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) $\text{Ag}_2\text{O}(s) + 2 \text{HCl}(aq) \rightarrow 2 \text{AgCl}(s) + \text{H}_2\text{O}(l)$
(b) $\text{NaOH}(aq) + \text{HCl}(aq) \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l)$
(c) $\text{AgNO}_3(aq) + \text{KCl}(aq) \rightarrow \text{AgCl}(s) + \text{KCl}(aq)$

**EXERCISES**

**Electrolytes**

4.11 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 When methanol, $\text{CH}_3\text{OH}$, is dissolved in water, a nonconducting solution results. When acetic acid, $\text{HC}_2\text{H}_3\text{O}_2$, 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 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 What does it mean to say that ions are hydrated when an ionic substance dissolves in water?

**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) $\text{NiCl}_2$,
(b) $\text{Ag}_2\text{S}$,
(c) $\text{Cs}_3\text{PO}_4$,
(d) $\text{SrCO}_3$,
(e) $\text{PbSO}_4$.

4.20 Predict whether each of the following compounds is soluble in water:
(a) $\text{Ni(OH)}_2$,
(b) $\text{PbF}_2$,
(c) $\text{Ba(NO}_3)_2$,
(d) $\text{AlPO}_4$,
(e) $\text{Ag}_2\text{HCO}_3$.

4.21 Will precipitation occur when the following solutions are mixed? If so, write a balanced chemical equation for the reaction.
(a) $\text{Na}_2\text{CO}_3$ and $\text{AgNO}_3$,
(b) $\text{Na}_2\text{NO}_3$ and $\text{NiSO}_4$,
(c) $\text{FeSO}_4$ and $\text{Pb(NO}_3)_2$.

4.22 Identify the precipitate (if any) that forms when the following solutions are mixed, and write a balanced chemical equation for each reaction.
(a) $\text{Ni(NO}_3)_2$ and $\text{NaOH}$,
(b) $\text{NaOH}$ and $\text{K}_2\text{SO}_4$,
(c) $\text{Na}_2\text{S}$ and $\text{Cu(C}_2\text{H}_3\text{O}_2)_2$.

4.23 Name the spectator ions in any reactions that may be involved when each of the following pairs of solutions are mixed.
(a) $\text{Na}_2\text{CO}_3(aq)$ and $\text{MgSO}_4(aq)$
(b) $\text{Pb(NO}_3)_2(aq)$ and $\text{Na}_2\text{S}(aq)$
(c) $\text{NH}_4\text{H}_2\text{PO}_4(aq)$ and $\text{CaCl}_2(aq)$

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

(a) $\text{Cr}_2\text{SO}_4(aq) + (\text{NH}_4)\text{CO}_3(aq)$
(b) $\text{Ba(NO}_3)_2(aq) + \text{K}_2\text{SO}_4(aq)$
(c) $\text{Fe(NO}_3)_2(aq) + \text{KOH}(aq)$

4.25 Separate samples of a solution of an unknown salt are treated with dilute solutions of $\text{HBr}$, $\text{H}_2\text{SO}_4$, and $\text{NaOH}$. A precipitate forms in all three cases. Which of the following cations could the salt contain? $\text{K}^+$, $\text{Pb}^{2+}$, $\text{Ba}^{2+}$?

4.26 Separate samples of a solution of an unknown ionic compound are treated with dilute $\text{AgNO}_3$, $\text{Pb(NO}_3)_2$, and $\text{BaCl}_2$. Precipitates form in all three cases. Which of the following could be the anion of the unknown salt? $\text{Br}^-$, $\text{CO}_3^{2-}$, $\text{NO}_3^-$?

4.27 You know that an unlabeled bottle contains a solution of one of the following: $\text{AgNO}_3$, $\text{CaCl}_2$, or $\text{Al}_2\text{(SO}_4)_3$. A friend suggests that you test a portion of the solution with $\text{Ba(NO}_3)_2$ and then with $\text{NaCl}$ solutions. Explain how these two tests together would be sufficient to determine which salt is present in the solution.

4.28 Three solutions are mixed together to form a single solution. One contains 0.2 mol $\text{Pb(C}_2\text{H}_3\text{O}_2)_2$; the second contains 0.1 mol $\text{Na}_2\text{S}$; and the third contains 0.1 mol $\text{CaCl}_2$. (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 (CH₃OH)? Explain.

4.30 Which of the following solutions is the most basic? (a) 0.5 M NH₃, (b) 0.1 M KOH, (c) 0.1 M Ca(OH)₂. Explain.

4.31 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 Explain the following observations: (a) NH₃ 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 H₂SO₄ contains more HSO₄⁻ ions than SO₄²⁻ ions.

4.33 It is said that HClO₄ is a strong acid, whereas HClO₂ is a weak acid. What does this mean in terms of the extent to which the two substances are ionized in solution?

4.34 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, CH₃CN; (c) NaClO₄; (d) Ba(OH)₂.

4.36 An aqueous solution of an unknown sugar 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, NH₃, HNO₃, KClO₄, H₃PO₄, CH₃COCH₃ (acetone)?

4.37 Classify each of the following substances as a nonelectrolyte, weak electrolyte, or strong electrolyte in water: (a) H₂SO₄, (b) C₆H₅OH (ethanol), (c) NH₃, (d) KClO₃, (e) Cu(NO₃)₂.

4.38 Classify each of the following aqueous solutions as a nonelectrolyte, weak electrolyte, or strong electrolyte: (a) HClO₄, (b) HNO₃, (c) NH₄Cl, (d) CH₃COCH₃ (acetone), (e) CoSO₄, (f) C₂H₂O₂ (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) →
(b) Cu(OH)₂(s) + HClO₄(aq) →
(c) Al(OH)₃(s) + HNO₃(aq) →

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 HClO₄(aq) → Fe(CIO₄)₂(aq) + H₂O(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 CaCO₃ reacts with an aqueous solution of nitric acid; (b) solid iron(II) sulfide reacts with an aqueous solution of hydrobromic acid.

