Continued—

Q9. What is the net ionic equation for the reaction that occurs when aqueous solutions of $KHCO_3$ and HBr are mixed? **MISSED THIS?** *Read Sections 5.6, 5.8*

a) $K^+(aq) + C_2H_3O_2^-(aq) \longrightarrow KC_2H_3O_2(s)$
b) $H^+(aq) + HCO_3^-(aq) \longrightarrow CO_2(g) + H_2O(l)$
c) $H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$
d) None of the above because no reaction occurs.

Q10. What is the oxidation state of carbon in CO_3^{2-}? **MISSED THIS?** *Read Section 5.9; Watch KCV 5.13*

a) +4 b) +3 c) −3 d) −2

Q11. Sodium reacts with water according to the reaction:

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

Identify the oxidizing agent. **MISSED THIS?** *Read Section 5.9; Watch KCV 5.13*

a) $Na(s)$ b) $H_2O(l)$c) $NaOH(aq)$ d) $H_2(aq)$

Q12. Which of these ions will spontaneously react with $Ni(s)$ in solution? **MISSED THIS?** *Read Section 5.9*

a) $Cu^{2+}(aq)$ b) $Zn^{2+}(aq)$
c) $Mg^{2+}(aq)$ d) $K^+(aq)$

Answers: 1. (c) **2.** (a) **3.** (b) **4.** (c) **5.** (d) **6.** (b) **7.** (c) **8.** (d) **9.** (b) **10.** (a) **11.** (b) **12.** (a)

CHAPTER 5 IN REVIEW

TERMS

Section 5.2
solution (168)
solvent (168)
solute (168)
aqueous solution (168)
dilute solution (168)
concentrated solution (168)
molarity (M) (168)
stock solution (171)

Section 5.4
electrolyte (175)
strong electrolyte (176)
nonelectrolyte (176)
strong acid (176)
weak acid (177)
weak electrolyte (177)
soluble (178)
insoluble (178)

Section 5.5
precipitation reaction (179)
precipitate (179)

Section 5.6
molecular equation (183)
complete ionic equation (183)
spectator ion (184)
net ionic equation (184)

Section 5.7
acid–base reaction (neutralization reaction) (185)
gas-evolution reaction (185)
Arrhenius definitions (186)
hydronium ion (186)
polyprotic acid (186)
diprotic acid (186)
salt (186)
titration (189)
equivalence point (189)
indicator (189)

Section 5.9
oxidation–reduction (redox) reaction (193)
oxidation (193)
reduction (193)
oxidation state (oxidation number) (194)
oxidizing agent (197)
reducing agent (197)
activity series of metals (200)

CONCEPTS

Solution Concentration and Stoichiometry (5.2, 5.3)
- An aqueous solution is a homogeneous mixture of water (the solvent) with another substance (the solute).
- We express the concentration of a solution in molarity, the number of moles of solute per liter of solution.
- We can use the molarities and volumes of reactant solutions to predict the amount of product that forms in an aqueous reaction.

Aqueous Solutions and Precipitation Reactions (5.4, 5.5)
- Solutes that completely dissociate (or completely ionize in the case of the strong acids) to ions in solution are strong electrolytes, and their solutions are good conductors of electricity.
- Solutes that only partially dissociate (or partially ionize) are weak electrolytes.
- Solutes that do not dissociate (or ionize) are nonelectrolytes.
- A substance that dissolves in water to form a solution is soluble.
- In a precipitation reaction, we mix two aqueous solutions and a solid (precipitate) forms.
- The solubility rules are an empirical set of guidelines that help predict the solubilities of ionic compounds; these rules are especially useful when determining whether or not a precipitate will form.

Equations for Aqueous Reactions (5.6)
- We can represent an aqueous reaction with a molecular equation, which shows the complete neutral formula for each compound in the reaction.
- We can also represent an aqueous reaction with a complete ionic equation, which shows the dissociated nature of strong electrolytes.
- A third representation of an aqueous reaction is the net ionic equation, in which the spectator ions—those that do not change in the course of the reaction—are left out of the equation.

Acid–Base and Gas-Evolution Reactions (5.7, 5.8)
- In an acid–base reaction, an acid, a substance that produces H^+ in solution, reacts with a base, a substance that produces OH^- in solution, and the two neutralize each other, producing water (or in some cases a weak electrolyte).

- An acid–base titration is a laboratory procedure in which a reaction is carried to its equivalence point—the point at which the reactants are in exact stoichiometric proportions; titrations are useful in determining the concentrations of unknown solutions.
- In gas-evolution reactions, two aqueous solutions combine, and a gas is produced.

Oxidation–Reduction Reactions (5.9)

- In oxidation–reduction reactions, one substance transfers electrons to another substance.
- In oxidation–reduction reactions, the substance that loses electrons is oxidized, and the substance that gains them is reduced.
- An oxidation state is a fictitious charge given to each atom in an oxidation–reduction reaction by assigning all shared electrons to the atom with the greater attraction for those electrons. An oxidation state is an imposed electronic bookkeeping scheme, not an actual physical state.
- The oxidation state of an atom increases upon oxidation and decreases upon reduction.
- The activity series of metals can be used to predict spontaneous redox reaction. Any half-reaction in the series is spontaneous when paired with any reverse half-reaction below it.

