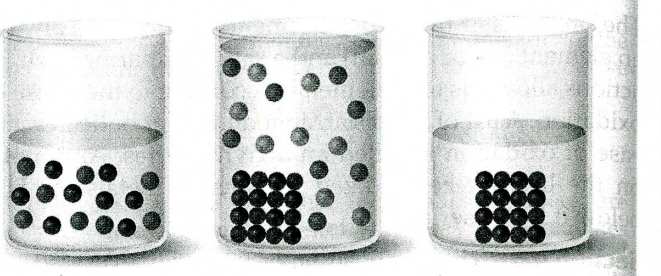
4.10 CQ Which of the three solutions shown schematically to the right corresponds to the result of each of the following reactions: (Water molecules are excluded for clarity) [Section 4.3]

(a) $Ag_2O(s) + 2\,HCl(aq) \longrightarrow 2\,AgCl(s) + H_2O(l)$
(b) $NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$
(c) $AgNO_3(aq) + KCl(aq) \longrightarrow AgCl(s) + KCl(aq)$



(i) (ii) (iii)

EXERCISES

Electrolytes

4.11 CQ When asked what causes electrolyte solutions to conduct electricity, a student responds that it is due to the movement of electrons through the solution. Is the student correct? If not, what is the correct response?

4.12 CQ When methanol, CH_3OH, is dissolved in water, a nonconducting solution results. When acetic acid, $HC_2H_3O_2$, dissolves in water, the solution is weakly conducting and acidic in nature. Describe what happens upon dissolution in the two cases, and account for the different results.

4.13 CQ We have learned in this chapter that many ionic solids dissolve in water as strong electrolytes, that is, as separated ions in solution. What properties of water facilitate this process?

4.14 CQ What does it mean to say that ions are hydrated when an ionic substance dissolves in water?

4.15 Specify what ions are present in solution upon dissolving each of the following substances in water: **(a)** $ZnCl_2$, **(b)** HNO_3, **(c)** $(NH_4)_2SO_4$, **(d)** $Ca(OH)_2$.

4.16 Specify what ions are present upon dissolving each of the following substances in water: **(a)** MgI_2, **(b)** $Al(NO_3)_3$, **(c)** $HClO_4$, **(d)** $KC_2H_3O_2$.

4.17 Formic acid, $HCHO_2$, is a weak electrolyte. What solute particles are present in an aqueous solution of this compound? Write the chemical equation for the ionization of $HCHO_2$.

4.18 CQ Acetone, CH_3COCH_3, is a nonelectrolyte; hypochlorous acid, HClO, is a weak electrolyte; and ammonium chloride, NH_4Cl, is a strong electrolyte. **(a)** What are the solute particles present in aqueous solutions of each compound? **(b)** If 0.1 mol of each compound is dissolved in solution, which one contains 0.2 mol of solute particles, which contains 0.1 mol of solute particles, and which contains somewhere between 0.1 and 0.2 mol of solute particles?

Precipitation Reactions and Net Ionic Equations

4.19 Using solubility guidelines, predict whether each of the following compounds is soluble or insoluble in water: **(a)** $NiCl_2$, **(b)** Ag_2S, **(c)** Cs_3PO_4, **(d)** $SrCO_3$, **(e)** $PbSO_4$.

4.20 Predict whether each of the following compounds is soluble in water: **(a)** $Ni(OH)_2$, **(b)** $PbBr_2$, **(c)** $Ba(NO_3)_2$, **(d)** $AlPO_4$, **(e)** $AgC_2H_3O_2$.

4.21 CQ Will precipitation occur when the following solutions are mixed? If so, write a balanced chemical equation for the reaction. **(a)** Na_2CO_3 and $AgNO_3$, **(b)** $NaNO_3$ and $NiSO_4$, **(c)** $FeSO_4$ and $Pb(NO_3)_2$.

4.22 CQ Identify the precipitate (if any) that forms when the following solutions are mixed, and write a balanced equation for each reaction. **(a)** $Ni(NO_3)_2$ and NaOH, **(b)** NaOH and K_2SO_4, **(c)** Na_2S and $Cu(C_2H_3O_2)_2$.

4.23 Name the spectator ions in any reactions that may be involved when each of the following pairs of solutions are mixed.

(a) $Na_2CO_3(aq)$ and $MgSO_4(aq)$
(b) $Pb(NO_3)_2(aq)$ and $Na_2S(aq)$
(c) $(NH_4)_3PO_4(aq)$ and $CaCl_2(aq)$

4.24 Write balanced net ionic equations for the reactions that occur in each of the following cases. Identify the spectator ion or ions in each reaction.

(a) $Cr_2(SO_4)_3(aq) + (NH_4)_2CO_3(aq) \longrightarrow$
(b) $Ba(NO_3)_2(aq) + K_2SO_4(aq) \longrightarrow$
(c) $Fe(NO_3)_2(aq) + KOH(aq) \longrightarrow$

4.25 CQ Separate samples of a solution of an unknown salt are treated with dilute solutions of HBr, H_2SO_4, and NaOH. A precipitate forms in all three cases. Which of the following cations could the solution contain: K^+; Pb^{2+}; Ba^{2+}?

4.26 CQ Separate samples of a solution of an unknown ionic compound are treated with dilute $AgNO_3$, $Pb(NO_3)_2$, and $BaCl_2$. Precipitates form in all three cases. Which of the following could be the anion of the unknown salt: Br^-; CO_3^{2-}; NO_3^-?

