d)** 0.0563 M; **(e)** 12.0 M.

146. In the reaction of 2.00 mol CCl_4 with an excess of HF, 1.70 mol CCl_2F_2 is obtained.

$$CCl_4 + 2\,HF \longrightarrow CCl_2F_2 + 2\,HCl$$

(a) The theoretical yield is 1.70 mol CCl_2F_2.
(b) The theoretical yield is 1.00 mol CCl_2F_2.
(c) The theoretical yield depends on how large an excess of HF is used.
(d) The percent yield is 85%.

147. Consider the reaction $2\,Fe_2O_3 + 3\,C \longrightarrow 4\,Fe + 3\,CO_2$. What is the maximum mass of Fe that can be obtained from a reaction mixture containing 18.0 g Fe_2O_3 and 2.5 g C?

148. A 26.4 g sample of a mixture of NaOH and CaO contains 40.0% CaO. When the sample is treated with aqueous HCl, the following reactions occur:

$$NaOH(s) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$$
$$CaO(s) + 2\,HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l)$$

All of the mixture reacts, and no HCl is left over. The resulting solution is evaporated to dryness. What is the mass (in grams) of solid obtained?

149. The incomplete combustion of gasoline produces CO(g) as well as CO_2(g). Write an equation for **(a)** the complete combustion of the gasoline component octane, C_8H_{18}(l), and **(b)** incomplete combustion of octane with 25% of the carbon appearing as CO(g).

150. The minerals calcite, $CaCO_3$, magnesite, $MgCO_3$, and dolomite, $CaCO_3 \cdot MgCO_3$, decompose when strongly heated to form the corresponding metal oxide(s) and carbon dioxide gas. A 1.000 g sample known to be one of the three minerals was strongly heated and 0.477 g CO_2 was obtained. Which of the three minerals was it?

151. A 1.000 g sample of a mixture of CH_4 and C_2H_6 is analyzed by burning it completely in O_2, yielding 2.776 g CO_2. What is the percentage by mass of CH_4 in the mixture? **(a)** 93%; **(b)** 82%; **(c)** 67%; **(d)** 36%; **(e)** less than 36%.

152. Nitric acid, HNO_3, can be manufactured from ammonia, NH_3, by using the three reactions shown below.

Step 1: $4\,NH_3(g) + 5\,O_2(g) \rightarrow 4\,NO(g) + 6\,H_2O(l)$
Step 2: $2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$
Step 3: $3\,NO_2(g) + H_2O(l) \rightarrow 2\,HNO_3(aq) + NO(g)$

What is the maximum number of moles of HNO_3 that can be obtained from 4.00 moles of NH_3? (Assume that the NO produced in step 3 is not recycled back into step 2.) **(a)** 1.33 mol; **(b)** 2.00 mol; **(c)** 2.67 mol; **(d)** 4.00 mol; **(e)** 6.00 mol.

153. For each of the following compounds, write a balanced chemical equation for forming the compound from its elements. What is the percent atom economy in each case? **(a)** $RbBrO_4$; **(b)** H_2SO_4; **(c)** $Mg(ClO_3)_2$; **(d)** $NaNO_2$.

154. Appendix E describes a useful study aid known as concept mapping. Using the method presented in Appendix E, construct a concept map relating the topics found in Sections 4-3, 4-4, and 4-5.

* assume that solution volumes simply add up