EQUATIONS AND RELATIONSHIPS

Molarity (M): Solution Concentration (5.2)

$$M = \frac{\text{amount of solute (in mol)}}{\text{volume of solution (in L)}}$$

Solution Dilution (5.2)

$$M_1V_1 = M_2V_2$$

Solution Stoichiometry (5.3)

volume A ⟶ amount A (in moles) ⟶ amount B (in moles) ⟶ volume B

LEARNING OUTCOMES

Chapter Objectives	Assessment
Calculate molarity and apply it to conversion and dilution problems (5.2)	Examples 5.1, 5.2, 5.3 **For Practice** 5.1, 5.2, 5.3 **For More Practice** 5.1, 5.2, 5.3 **Exercises** 21–32
Calculate the amounts of reactants and products involved in aqueous reactions (5.3)	Example 5.4 **For Practice** 5.4 **For More Practice** 5.4 **Exercises** 33–38
Classify compounds as soluble or insoluble, electrolyte or nonelectrolyte (5.4)	Example 5.5 **For Practice** 5.5 **Exercises** 39–42
Write chemical equations for precipitation reactions between two or more aqueous solutions (5.5)	Examples 5.6, 5.7 **For Practice** 5.6, 5.7 **Exercises** 43–46
Express molecular equations as complete ionic and net ionic equations (5.6)	Example 5.8 **For Practice** 5.8 **Exercises** 47–50
Write molecular, complete ionic, and net ionic equations for neutralization reactions (5.7)	Examples 5.9, 5.10 **For Practice** 5.9, 5.10 **Exercises** 51–56
Perform calculations involving titration reactions (5.7)	Example 5.11 **For Practice** 5.11 **For More Practice** 5.11 **Exercises** 57–58
Write equations for gas-evolution reactions (5.8)	Example 5.12 **For Practice** 5.12 **For More Practice** 5.12 **Exercises** 59–60
Determine the oxidation state of elements in compounds (5.9)	Example 5.13 **For Practice** 5.13 **Exercises** 61–64
Determine if a reaction is a redox reaction and if so, identify the oxidizing and reducing agents (5.9)	Examples 5.14, 5.15 **For Practice** 5.14, 5.15 **For More Practice** 5.14 **Exercises** 65–68
Predict the spontaneity of redox reactions (5.9)	Example 5.16 **For Practice** 5.16 **Exercises** 69–72

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 an aqueous solution? What is the difference between the solute and the solvent?

2. What is molarity? How is it useful?

3. Explain how a strong electrolyte, a weak electrolyte, and a nonelectrolyte differ.

4. Explain the difference between a strong acid and a weak acid.

5. What does it mean for a compound to be soluble? Insoluble?

6. What are the solubility rules? How are they useful?

7. What are the cations and anions whose compounds are usually soluble? What are the exceptions? What are the anions whose compounds are mostly insoluble? What are the exceptions?

8. What is a precipitation reaction? Give an example.

9. How can you predict whether a precipitation reaction will occur upon mixing two aqueous solutions?

10. Explain how a molecular equation, a complete ionic equation, and a net ionic equation differ.

11. What is the Arrhenius definition of an acid? A base?

12. What is an acid–base reaction? Give an example.

13. Explain the principles behind an acid–base titration. What is an indicator?

14. What is a gas-evolution reaction? Give an example.

15. What reactant types give rise to gas-evolution reactions?

16. What is an oxidation–reduction reaction? Give an example.

17. What are oxidation states?

18. How can oxidation states be used to identify redox reactions?

19. What happens to a substance when it becomes oxidized? Reduced?

20. In a redox reaction, which reactant is the oxidizing agent? The reducing agent?

PROBLEMS BY TOPIC

Solution Concentration and Solution Stoichiometry

21. Calculate the molarity of each solution.
MISSED THIS? *Read Section 5.2; Watch KCV 5.2, IWE 5.1*
a. 3.25 mol of LiCl in 2.78 L solution
b. 28.33 g $C_6H_{12}O_6$ in 1.28 L of solution
c. 32.4 mg NaCl in 122.4 mL of solution

22. Calculate the molarity of each solution.
a. 0.38 mol of $LiNO_3$ in 6.14 L of solution
b. 72.8 g C_2H_6O in 2.34 L of solution
c. 12.87 mg KI in 112.4 mL of solution

23. What is the molarity of NO_3^- in each solution?
MISSED THIS? *Read Sections 5.2, 5.4; Watch KCV 5.2, IWE 5.1*
a. 0.150 M KNO_3
b. 0.150 M $Ca(NO_3)_2$
c. 0.150 M $Al(NO_3)_3$

24. What is the molarity of Cl^- in each solution?
a. 0.200 M NaCl
b. 0.150 M $SrCl_2$
c. 0.100 M $AlCl_3$

25. How many moles of KCl are contained in each solution?
MISSED THIS? *Read Section 5.2; Watch KCV 5.2, IWE 5.2*
a. 0.556 L of a 2.3 M KCl solution
b. 1.8 L of a 0.85 M KCl solution
c. 114 mL of a 1.85 M KCl solution