4.27 CQ You know that an unlabeled bottle contains a solution of one of the following: $AgNO_3$, $CaCl_2$, or $Al_2(SO_4)_3$. A friend suggests that you test a portion of the solution with $Ba(NO_3)_2$ and then with NaCl solutions. Explain how these two tests together would be sufficient to determine which salt is present in the solution.

4.28 CQ Three solutions are mixed together to form a single solution. One contains 0.2 mol $Pb(C_2H_3O_2)_2$, the second contains 0.1 mol Na_2S, and the third contains 0.1 mol $CaCl_2$. **(a)** Write the net ionic equations for the precipitation reaction or reactions that occur. **(b)** What are the spectator ions in the solution?

Acid-Base Reactions

4.29 Which of the following solutions has the largest concentration of solvated protons: **(a)** 0.1 *M* LiOH, **(b)** 0.1 *M* HI, **(c)** 0.5 *M* methyl alcohol (CH_3OH)? Explain.

4.30 Which of the following solutions is the most basic? **(a)** 0.5 *M* NH_3, **(b)** 0.1 *M* KOH, **(c)** 0.1 *M* $Ca(OH)_2$. Explain.

4.31 **CQ** What is the difference between **(a)** a monoprotic acid and a diprotic acid, **(b)** a weak acid and a strong acid, **(c)** an acid and a base?

4.32 **CQ** Explain the following observations: **(a)** NH_3 contains no OH^- ions, and yet its aqueous solutions are basic; **(b)** HF is called a weak acid, and yet it is very reactive; **(c)** although sulfuric acid is a strong electrolyte, an aqueous solution of H_2SO_4 contains more HSO_4^- ions than SO_4^{2-} ions.

4.33 **CQ** It is said that $HClO_4$ is a strong acid, whereas $HClO_2$ is a weak acid. What does this mean in terms of the extent to which the two substances are ionized in solution?

4.34 **CQ** What is the relationship between the solubility rules in Table 4.1 and the list of strong bases in Table 4.2? Another way of asking this question is, why is $Cd(OH)_2$, for example, not listed as a strong base in Table 4.2?

4.35 Label each of the following substances as an acid, base, salt, or none of the above. Indicate whether the substance exists in aqueous solution entirely in molecular form, entirely as ions, or as a mixture of molecules and ions. **(a)** HF; **(b)** acetonitrile, CH_3CN; **(c)** $NaClO_4$; **(d)** $Ba(OH)_2$.

4.36 **CQ** An aqueous solution of an unknown solute is tested with litmus paper and found to be acidic. The solution is weakly conducting compared with a solution of NaCl of the same concentration. Which of the following substances could the unknown be: KOH, NH_3, HNO_3, $KClO_2$, H_3PO_3, CH_3COCH_3 (acetone)?

4.37 Classify each of the following substances as a nonelectrolyte, weak electrolyte, or strong electrolyte in water: **(a)** H_2SO_3, **(b)** C_2H_5OH (ethanol), **(c)** NH_3, **(d)** $KClO_3$, **(e)** $Cu(NO_3)_2$.

4.38 Classify each of the following aqueous solutions as a nonelectrolyte, weak electrolyte, or strong electrolyte: **(a)** $HClO_4$, **(b)** HNO_3, **(c)** NH_4Cl, **(d)** CH_3COCH_3 (acetone), **(e)** $CoSO_4$, **(f)** $C_{12}H_{22}O_{11}$ (sucrose).

4.39 Complete and balance the following molecular equations, and then write the net ionic equation for each:
(a) $HBr(aq) + Ca(OH)_2(aq) \longrightarrow$
(b) $Cu(OH)_2(s) + HClO_4(aq) \longrightarrow$
(c) $Al(OH)_3(s) + HNO_3(aq) \longrightarrow$

4.40 Write the balanced molecular and net ionic equations for each of the following neutralization reactions:
(a) Aqueous acetic acid is neutralized by aqueous potassium hydroxide.
(b) Solid chromium(III) hydroxide reacts with nitric acid.
(c) Aqueous hypochlorous acid and aqueous calcium hydroxide react.

4.41 Write balanced molecular and net ionic equations for the following reactions, and identify the gas formed in each: **(a)** solid cadmium sulfide reacts with an aqueous solution of sulfuric acid; **(b)** solid magnesium carbonate reacts with an aqueous solution of perchloric acid.

4.42 Because the oxide ion is basic, metal oxides react readily with acids. **(a)** Write the net ionic equation for the following reaction:

$$FeO(s) + 2\,HClO_4(aq) \longrightarrow Fe(ClO_4)_2(aq) + H_2O(l).$$

(b) Based on the equation in part (a), write the net ionic equation for the reaction that occurs between NiO(s) and an aqueous solution of nitric acid.

4.43 Write a balanced molecular equation and a net ionic equation for the reaction that occurs when **(a)** solid $CaCO_3$ reacts with an aqueous solution of nitric acid; **(b)** solid iron(II) sulfide reacts with an aqueous solution of hydrobromic acid.

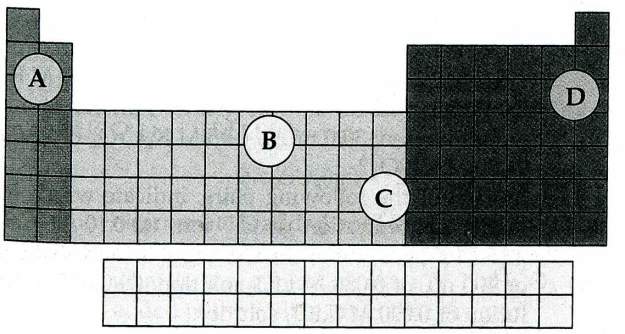
4.44 As K_2O dissolves in water, the oxide ion reacts with water molecules to form hydroxide ions. Write the molecular and net ionic equations for this reaction. Based on the definitions of acid and base, what ion is the base in this reaction? What is the acid? What is the spectator ion in the reaction?