26. What volume of 0.200 M ethanol solution contains each amount in moles of ethanol?
a. 0.45 mol ethanol
b. 1.22 mol ethanol
c. 1.2×10^{-2} mol ethanol

27. A laboratory procedure calls for making 400.0 mL of a 1.1 M $NaNO_3$ solution. What mass of $NaNO_3$ (in g) is needed?
MISSED THIS? *Read Section 5.2; Watch KCV 5.2, IWE 5.2*

28. A chemist wants to make 5.5 L of a 0.300 M $CaCl_2$ solution. What mass of $CaCl_2$ (in g) should the chemist use?

29. If 123 mL of a 1.1 M glucose solution is diluted to 500.0 mL, what is the molarity of the diluted solution?
MISSED THIS? *Read Section 5.2; Watch KCV 5.2, IWE 5.3*

30. If 3.5 L of a 4.8 M $SrCl_2$ solution is diluted to 45 L, what is the molarity of the diluted solution?

31. To what volume should you dilute 50.0 mL of a 12 M stock HNO_3 solution to obtain a 0.100 M HNO_3 solution?
MISSED THIS? *Read Section 5.2; Watch KCV 5.2, IWE 5.3*

32. To what volume should you dilute 25 mL of a 10.0 M H_2SO_4 solution to obtain a 0.150 M H_2SO_4 solution?

33. Consider the precipitation reaction:
MISSED THIS? *Read Section 5.3; Watch IWE 5.4*

$$2\,Na_3PO_4(aq) + 3\,CuCl_2(aq) \longrightarrow Cu_3(PO_4)_2(s) + 6\,NaCl(aq)$$

What volume of 0.175 M Na_3PO_4 solution is necessary to completely react with 95.4 mL of 0.102 M $CuCl_2$?

34. Consider the reaction:

$$Li_2S(aq) + Co(NO_3)_2(aq) \longrightarrow 2\,LiNO_3(aq) + CoS(s)$$

What volume of 0.150 M Li_2S solution is required to completely react with 125 mL of 0.150 M $Co(NO_3)_2$?

35. What is the minimum amount of 6.0 M H_2SO_4 necessary to produce 25.0 g of $H_2(g)$ according to the reaction between aluminum and sulfuric acid?
MISSED THIS? *Read Section 5.3; Watch IWE 5.4*

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

36. What is the molarity of $ZnCl_2$ that forms when 25.0 g of zinc completely reacts with $CuCl_2$ according to the following reaction? Assume a final volume of 275 mL.

$$Zn(s) + CuCl_2(aq) \longrightarrow ZnCl_2(aq) + Cu(s)$$

37. A 25.0-mL sample of a 1.20 M potassium chloride solution is mixed with 15.0 mL of a 0.900 M lead(II) nitrate solution, and this precipitation reaction occurs:
MISSED THIS? *Read Section 4.3, 5.3; Watch KCV 4.3, IWE 4.6, 5.4*

$$2\,KCl(aq) + Pb(NO_3)_2(aq) \longrightarrow PbCl_2(s) + 2\,KNO_3(aq)$$

The solid $PbCl_2$ is collected, dried, and found to have a mass of 2.45 g. Determine the limiting reactant, the theoretical yield, and the percent yield.

38. A 55.0-mL sample of a 0.102 M potassium sulfate solution is mixed with 35.0 mL of a 0.114 M lead(II) acetate solution and this precipitation reaction occurs:

$$K_2SO_4(aq) + Pb(C_2H_3O_2)_2(aq) \longrightarrow 2\,KC_2H_3O_2(aq) + PbSO_4(s)$$

The solid $PbSO_4$ is collected, dried, and found to have a mass of 1.01 g. Determine the limiting reactant, the theoretical yield, and the percent yield.

Types of Aqueous Solutions and Solubility

39. For each compound (all water soluble), would you expect the resulting aqueous solution to conduct electrical current?
MISSED THIS? *Read Section 5.4*
a. $CsCl$ **b.** CH_3OH **c.** $Ca(NO_2)_2$ **d.** $C_6H_{12}O_6$

40. Classify each compound as a strong electrolyte or nonelectrolyte.
a. $MgBr_2$ **b.** $C_{12}H_{22}O_{11}$ **c.** Na_2CO_3 **d.** KOH

41. Determine whether each compound is soluble or insoluble. If the compound is soluble, list the ions present in solution.
MISSED THIS? *Read Section 5.4; Watch IWE 5.5*
a. $AgNO_3$ **b.** $Pb(C_2H_3O_2)_2$
c. KNO_3 **d.** $(NH_4)_2S$

42. Determine whether each compound is soluble or insoluble. If the compound is soluble, list the ions present in solution.
a. AgI **b.** $Cu_3(PO_4)_2$
c. $CoCO_3$ **d.** K_3PO_4