Oxidation-Reduction Reactions

4.45 Define oxidation and reduction in terms of **(a)** electron transfer and **(b)** oxidation numbers.

4.46 Can oxidation occur without accompanying reduction? Explain.

4.47 **CQ** Which circled region of the periodic table shown here contains the most readily oxidized elements? Which contains the least readily oxidized?



4.48 **CQ** From the elements listed in Table 4.5, select an element that lies in region A of the periodic table shown to the left and an element that lies in region C. Write a balanced oxidation-reduction equation that shows the oxidation of one metal and reduction of an ion of the other. You will need to decide which element is oxidized and which is reduced.

4.49 Determine the oxidation number for the indicated element in each of the following substances: **(a)** S in SO_2, **(b)** C in $COCl_2$, **(c)** Mn in MnO_4^-, **(d)** Br in HBrO, **(e)** As in As_4, **(f)** O in K_2O_2.

4.50 Determine the oxidation number for the indicated element in each of the following compounds: **(a)** Ti in TiO_2, **(b)** Sn in $SnCl_3^-$, **(c)** C in $C_2O_4^{2-}$, **(d)** N in N_2H_4, **(e)** N in HNO_2, **(f)** Cr in $Cr_2O_7^{2-}$.

4.51 Which element is oxidized and which is reduced in the following reactions?
(a) $Ni(s) + Cl_2(g) \longrightarrow NiCl_2(s)$
(b) $3\,Fe(NO_3)_2(aq) + 2\,Al(s) \longrightarrow 3\,Fe(s) + 2\,Al(NO_3)_3(aq)$

(c) $Cl_2(aq) + 2\,NaI(aq) \longrightarrow I_2(aq) + 2\,NaCl(aq)$
(d) $PbS(s) + 4\,H_2O_2(aq) \longrightarrow PbSO_4(s) + 4\,H_2O(l)$

4.52 Which of the following are redox reactions? For those that are, indicate which element is oxidized and which is reduced. For those that are not, indicate whether they are precipitation or acid-base reactions.
(a) $Cu(OH)_2(s) + 2\,HNO_3(aq) \longrightarrow Cu(NO_3)_2(aq) + 2\,H_2O(l)$
(b) $Fe_2O_3(s) + 3\,CO(g) \longrightarrow 2\,Fe(s) + 3\,CO_2(g)$
(c) $Sr(NO_3)_2(aq) + H_2SO_4(aq) \longrightarrow SrSO_4(s) + 2\,HNO_3(aq)$
(d) $4\,Zn(s) + 10\,H^+(aq) + 2\,NO_3^-(aq) \longrightarrow 4\,Zn^{2+}(aq) + N_2O(g) + 5\,H_2O(l)$

4.53 Write balanced molecular and net ionic equations for the reactions of **(a)** manganese with dilute sulfuric acid; **(b)** chromium with hydrobromic acid; **(c)** tin with hydrochloric acid; **(d)** aluminum with formic acid, $HCHO_2$.

4.54 Write balanced molecular and net ionic equations for the reactions of **(a)** hydrochloric acid with nickel; **(b)** dilute sulfuric acid with iron; **(c)** hydrobromic acid with magnesium; **(d)** acetic acid, $HC_2H_3O_2$, with zinc.

4.55 **CQ** Using the activity series (Table 4.5), write balanced chemical equations for the following reactions. If no reaction occurs, simply write NR. **(a)** Iron metal is added to a solution of copper(II) nitrate; **(b)** zinc metal is added to a solution of magnesium sulfate; **(c)** hydrobromic acid is added to tin metal; **(d)** hydrogen gas is bubbled through an aqueous solution of nickel(II) chloride; **(e)** aluminum metal is added to a solution of cobalt(II) sulfate.

4.56 **CQ** Based on the activity series (Table 4.5), what is the outcome (if any) of each of the following reactions?
(a) $Mn(s) + NiCl_2(aq) \longrightarrow$
(b) $Cu(s) + Cr(C_2H_3O_2)_3(aq) \longrightarrow$
(c) $Cr(s) + NiSO_4(aq) \longrightarrow$
(d) $Pt(s) + HBr(aq) \longrightarrow$
(e) $H_2(g) + CuCl_2(aq) \longrightarrow$

4.57 **CQ** The metal cadmium tends to form Cd^{2+} ions. The following observations are made: (i) When a strip of zinc metal is placed in $CdCl_2(aq)$, cadmium metal is deposited on the strip. (ii) When a strip of cadmium metal is placed in $Ni(NO_3)_2(aq)$, nickel metal is deposited on the strip. **(a)** Write net ionic equations to explain each of the observations made above. **(b)** What can you conclude about the position of cadmium in the activity series? **(c)** What experiments would you need to perform to locate more precisely the position of cadmium in the activity series?

4.58 **CQ** **(a)** Use the following reactions to prepare an activity series for the halogens:

$$Br_2(aq) + 2\,NaI(aq) \longrightarrow 2\,NaBr(aq) + I_2(aq);$$

$$Cl_2(aq) + 2\,NaBr(aq) \longrightarrow 2\,NaCl(aq) + Br_2(aq).$$

(b) Relate the positions of the halogens in the periodic table with their locations in this activity series. **(c)** Predict whether a reaction occurs when the following reagents are mixed: $Cl_2(aq)$ and $KI(aq)$; $Br_2(aq)$ and $LiCl(aq)$.

Solution Composition; Molarity

4.59 **CQ** **(a)** Is the concentration of a solution an intensive or an extensive property? **(b)** What is the difference between 0.50 mol HCl and 0.50 *M* HCl?

4.60 **CQ** **(a)** Suppose you prepare 500 mL of a 0.10 *M* solution of some salt and then spill some of it. What happens to the concentration of the solution left in the container? **(b)** A certain volume of a 0.50 *M* solution contains 4.5 g of a salt. What mass of the salt is present in the same volume of a 2.50 *M* solution?

4.61 **(a)** Calculate the molarity of a solution that contains 0.0345 mol NH_4Cl in exactly 400 mL of solution. **(b)** How many moles of HNO_3 are present in 35.0 mL of a 2.20 *M* solution of nitric acid? **(c)** How many milliliters of 1.50 *M* KOH solution are needed to provide 0.125 mol of KOH?

4.62 **(a)** Calculate the molarity of a solution made by dissolving 0.145 mol Na_2SO_4 in enough water to form exactly 750 mL of solution. **(b)** How many moles of $KMnO_4$ are present in 125 mL of a 0.0850 *M* solution? **(c)** How many milliliters of 11.6 *M* HCl solution are needed to obtain 0.255 mol of HCl?

4.63 The average adult human male has a total blood volume of 5.0 L. If the concentration of sodium ion in this average individual is 0.135 *M*, what is the mass of sodium ion circulating in the blood?

4.64 A person suffering from hyponatremia has a sodium ion concentration in the blood of 0.118 *M* and a total blood volume of 4.6 L. What mass of sodium chloride would need to be added to the blood to bring the sodium ion concentration up to 0.138 *M*, assuming no change in blood volume?

4.65 Calculate **(a)** the number of grams of solute in 0.250 L of 0.150 *M* KBr, **(b)** the molar concentration of a solution containing 4.75 g of $Ca(NO_3)_2$ in 0.200 L, **(c)** the volume of 1.50 *M* Na_3PO_4 in milliliters that contains 5.00 g of solute.

4.66 **(a)** How many grams of solute are present in 50.0 mL of 0.360 *M* $K_2Cr_2O_7$? **(b)** If 4.28 g of $(NH_4)_2SO_4$ is dissolved in enough water to form 300 mL of solution, what is the molarity of the solution? **(c)** How many milliliters of 0.240 *M* $CuSO_4$ contain 2.25 g of solute?

4.67 **(a)** Which will have the highest concentration of potassium ion: 0.20 *M* KCl, 0.15 *M* K_2CrO_4, or 0.080 *M* K_3PO_4? **(b)** Which will contain the greater number of moles of potassium ion: 30.0 mL of 0.15 M K_2CrO_4 or 25.0 mL of 0.080 *M* K_3PO_4?

4.68 In each of the following pairs, indicate which has the higher concentration of Cl^- ion: **(a)** 0.10 *M* $CaCl_2$ or 0.15 *M* KCl solution, **(b)** 100 mL of 0.10 *M* KCl solution or 400 mL of 0.080 *M* LiCl solution, **(c)** 0.050 *M* HCl solution or 0.020 *M* $CdCl_2$ solution.

4.69 Indicate the concentration of each ion or molecule present in the following solutions: **(a)** 0.22 *M* NaOH, **(b)** 0.16 *M* $CaBr_2$, **(c)** 0.15 *M* CH_3OH, **(d)** a mixture of 40.0 mL of 0.15 *M* $KClO_3$ and 35.0 mL of 0.22 *M* Na_2SO_4. Assume the volumes are additive.

4.70 Indicate the concentration of each ion present in the solution formed by mixing **(a)** 16.0 mL of 0.130 *M* HCl and 12.0 mL of 0.600 *M* HCl, **(b)** 18.0 mL of 0.200 *M* Na_2SO_4 and 15.0 mL of 0.150 *M* KCl, **(c)** 2.38 g of NaCl in 50.0 mL of 0.400 *M* $CaCl_2$ solution. (Assume that the volumes are additive.)

4.71 **(a)** You have a stock solution of 14.8 *M* NH_3. How many milliliters of this solution should you dilute to make 100.0 mL of 0.250 *M* NH_3? **(b)** If you take a 10.0-mL portion of the stock solution and dilute it to a total volume of 0.250 L, what will be the concentration of the final solution?

4.72 **(a)** How many milliliters of a stock solution of 10.0 *M* HNO_3 would you have to use to prepare 0.350 L of 0.400 *M* HNO_3? **(b)** If you dilute 25.0 mL of the stock solution to a final volume of 0.500 L, what will be the concentration of the diluted solution?

4.73 **(a)** Starting with solid sucrose, $C_{12}H_{22}O_{11}$, describe how you would prepare 125 mL of 0.150 *M* sucrose solution. **(b)** Describe how you would prepare 400.0 mL of 0.100 *M* $C_{12}H_{22}O_{11}$ starting with 2.00 L of 1.50 *M* $C_{12}H_{22}O_{11}$.