Precipitation Reactions

43. Complete and balance each equation. If no reaction occurs, write "NO REACTION."
MISSED THIS? *Read Section 5.5; Watch KCV 5.5, IWE 5.6*
a. $LiI(aq) + BaS(aq) \longrightarrow$
b. $KCl(aq) + CaS(aq) \longrightarrow$
c. $CrBr_2(aq) + Na_2CO_3(aq) \longrightarrow$
d. $NaOH(aq) + FeCl_3(aq) \longrightarrow$

44. Complete and balance each equation. If no reaction occurs, write "NO REACTION."
a. $NaNO_3(aq) + KCl(aq) \longrightarrow$
b. $NaCl(aq) + Hg_2(C_2H_3O_2)_2(aq) \longrightarrow$
c. $(NH_4)_2SO_4(aq) + SrCl_2(aq) \longrightarrow$
d. $NH_4Cl(aq) + AgNO_3(aq) \longrightarrow$

45. Write a molecular equation for the precipitation reaction that occurs (if any) when each pair of aqueous solutions is mixed. If no reaction occurs, write "NO REACTION."
MISSED THIS? *Read Section 5.5; Watch KCV 5.5, IWE 5.6*
a. potassium carbonate and lead(II) nitrate
b. lithium sulfate and lead(II) acetate
c. copper(II) nitrate and magnesium sulfide
d. strontium nitrate and potassium iodide

46. Write a molecular equation for the precipitation reaction that occurs (if any) when each pair of aqueous solutions is mixed. If no reaction occurs, write "NO REACTION."
a. sodium chloride and lead(II) acetate
b. potassium sulfate and strontium iodide
c. cesium chloride and calcium sulfide
d. chromium(III) nitrate and sodium phosphate

Ionic and Net Ionic Equations

47. Write balanced complete ionic and net ionic equations for each reaction. **MISSED THIS?** *Read Section 5.6*
a. $HCl(aq) + LiOH(aq) \longrightarrow H_2O(l) + LiCl(aq)$
b. $CaS(aq) + CuCl_2(aq) \longrightarrow CuS(s) + CaCl_2(aq)$
c. $NaOH(aq) + HC_2H_3O_2(aq) \longrightarrow H_2O(l) + NaC_2H_3O_2(aq)$
d. $Na_3PO_4(aq) + NiCl_2(aq) \longrightarrow Ni_3(PO_4)_2(s) + NaCl(aq)$

48. Write balanced complete ionic and net ionic equations for each reaction.
a. $K_2SO_4(aq) + CaI_2(aq) \longrightarrow CaSO_4(s) + KI(aq)$
b. $NH_4Cl(aq) + NaOH(aq) \longrightarrow H_2O(l) + NH_3(g) + NaCl(aq)$
c. $AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$
d. $HC_2H_3O_2(aq) + K_2CO_3(aq) \longrightarrow H_2O(l) + CO_2(g) + KC_2H_3O_2(aq)$

49. Mercury(I) ions ($Hg_2^{\,2+}$) can be removed from solution by precipitation with Cl^-. Suppose that a solution contains aqueous $Hg_2(NO_3)_2$. Write complete ionic and net ionic equations for the reaction of aqueous $Hg_2(NO_3)_2$ with aqueous sodium chloride to form solid Hg_2Cl_2 and aqueous sodium nitrate.
MISSED THIS? *Read Section 5.6*

50. Lead(II) ions can be removed from solution by precipitation with sulfate ions. Suppose that a solution contains lead(II) nitrate. Write complete ionic and net ionic equations for the reaction of aqueous lead(II) nitrate with aqueous potassium sulfate to form solid lead(II) sulfate and aqueous potassium nitrate.

Acid–Base and Gas-Evolution Reactions

51. Write balanced molecular and net ionic equations for the reaction between hydrobromic acid and potassium hydroxide.
MISSED THIS? *Read Section 5.7; Watch KCV 5.5, IWE 5.9*

52. Write balanced molecular and net ionic equations for the reaction between nitric acid and calcium hydroxide.

53. Complete and balance each acid–base equation.
MISSED THIS? *Read Section 5.7; Watch IWE 5.9*
a. $H_2SO_4(aq) + Ca(OH)_2(aq) \longrightarrow$
b. $HClO_4(aq) + KOH(aq) \longrightarrow$
c. $H_2SO_4(aq) + NaOH(aq) \longrightarrow$

54. Complete and balance each acid–base equation.
a. $HI(aq) + LiOH(aq) \longrightarrow$
b. $HC_2H_3O_2(aq) + Ca(OH)_2(aq) \longrightarrow$
c. $HCl(aq) + Ba(OH)_2(aq) \longrightarrow$

55. Write balanced complete ionic and net ionic equations for each acid–base reaction.
MISSED THIS? *Read Section 5.7; Watch KCV 5.5, IWE 5.9*
a. $HBr(aq) + NaOH(aq) \longrightarrow$
b. $HF(aq) + NaOH(aq) \longrightarrow$
c. $HC_2H_3O_2(aq) + RbOH(aq) \longrightarrow$