4.74 **(a)** How would you prepare 250.0 mL of 0.150 *M* $AgNO_3$ solution starting with pure solute? **(b)** An experiment calls for you to use 100 mL of 0.50 *M* HNO_3 solution. All you have available is a bottle of 6.0 *M* HNO_3. How would you prepare the desired solution?

[4.75] Pure acetic acid, known as glacial acetic acid, is a liquid with a density of 1.049 g/mL at 25°C. Calculate the molarity of a solution of acetic acid made by dissolving 20.00 mL of glacial acetic acid at 25°C in enough water to make 250.0 mL of solution.

[4.76] Glycerol, $C_3H_8O_3$, is a substance used extensively in the manufacture of cosmetics, foodstuffs, antifreeze, and plastics. Glycerol is a water-soluble liquid with a density of 1.2656 g/L at 15°C. Calculate the molarity of a solution of glycerol made by dissolving 50.000 mL glycerol at 15°C in enough water to make 250.00 mL of solution.

Solution Stoichiometry; Titrations

4.77 What mass of NaCl is needed to precipitate the silver ions from 20.0 mL of 0.100 *M* $AgNO_3$ solution?

4.78 What mass of NaOH is needed to precipitate the Cd^{2+} ions from 25.0 mL of 0.500 *M* $Cd(NO_3)_2$ solution?

4.79 **(a)** What volume of 0.115 *M* $HClO_4$ solution is needed to neutralize 50.00 mL of 0.0875 *M* NaOH? **(b)** What volume of 0.128 *M* HCl is needed to neutralize 2.87 g of $Mg(OH)_2$? **(c)** If 25.8 mL of $AgNO_3$ is needed to precipitate all the Cl^- ions in a 785-mg sample of KCl (forming AgCl), what is the molarity of the $AgNO_3$ solution? **(d)** If 45.3 mL of 0.108 *M* HCl solution is needed to neutralize a solution of KOH, how many grams of KOH must be present in the solution?

4.80 **(a)** How many milliliters of 0.120 *M* HCl are needed to completely neutralize 50.0 mL of 0.101 *M* $Ba(OH)_2$ solution? **(b)** How many milliliters of 0.125 *M* H_2SO_4 are needed to neutralize 0.200 g of NaOH? **(c)** If 55.8 mL of $BaCl_2$ solution is needed to precipitate all the sulfate ion in a 752-mg sample of Na_2SO_4, what is the molarity of the solution? **(d)** If 42.7 mL of 0.208 *M* HCl solution is needed to neutralize a solution of $Ca(OH)_2$, how many grams of $Ca(OH)_2$ must be in the solution?

4.81 Some sulfuric acid is spilled on a lab bench. It can be neutralized by sprinkling sodium bicarbonate on it and then mopping up the resultant solution. The sodium bicarbonate reacts with sulfuric acid as follows:

$$2\,NaHCO_3(s) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2\,H_2O(l) + 2\,CO_2(g)$$

Sodium bicarbonate is added until the fizzing due to the formation of $CO_2(g)$ stops. If 27 mL of 6.0*M* H_2SO_4 was spilled, what is the minimum mass of $NaHCO_3$ that must be added to the spill to neutralize the acid?

4.82 The distinctive odor of vinegar is due to acetic acid, $HC_2H_3O_2$, which reacts with sodium hydroxide in the following fashion:

$$HC_2H_3O_2(aq) + NaOH(aq) \longrightarrow H_2O(l) + NaC_2H_3O_2(aq)$$

If 3.45 mL of vinegar needs 42.5 mL of 0.115 *M* NaOH to reach the equivalence point in a titration, how many grams of acetic acid are in a 1.00-qt sample of this vinegar?

4.83 A sample of solid $Ca(OH)_2$ is stirred in water at 30°C until the solution contains as much dissolved $Ca(OH)_2$ as it can hold. A 100-mL sample of this solution is withdrawn and titrated with 5.00×10^{-2} *M* HBr. It requires 48.8 mL of the acid solution for neutralization. What is the molarity of the $Ca(OH)_2$ solution? What is the solubility of $Ca(OH)_2$ in water, at 30°C in grams of $Ca(OH)_2$ per 100 mL of solution?

4.84 In the laboratory 6.82 g of $Sr(NO_3)_2$ is dissolved in enough water to form 0.500 L. A 0.100-L sample is withdrawn from this stock solution and titrated with a 0.0335 *M* solution of Na_2CrO_4. What volume of Na_2CrO_4 solution is needed to precipitate all the $Sr^{2+}(aq)$ as $SrCrO_4$?

4.85 A solution of 100.0 mL of 0.200 *M* KOH is mixed with a solution of 200.0 mL of 0.150 *M* $NiSO_4$. **(a)** Write the balanced chemical equation for the reaction that occurs. **(b)** What precipitate forms? **(c)** What is the limiting reactant? **(d)** How many grams of this precipitate form? **(e)** What is the concentration of each ion that remains in solution?

4.86 A solution is made by mixing 12.0 g of NaOH and 75.0 mL of 0.200 *M* HNO_3. **(a)** Write a balanced equation for the reaction that occurs between the solutes. **(b)** Calculate the concentration of each ion remaining in solution. **(c)** Is the resultant solution acidic or basic?