56. Write balanced complete ionic and net ionic equations for each acid–base reaction.
a. $HI(aq) + RbOH(aq) \longrightarrow$
b. $HCHO_2(aq) + NaOH(aq) \longrightarrow$
c. $HC_2H_3O_2(aq) + LiOH(aq) \longrightarrow$

57. A 25.00-mL sample of an unknown $HClO_4$ solution requires titration with 22.62 mL of 0.2000 M NaOH to reach the equivalence point. What is the concentration of the unknown $HClO_4$ solution? The neutralization reaction is
MISSED THIS? *Read Section 5.7; Watch IWE 5.11*

$$HClO_4(aq) + NaOH(aq) \longrightarrow H_2O(l) + NaClO_4(aq)$$

58. A 30.00-mL sample of an unknown H_3PO_4 solution is titrated with a 0.100 M NaOH solution. The equivalence point is reached when 26.38 mL of NaOH solution is added. What is the concentration of the unknown H_3PO_4 solution? The neutralization reaction is

$$H_3PO_4(aq) + 3\,NaOH(aq) \longrightarrow 3\,H_2O(l) + Na_3PO_4(aq)$$

59. Complete and balance each gas-evolution equation.
MISSED THIS? *Read Section 5.8; Watch KCV 5.5*
a. $HBr(aq) + NiS(s) \longrightarrow$
b. $NH_4I(aq) + NaOH(aq) \longrightarrow$
c. $HBr(aq) + Na_2S(aq) \longrightarrow$
d. $HClO_4(aq) + Li_2CO_3(aq) \longrightarrow$

60. Complete and balance each gas-evolution equation.
a. $HNO_3(aq) + Na_2SO_3(aq) \longrightarrow$
b. $HCl(aq) + KHCO_3(aq) \longrightarrow$
c. $HC_2H_3O_2(aq) + NaHSO_3(aq) \longrightarrow$
d. $(NH_4)_2SO_4(aq) + Ca(OH)_2(aq) \longrightarrow$

Oxidation–Reduction

61. Assign oxidation states to each atom in each element, ion, or compound. **MISSED THIS?** *Read Section 5.9; Watch IWE 5.13*
a. Ag **b.** Ag^+ **c.** CaF_2
d. H_2S **e.** CO_3^{2-} **f.** CrO_4^{2-}

62. Assign oxidation states to each atom in each element, ion, or compound.
a. Cl_2 **b.** Fe^{3+} **c.** $CuCl_2$
d. CH_4 **e.** $Cr_2O_7^{2-}$ **f.** HSO_4^-

63. What is the oxidation state of Cr in each compound?
MISSED THIS? *Read Section 5.9; Watch IWE 5.13*
a. CrO **b.** CrO_3 **c.** Cr_2O_3

64. What is the oxidation state of Cl in each ion?
a. ClO^- **b.** ClO_2^- **c.** ClO_3^- **d.** ClO_4^-

65. Determine whether each reaction is a redox reaction. For each redox reaction, identify the oxidizing agent and the reducing agent. **MISSED THIS?** *Read Section 5.9*
a. $4\,Li(s) + O_2(g) \longrightarrow 2\,Li_2O(s)$
b. $Mg(s) + Fe^{2+}(aq) \longrightarrow Mg^{2+}(aq) + Fe(s)$
c. $Pb(NO_3)_2(aq) + Na_2SO_4(aq) \longrightarrow PbSO_4(s) + 2\,NaNO_3(aq)$
d. $HBr(aq) + KOH(aq) \longrightarrow H_2O(l) + KBr(aq)$

66. Determine whether each reaction is a redox reaction. For each redox reaction, identify the oxidizing agent and the reducing agent.
a. $Al(s) + 3\,Ag^+(aq) \longrightarrow Al^{3+}(aq) + 3\,Ag(s)$
b. $SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$
c. $Ba(s) + Cl_2(g) \longrightarrow BaCl_2(s)$
d. $Mg(s) + Br_2(l) \longrightarrow MgBr_2(s)$

67. Determine whether each redox reaction occurs spontaneously in the forward direction. **MISSED THIS?** *Read Section 5.9*
a. $Ni(s) + Zn^{2+}(aq) \longrightarrow Ni^{2+}(aq) + Zn(s)$
b. $Ni(s) + Pb^{2+}(aq) \longrightarrow Ni^{2+}(aq) + Pb(s)$
c. $Al(s) + 3\,Ag^+(aq) \longrightarrow Al^{3+}(aq) + 3\,Ag(s)$
d. $Pb(s) + Mn^{2+}(aq) \longrightarrow Pb^{2+}(aq) + Mn(s)$

68. Determine whether each redox reaction occurs spontaneously in the forward direction.
a. $Ca^{2+}(aq) + Zn(s) \longrightarrow Ca(s) + Zn^{2+}(aq)$
b. $2\,Ag^+(aq) + Ni(s) \longrightarrow 2\,Ag(s) + Ni^{2+}(aq)$
c. $Fe(s) + Mn^{2+}(aq) \longrightarrow Fe^{2+}(aq) + Mn(s)$
d. $2\,Al(s) + 3\,Pb^{2+}(aq) \longrightarrow 2\,Al^{3+}(aq) + 3\,Pb(s)$

69. Suppose you wanted to cause Ni^{2+} ions to come out of solution as solid Ni. Which metal could you use to accomplish this?
MISSED THIS? *Read Section 5.9*

70. Suppose you wanted to cause Pb^{2+} ions to come out of solution as solid Pb. Which metal could you use to accomplish this?

71. Which metal in the activity series reduces Al^{3+} ions but not Na^+ ions? **MISSED THIS?** *Read Section 5.9*

72. Which metal in the activity series is oxidized with a Ni^{2+} solution but not with a Cr^{3+} solution?

CUMULATIVE PROBLEMS

73. The density of a 20.0% by mass ethylene glycol ($C_2H_6O_2$) solution in water is 1.03 g/mL. Find the molarity of the solution.

74. Find the percent by mass of sodium chloride in a 1.35 M NaCl solution. The density of the solution is 1.05 g/mL.

75. People sometimes use sodium bicarbonate as an antacid to neutralize excess hydrochloric acid in an upset stomach. What mass of hydrochloric acid (in grams) can 2.5 g of sodium bicarbonate neutralize? (*Hint*: Begin by writing a balanced equation for the reaction between aqueous sodium bicarbonate and aqueous hydrochloric acid.)

76. Toilet bowl cleaners often contain hydrochloric acid, which dissolves the calcium carbonate deposits that accumulate within a toilet bowl. What mass of calcium carbonate (in grams) can 3.8 g of HCl dissolve? (*Hint*: Begin by writing a balanced equation for the reaction between hydrochloric acid and calcium carbonate.)

77. Predict the products and write a balanced molecular equation for each reaction. If no reaction occurs, write "NO REACTION."
a. $HCl(aq) + Hg_2(NO_3)_2(aq) \longrightarrow$
b. $KHSO_3(aq) + HNO_3(aq) \longrightarrow$
c. aqueous ammonium chloride and aqueous lead(II) nitrate
d. aqueous ammonium chloride and aqueous calcium hydroxide

78. Predict the products and write a balanced molecular equation for each reaction. If no reaction occurs, write "NO REACTION."
a. $H_2SO_4(aq) + HNO_3(aq) \longrightarrow$
b. $Cr(NO_3)_3(aq) + LiOH(aq) \longrightarrow$
c. aqueous strontium sulfide and aqueous copper(II) sulfate

79. Hard water often contains dissolved Ca^{2+} and Mg^{2+} ions. One way to soften water is to add phosphates. The phosphate ion forms insoluble precipitates with calcium and magnesium ions, removing them from solution. A solution is 0.050 M in calcium chloride and 0.085 M in magnesium nitrate. What mass of sodium phosphate would you add to 1.5 L of this solution to completely eliminate the hard water ions? Assume complete reaction.

80. An acid solution is 0.100 M in HCl and 0.200 M in H_2SO_4. What volume of a 0.150 M KOH solution would completely neutralize all the acid in 500.0 mL of this solution?

81. Find the mass of barium metal (in grams) that must react with O_2 to produce enough barium oxide to prepare 1.0 L of a 0.10 M solution of OH^-. (*Hint*: Barium metal reacts with oxygen to form BaO; BaO reacts with water to form $Ba(OH)_2$.)

82. A solution contains Cr^{3+} ions and Mg^{2+} ions. The addition of 1.00 L of 1.51 M NaF solution causes the complete precipitation of these ions as $CrF_3(s)$ and $MgF_2(s)$. The total mass of the precipitate is 49.6 g. Find the mass of Cr^{3+} in the original solution.

83. Treatment of gold metal with BrF_3 and KF produces Br_2 and $KAuF_4$, a salt of gold. Identify the oxidizing agent and the reducing agent in this reaction. Find the mass of the gold salt that forms when a 73.5-g mixture of equal masses of all three reactants is prepared.

84. We prepare a solution by mixing 0.10 L of 0.12 M sodium chloride with 0.23 L of a 0.18 M $MgCl_2$ solution. What volume of a 0.20 M silver nitrate solution do we need to precipitate all the Cl^- ion in the solution as AgCl?

85. A solution contains one or more of the following ions: Ag^+, Ca^{2+}, and Cu^{2+}. When you add sodium chloride to the solution, no precipitate forms. When you add sodium sulfate to the solution, a white precipitate forms. You filter off the precipitate and add sodium carbonate to the remaining solution, producing another precipitate. Which ions were present in the original solution? Write net ionic equations for the formation of each of the precipitates observed.

86. A solution contains one or more of the following ions: Hg_2^{2+}, Ba^{2+}, and Fe^{2+}. When you add potassium chloride to the solution, a precipitate forms. The precipitate is filtered off, and you add potassium sulfate to the remaining solution, producing no precipitate. When you add potassium carbonate to the remaining solution, a precipitate forms. Which ions were present in the original solution? Write net ionic equations for the formation of each of the precipitates observed.

CHALLENGE PROBLEMS

87. A solution contains Ag^+ and Hg^{2+} ions. The addition of 0.100 L of 1.22 M NaI solution is just enough to precipitate all the ions as AgI and HgI_2. The total mass of the precipitate is 28.1 g. Find the mass of AgI in the precipitate.