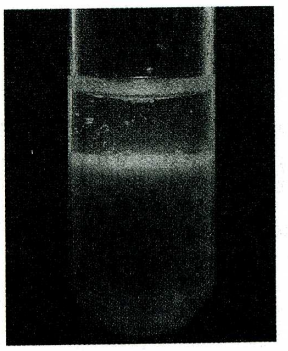
[4.87] A 0.5895-g sample of impure magnesium hydroxide is dissolved in 100.0 mL of 0.2050 *M* HCl solution. The excess acid then needs 19.85 mL of 0.1020 *M* NaOH for neutralization. Calculate the percent by mass of magnesium hydroxide in the sample, assuming that it is the only substance reacting with the HCl solution.

[4.88] A 1.248-g sample of limestone rock is pulverized and then treated with 30.00 mL of 1.035 *M* HCl solution. The excess acid then requires 11.56 mL of 1.010 *M* NaOH for neutralization. Calculate the percent by mass of calcium carbonate in the rock, assuming that it is the only substance reacting with the HCl solution.

Additional Exercises

[4.89] **CQ** Suppose it were possible to instantaneously form a solution of uniformly dispersed K^+ and Br^- ions in a solvent such as mineral oil. What would you expect to occur? How does this compare with what would happen if the same uniform dispersion of ions were formed in water? How do you account for the difference?

4.90 The accompanying photo shows the reaction between a solution of $Cd(NO_3)_2$ and one of Na_2S. What is the identity of the precipitate? What ions remain in solution? Write the net ionic equation for the reaction.



4.91 **CQ** Suppose you have a solution that might contain any or all of the following cations: Ni^{2+}, Ag^+, Sr^{2+}, and Mn^{2+}. Addition of HCl solution causes a precipitate to form. After filtering off the precipitate, H_2SO_4 solution is added to the resultant solution and another precipitate forms. This is filtered off, and a solution of NaOH is added to the resulting solution. No precipitate is observed. Which ions are present in each of the precipitates? Which of the four ions listed above must be absent from the original solution?

4.92 **CQ** You choose to investigate some of the solubility guidelines for two ions not listed in Table 4.1, the chromate ion (CrO_4^{2-}) and the oxalate ion ($C_2O_4^{2-}$). You are given 0.01 *M* solutions (A, B, C, D) of four water-soluble salts:

Solution	Solute	Color of Solution
A	Na_2CrO_4	Yellow
B	$(NH_4)_2C_2O_4$	Colorless
C	$AgNO_3$	Colorless
D	$CaCl_2$	Colorless

When these solutions are mixed, the following observations are made:

Expt Number	Solutions Mixed	Result
1	A + B	No precipitate, yellow solution
2	A + C	Red precipitate forms
3	A + D	No precipitate, yellow solution
4	B + C	White precipitate forms
5	B + D	White precipitate forms
6	C + D	White precipitate forms

(a) Write a net ionic equation for the reaction that occurs in each of the experiments. **(b)** Identify the precipitate formed, if any, in each of the experiments. **(c)** Based on these limited observations, which ion tends to form the more soluble salts, chromate or oxalate?

4.93 Antacids are often used to relieve pain and promote healing in the treatment of mild ulcers. Write balanced net ionic equations for the reactions between the HCl(*aq*) in the stomach and each of the following substances used in various antacids: **(a)** $Al(OH)_3(s)$, **(b)** $Mg(OH)_2(s)$, **(c)** $MgCO_3(s)$, **(d)** $NaAl(CO_3)(OH)_2(s)$, **(e)** $CaCO_3(s)$.

[4.94] Salts of the sulfite ion, SO_3^{2-}, react with acids in a way similar to that of carbonates. **(a)** Predict the chemical formula, and name the weak acid that forms when the sulfite ion reacts with acids. **(b)** The acid formed in part (a) decomposes to form water and a gas. Predict the molecular formula, and name the gas formed. **(c)** Use a source book such as the *CRC Handbook of Chemistry and Physics* to confirm that the substance in part (b) is a gas under normal room-temperature conditions. **(d)** Write balanced net ionic equations of the reaction of HCl(*aq*) with (i) $Na_2SO_3(aq)$, (ii) $Ag_2SO_3(s)$, (iii) $KHSO_3(s)$, and (iv) $ZnSO_3(aq)$.

4.95 **CQ** The commercial production of nitric acid involves the following chemical reactions:

$$4\,NH_3(g) + 5\,O_2(g) \longrightarrow 4\,NO(g) + 6\,H_2O(g)$$

$$2\,NO(g) + O_2(g) \longrightarrow 2\,NO_2(g)$$

$$3\,NO_2(g) + H_2O(l) \longrightarrow 2\,HNO_3(aq) + NO(g)$$

(a) Which of these reactions are redox reactions? **(b)** In each redox reaction identify the element undergoing oxidation and the element undergoing reduction.

4.96 Use Table 4.5 to predict which of the following ions can be reduced to their metal forms by reacting with zinc: **(a)** $Na^+(aq)$, **(b)** $Pb^{2+}(aq)$, **(c)** $Mg^{2+}(aq)$, **(d)** $Fe^{2+}(aq)$, **(e)** $Cu^{2+}(aq)$, **(f)** $Al^{3+}(aq)$. Write the balanced net ionic equation for each reaction that occurs.

[4.97] CQ Lanthanum metal forms cations with a charge of 3+. Consider the following observations about the chemistry of lanthanum: When lanthanum metal is exposed to air, a white solid (compound A) is formed that contains lanthanum and one other element. When lanthanum metal is added to water, gas bubbles are observed and a different white solid (compound B) is formed. Both A and B dissolve in hydrochloric acid to give a clear solution. When either of these solution is evaporated, a soluble white solid (compound C) remains. If compound C is dissolved in water and sulfuric acid is added, a white precipitate (compound D) forms. **(a)** Propose identities for the substances A, B, C, and D. **(b)** Write net ionic equations for all the reactions described. **(c)** Based on the preceding observations, what can be said about the position of lanthanum in the activity series (Table 4.5)?