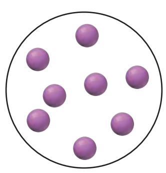
88. The water in lakes that have been acidified by acid rain (HNO_3 and H_2SO_4) can be neutralized by a process called liming, in which limestone ($CaCO_3$) is added to the acidified water. What mass of limestone (in kg) would completely neutralize a 15.2 billion-liter lake that is 1.8×10^{-5} M in H_2SO_4 and 8.7×10^{-6} M in HNO_3?

89. Sodium carbonate is often added to laundry detergents to soften hard water and make the detergent more effective. Suppose that a particular detergent mixture is designed to soften hard water that is 3.5×10^{-3} M in Ca^{2+} and 1.1×10^{-3} M in Mg^{2+} and that the average capacity of a washing machine is 19.5 gallons of water. If the detergent requires using 0.65 kg detergent per load of laundry, what percentage (by mass) of the detergent should be sodium carbonate in order to completely precipitate all of the calcium and magnesium ions in an average load of laundry water?

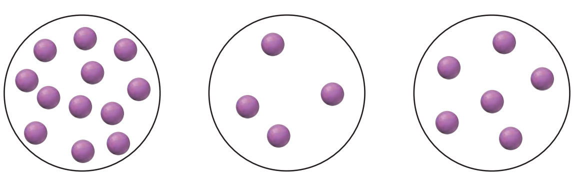
90. Lead poisoning is a serious condition resulting from the ingestion of lead in food, water, or other environmental sources. It affects the central nervous system, leading to a variety of symptoms such as distractibility, lethargy, and loss of motor coordination. Lead poisoning is treated with chelating 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 1 mol of succimer binds 1 mol of lead.

CONCEPTUAL PROBLEMS

91. The following circle represents 1.0 liter of a solution with a solute concentration of 1 M:



Explain what you would add (the amount of solute or volume of solvent) to the solution to obtain a solution represented by each diagram:

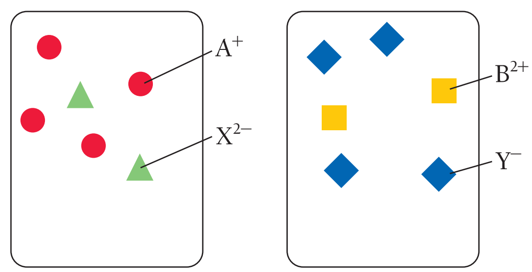


a. b. c.

92. Consider the generic ionic compounds with the formulas A_2X and BY_2 and the following solubility rules:

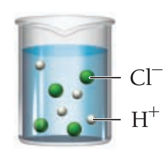
A_2X soluble; BY_2 soluble; AY insoluble; BX soluble.

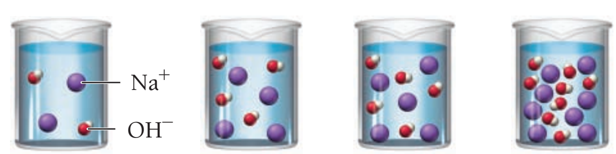
Assume A^+ ions are circles, B^{2+} ions are squares, X^{2-} ions are triangles, and Y^- ions are diamonds. Solutions of the two compounds (A_2X and BY_2) are represented as follows:



Draw a molecular-level representation showing the result of mixing the two given solutions and write an equation to represent the reaction.

93. A hydrochloric acid solution will neutralize a sodium hydroxide solution. Look at the molecular views showing one beaker of HCl and four beakers of NaOH. Which NaOH beaker will just neutralize the HCl beaker? Begin by writing a balanced chemical equation for the neutralization reaction.





a. b. c. d.

QUESTIONS FOR GROUP WORK

Active Classroom Learning

94. Write a detailed set of instructions for making two solutions: (1) 100 mL of 12 M NaOH from solid sodium hydroxide and (2) 1.00 L of 0.1 M NaOH from your first solution. You have in your lab: volumetric flasks marked to contain 100.0 mL and 1.000 L, a graduated cylinder, and a balance.

95. Review the solubility rules. Without referring back to the rules, have each group member list two ionic compounds that are expected to be soluble and two that are expected to be insoluble. Include at least one exception. Check the work of the other members of your group.

96. Define and give an example of each of the following classes of reactions: precipitation, acid–base, gas-evolution, and redox. Each group member can do one, and then present his or her reaction to the group.

97. Using group members to represent atoms, ions, or electrons, act out the reaction $Zn(s) + Fe^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Fe(s)$. Which group member is oxidized? Which is reduced? Which is the oxidizing agent? Which is the reducing agent?