4.98 A 35.0-mL sample of 1.00 *M* KBr and a 60.0-mL sample of 0.600 *M* KBr are mixed. The solution is then heated to evaporate water until the total volume is 50.0 mL. What is the molarity of the KBr in the final solution?

4.99 Calculate the molarity of the solution produced by mixing **(a)** 40.0 mL of 0.160 *M* NaCl and 65.0 mL of 0.150 *M* NaCl, **(b)** 32.5 mL of 0.750 *M* NaOH and 26.8 mL of 0.750 *M* NaOH. (Assume that the volumes are additive.)

4.100 Using modern analytical techniques, it is possible to detect sodium ions in concentrations as low as 50 pg/mL. What is this detection limit expressed in **(a)** molarity of Na^+, **(b)** Na^+ ions per cubic centimeter?

4.101 Hard water contains Ca^{2+}, Mg^{2+}, and Fe^{2+}, which interfere with the action of soap and leave an insoluble coating on the insides of containers and pipes when heated. Water softeners replace these ions with Na^+. If 1.0×10^3 L of hard water contains 0.010 *M* Ca^{2+} and 0.0050 *M* Mg^{2+}, how many moles of Na^+ are needed to replace these ions?

4.102 Tartaric acid, $H_2C_4H_4O_6$, has two acidic hydrogens. The acid is often present in wines and precipitates from solution as the wine ages. A solution containing an unknown concentration of the acid is titrated with NaOH. It requires 22.62 mL of 0.2000 *M* NaOH solution to titrate both acidic protons in 40.00 mL of the tartaric acid solution. Write a balanced net ionic equation for the neutralization reaction, and calculate the molarity of the tartaric acid solution.

4.103 The concentration of hydrogen peroxide in a solution is determined by titrating a 10.0-mL sample of the solution with permanganate ion.

$$2\,MnO_4^-(aq) + 5\,H_2O_2(aq) + 6\,H^+(aq) \longrightarrow 2\,Mn^{2+}(aq) + 5\,O_2(g) + 8\,H_2O(l)$$

If it takes 16.8 mL of 0.124 *M* MnO_4^- solution to reach the equivalence point, what is the molarity of the hydrogen peroxide solution?

[4.104] A solid sample of $Zn(OH)_2$ is added to 0.400 L of 0.500 *M* aqueous HBr. The solution that remains is still acidic. It is then titrated with 0.500 *M* NaOH solution, and it takes 98.5 mL of the NaOH solution to reach the equivalence point. What mass of $Zn(OH)_2$ was added to the HBr solution?

Integrative Exercises

4.105 A solution of sodium chlorate is prepared by dissolving 1.28 g of the salt in water to form 1.00 L of solution. To form a solution of sodium chlorite of the same molarity and volume, what mass of sodium chlorite would be needed?

4.106 **(a)** By titration, 15.0 mL of 0.1008 *M* sodium hydroxide is needed to neutralize a 0.2053-g sample of an organic acid. What is the molar mass of the acid if it is monoprotic? **(b)** An elemental analysis of the acid indicates that it is composed of 5.89% H, 70.6% C, and 23.5% O by mass. What is its molecular formula?

4.107 A 3.455-g sample of a mixture was analyzed for barium ion by adding a small excess of sulfuric acid to an aqueous solution of the sample. The resultant reaction produced a precipitate of barium sulfate, which was collected by filtration, washed, dried, and weighed. If 0.2815 g of barium sulfate was obtained, what was the mass percentage of barium in the sample?

[4.108] A tanker truck carrying 5.0×10^3 kg of concentrated sulfuric acid solution tips over and spills its load. If the sulfuric acid is 95.0% H_2SO_4 by mass and has a density of 1.84 gm/L, how many kilograms of sodium carbonate must be added to neutralize the acid?

4.109 A sample of 5.53 g of $Mg(OH)_2$ is added to 25.0 mL of 0.200 *M* HNO_3. **(a)** Write the chemical equation for the reaction that occurs. **(b)** Which is the limiting reactant in the reaction? **(c)** How many moles of $Mg(OH)_2$, HNO_3, and $Mg(NO_3)_2$ are present after the reaction is complete?

4.110 A sample of 1.50 g of lead(II) nitrate is mixed with 125 mL of 0.100 *M* sodium sulfate solution. **(a)** Write the chemical equation for the reaction that occurs. **(b)** Which is the limiting reactant in the reaction? **(c)** What are the concentrations of all ions that remain in solution after the reaction is complete?

4.111 A mixture contains 76.5% NaCl, 6.5% $MgCl_2$, and 17.0% Na_2SO_4 by mass. What is the molarity of Cl^- ions in a solution formed by dissolving 7.50 g of the mixture in enough water to form 500.0 mL of solution?

[4.112] The average concentration of bromide ion in seawater is 65 mg of bromide ion per kg of seawater. What is the molarity of the bromide ion if the density of the seawater is 1.025 g/mL?

[4.113] The mass percentage of chloride ion in a 25.00-mL sample of seawater was determined by titrating the sample with silver nitrate, precipitating silver chloride. It took 42.58 mL of 0.2997 *M* silver nitrate solution to reach the equivalence point in the titration. What is the mass percentage of chloride ion in the seawater if its density is 1.025 g/mL?

4.114 The arsenic in a 1.22-g sample of a pesticide was converted to AsO_4^{3-} by suitable chemical treatment. It was then titrated using Ag^+ to form Ag_3AsO_4 as a precipitate. **(a)** What is the oxidation state of As in AsO_4^{3-}? **(b)** Name Ag_3AsO_4 by analogy to the corresponding compound containing phosphorus in place of arsenic. **(c)** If it took 25.0 mL of 0.102 *M* Ag^+ to reach the equivalence point in this titration, what is the mass percentage of arsenic in the pesticide?

[4.115] The new standard for arsenate in drinking water, mandated by the Safe Drinking Water Act, requires that by January, 2006, public water supplies must contain no greater than 10 parts per billion (ppb) arsenic. Assuming that this arsenic is present as arsenate, AsO_4^{3-}, what mass of sodium arsenate would be present in a 1.00-L sample of drinking water that just meets the standard?

[4.116] Federal regulations set an upper limit of 50 parts per million (ppm) of NH_3 in the air in a work environment (that is, 50 molecules of $NH_3(g)$ for every million molecules in the air). Air from a manufacturing operation was drawn through a solution containing 1.00×10^2 mL of 0.0105 *M* HCl. The NH_3 reacts with HCl as follows:

$$NH_3(aq) + HCl(aq) \longrightarrow NH_4Cl(aq)$$

After drawing air through the acid solution for 10.0 min at a rate of 10.0 L/min, the acid was titrated. The remaining acid needed 13.1 mL of 0.0588 *M* NaOH to reach the equivalence point. **(a)** How many grams of NH_3 were drawn into the acid solution? **(b)** How many ppm of NH_3 were in the air? (Air has a density of 1.20 g/L and an average molar mass of 29.0 g/mol under the conditions of the experiment.) **(c)** Is this manufacturer in compliance with regulations?

eMEDIA EXERCISES

These exercises make use of the interactive objects available online in OneKey or the Companion Website, and on your Accelerator CD. Access to these resources comes in your MediaPak.

4.117 The **Electrolytes and Non-Electrolytes** animation (*4.1*) and the **Introduction to Aqueous Acids** and **Introduction to Aqueous Bases** animations (*4.3*) illustrate the behavior of various substances in aqueous solution. For each of the seven substances mentioned in the animations, write the chemical equation that corresponds to dissolution in water. (The chemical formula of sugar is $C_{12}H_{22}O_{11}$.) Where appropriate, use the double arrow notation.

4.118 In the **Strong and Weak Electrolytes** movie (*4.1*), the lightbulb glows brightly when the beaker contains aqueous hydrochloric acid, but relatively dimly when the beaker contains aqueous acetic acid. **(a)** For each of the compounds in Exercise 4.3, would you expect an aqueous solution to cause the bulb to light? If so, how brightly? **(b)** Consider the use of aqueous solutions of each of the following compounds in the apparatus shown in the demonstration. For each compound, tell whether you would expect the lightbulb to glow brightly, dimly, or not at all: H_2CO_3, C_2H_5OH, NH_4Cl, CaF_2, and HF.

4.119 **(a)** Use the solubility rules to predict what precipitate, if any, will form as the result of each combination. (i) $Na_2CO_3(aq)$ and $Fe(NO_3)_2(aq)$, (ii) $NH_4NO_3(aq)$ and $K_2SO_4(aq)$, (iii) $AlBr_3(aq)$ and $Fe_2(SO_4)_3(aq)$, (iv) $H_2SO_4(aq)$ and $Pb(NO_3)_2(aq)$, (v) $Na_2S(aq)$ and $(NH_4)_2SO_4(aq)$. Use the **Ionic Compounds** activity (*4.2*) to check your answers. **(b)** For each combination that produces a precipitate, write a balanced net ionic equation. **(c)** When $NH_4Cl(aq)$ and $Pb(NO_3)_2(aq)$ are combined, a precipitate forms. What ions are still present in the solution in significant concentration after the precipitation? Explain.

4.120 In the **Oxidation-Reduction Chemistry of Tin and Zinc** movie (*4.4*), zinc is oxidized by a solution containing tin ions. **(a)** Write the equation corresponding to this redox reaction. **(b)** In addition to the reaction between zinc metal and tin ions, there is another process occurring. Write the net ionic equation corresponding to this process. (Refer to Exercise 4.54.)

4.121 After watching the **Solution Formation from a Solid** animation (*4.5*), answer the following questions: **(a)** If we neglect to account for the mass of the weighing paper, how would our calculated concentration differ from the actual concentration of the solution? **(b)** Describe the process of preparing an aqueous solution of known concentration, starting with a solid. **(c)** Why is it necessary to make the solution as described in the animation, rather than simply filling the flask up to the mark with water and then adding the solute? **(d)** Describe how you would prepare the solution in part (a) starting with the concentrated stock solution in the **Solution Formation by Dilution** animation (*4.5*).

4.122 Use the **Acid-Base Titration** activity (*4.6*) to determine the concentration of an unknown acid by adding 0.40 *M* NaOH in increments of 1.0 mL. Repeat the titration, adding increments of 0.10 mL of base near the end point. Once more, repeat the titration, adding increments of 0.05 mL of base near the end point. If your acid is dilute enough, repeat the titration three more times, using 0.10 *M* NaOH in 1.0-mL, 0.50-mL, and 0.05-mL increments. **(a)** Tabulate the acid concentrations that you