DATA INTERPRETATION AND ANALYSIS

The Flint, Michigan Water Crisis

98. In April of 2014, in an effort to save money, officials in Flint, Michigan, changed their water source from Lake Huron to the Flint River. In subsequent months, residents began complaining about the quality of the water, and General Motors stopped using the water in manufacturing processes because of its corrosiveness. That corrosiveness was causing problems that would soon fuel a national outrage. The water flowed through pipes to taps in homes, and as it flowed through the pipes—many of which contained lead—the corrosive water became contaminated with lead. Routine monitoring of the tap water in select homes did not reveal the magnitude of the problem because samples were collected only after preflushing the tap (allowing the water to run for a time). A Virginia Tech professor and his students began an independent test of the water coming from Flint's taps and got much different results by analyzing the water that initially came from the taps (called 1st draw). Their results—which showed elevated lead levels in the tap water—ultimately forced officials to switch back to the Lake Huron water source.

The table below shows a set of data collected by the Virginia Tech team. The lead levels in water are expressed in units of part per billion (ppb). 1 ppb = 1 g Pb/10^9 parts solution. Examine the data and answer the questions that follow.

Sample #	Lead Level 1st draw (ppb)	Lead Level 45 sec flush (ppb)	Lead Level 2 min flush (ppb)
1	0.344	0.226	0.145
2	8.133	10.77	2.761
3	1.111	0.11	0.123
4	8.007	7.446	3.384
5	1.951	0.048	0.035
6	7.2	1.4	0.2
7	40.63	9.726	6.132
8	1.1	2.5	0.1
9	10.6	1.038	1.294
10	6.2	4.2	2.3
11	4.358	0.822	0.147
12	24.37	8.796	4.347
13	6.609	5.752	1.433
14	4.062	1.099	1.085
15	29.59	3.258	1.843

Source: FlintWaterStudy.org (2015) "Lead Results from Tap Water Sampling in Flint, MI during the Flint Water Crisis"

a. Determine the average value of lead for 1st draw, 45-second flush, and 2-minute flush (round to three significant figures).

b. Does the data support the idea that running the tap water before taking a sample made the lead levels in the water appear lower? Why might this occur?

c. The EPA requires water providers to monitor drinking water at customer taps. If lead concentrations exceed 15 ppb in 10% or more of the taps sampled, the water provider must notify the customer and take steps to control the corrosiveness of the water. If the water provider in Flint had used 1st-draw samples to monitor lead levels, would they have been required to take action by EPA requirements? If the Flint water provider used 2-min flush samples, would they have had to take action? Which drawing technique do you think more closely mimics the way residents actually use their water?

d. Using the highest value of lead from the 1st-draw data set, and assuming a resident drinks 2 L of water per day, calculate the mass of lead that the resident would consume over the course of 1 year. (Assume the water has a density of 1.0 g/mL.)

Cc ANSWERS TO CONCEPTUAL CONNECTIONS

Molarity

5.1 **(d)** $3.0\,\cancel{L} \times \frac{2.0\text{ mol}}{\cancel{L}} = 6.0\text{ mol}$

Solutions

5.2 **(b)** The mass of a solution is equal to the mass of the solute plus the mass of the solvent. Although the solute seems to disappear, it really does not, and its mass becomes part of the mass of the solution, in accordance with the law of mass conservation.

Solution Dilution

5.3 **(c)** Since the volume has doubled, the concentration is halved, so the same volume should contain half as many solute molecules.

Solution Stoichiometry

5.4 **(a)** A is the limiting reactant. You have equal amounts of both reactants, but the reaction requires twice as much of A as B.

Electrolyte Solutions

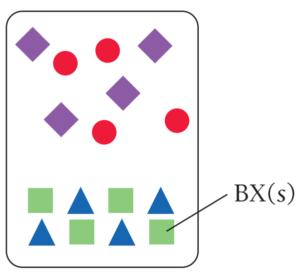
5.5 **(a)** KBr is an ionic compound and a strong electrolyte.

Solubility of Ionic Compounds

5.6 **(c)** Compounds containing the NO_3^- ion are soluble with no exceptions.

Precipitation Reactions

5.7 **(c)**



$$AX(aq) + BY(aq) \longrightarrow BX(s) + AY(aq)$$

Spectator Ions

5.8 **(b)** NO_3^- does not participate in the reaction and is therefore a spectator ion.

Acid–Base Titration

5.9 **(b)** The endpoint occurs when moles of added OH^- equals moles of H^+ in the solution. The solution contains 0.0020 mol H^+, and 20.0 mL of 0.10 M NaOH only contains 0.0020 mol OH^-.

Oxidation Numbers in Polyatomic Ions

5.10 **(a)** The charge of a polyatomic ion is the charge associated with the ion *as a whole*. The oxidation states of the individual atoms must sum to the charge of the ion, but they are assigned to *the individual atoms themselves*. Answer **(b)** is incorrect because oxidation state and charge *are not identical*, even though the charge of a *monoatomic* ion is equal to its oxidation state. Answer **(c)** is incorrect because charge *is* a physical property of ions. Conversely, the oxidation states of atoms are *not* real physical properties but an imposed electron bookkeeping scheme.

Oxidation and Reduction

5.11 **(d)** Since oxidation and reduction must occur together, an increase in the oxidation state of a reactant is always accompanied by a decrease in the oxidation state of another reactant.

Activity Series

5.12 **(a)** Sodium is highest on the activity series and therefore most easily oxidized.