4.44 As K₂O 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?

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

Oxidation-Reduction Reactions

4.48 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 SO₂, (b) C in COCl₂, (c) Mn in MnO₄⁻, (d) Br in HBrO, (e) As in As₄, (f) O in K₂O₂.

4.50 Determine the oxidation number for the indicated element in each of the following compounds: (a) Ti in TiO₂, (b) Sn in SnCl₄⁻, (c) C in C₂O₄²⁻, (d) N in N₂H₄, (e) N in HNO₂, (f) Cr in Cr₂O₇²⁻.

4.51 Which element is oxidized and which is reduced in the following reactions?

(a) Ni(s) + Cl₂(g) → NiCl₂(s)
(b) 3 Fe(NO₃)₂(aq) + 2 Al(s) → 3 Fe(s) + 2 Al(NO₃)₃(aq)
Based on the activity series (Table 4.5), what is the outcome (if any) of each of the following reactions?

(a) Mn(s) + NiCl₂(aq) →
(b) Cu(s) + Cr₂(Cr₂O₇)₃(aq) →
(c) Cr(s) + NiSO₄(aq) →
(d) Pt(s) + HBr(aq) →
(e) H₂(g) + CuCl₂(aq) →

4.57 The metal cadmium tends to form Cd²⁺ ions. The following observations are made: (i) When a strip of zinc metal is placed in CdCl₂(aq), cadmium metal is deposited on the strip. (ii) When a strip of cadmium metal is placed in Ni(NO₃)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 (a) Use the following reactions to prepare an activity series for the halogens:

Br₂(aq) + 2 NaI(aq) → 2 NaBr(aq) + I₂(aq);
Cl₂(aq) + 2 NaBr(aq) → 2 NaCl(aq) + Br₂(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: Cl₂(aq) and KI(aq); Br₂(aq) and LiCl(aq).

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(NO₃)₂ in 0.200 L; (c) the volume of 1.50 M Na₃PO₄ 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 K₂Cr₂O₇? (b) If 4.28 g of (NH₄)₂SO₄ 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 CuSO₄ 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 K₂CrO₄, or 0.080 M K₃PO₄? (b) Which will contain the greater number of moles of potassium ion: 30.0 mL of 0.15 M K₂CrO₄ or 25.0 mL of 0.080 M K₃PO₄?

4.68 In each of the following pairs, indicate which has the higher concentration of Cl⁻ ion: (a) 0.10 M CaCl₂ 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 CdCl₂ 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 CaBr₂, (c) 0.15 M CH₃OH, (d) a mixture of 40.0 mL of 0.15 M KClO₃ and 35.0 mL of 0.22 M Na₂SO₄. 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 HNO₃, (b) 18.0 mL of 0.200 M Na₂SO₄ and 15.0 mL of 0.150 M KCl, (c) 2.38 g of NaCl in 50.0 mL of 0.400 M CaCl₂ solution. (Assume that the volumes are additive.)

4.71 (a) You have a stock solution of 14.8 M NH₃. How many milliliters of this solution should you dilute to make 100.0 mL of 0.250 M NH₃? (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 HNO₃ would you have to prepare to make 0.350 L of 0.400 M HNO₃? (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, C₁₂H₂₂O₁₁, 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 C₁₂H₂₂O₁₁ starting with 2.00 L of 1.50 M C₁₂H₂₂O₁₁.

4.74 (a) How would you prepare 250.0 mL of 0.150 M AgNO₃ solution starting with pure solute? (b) An experiment calls for you to use 100 mL of 0.50 M HNO₃ solution. All you have available is a bottle of 6.0 M HNO₃. 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, C₃H₈O₃, 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.

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Solution Stoichiometry: Titrations

4.77 What mass of NaCl is needed to precipitate the silver ions from 20.0 mL of 0.100 M AgNO₃ solution?

4.78 What mass of NaOH is needed to precipitate the Cd²⁺ ions from 25.0 mL of 0.500 M Cd(NO₃)₂ solution?

4.79 (a) What volume of 0.115 M HClO₄ 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 AgNO₃ is needed to precipitate all the Cl⁻ ions in a 785-mg sample of KCl (forming AgCl), what is the molarity of the AgNO₃ 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 H₂SO₄ are needed to neutralize 0.200 g of NaOH? (c) If 55.8 mL of BaCl₂ solution is needed to precipitate all the sulfate ion in a 752-mg sample of Na₂SO₄, 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:

\[ 2 \text{NaHCO}_3(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + 2 \text{H}_2\text{O}(l) + 2 \text{CO}_2(g) \]

Sodium bicarbonate is added until the fizzing due to the formation of CO₂(g) stops. If 27 mL of 6.0 M H₂SO₄ was spilled, what is the minimum mass of NaHCO₃ that must be added to the spill to neutralize the acid?

4.82 The distinctive odor of vinegar is due to acetic acid, CH₃CO₂H, which reacts with sodium hydroxide in the following fashion:

\[ \text{CH}_3\text{CO}_2\text{H}(aq) + \text{NaOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{NaC}_2\text{H}_3\text{O}_2(aq) \]

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(NO₃)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 Na₂CrO₄. What volume of Na₂CrO₄ solution is needed to precipitate all the Sr²⁺(aq) as SrCrO₄?

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 NiSO₄. (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 HNO₃. (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?
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.

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.

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

<table>
<thead>
<tr>
<th>Expt Number</th>
<th>Solutions Mixed</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A + B</td>
<td>No precipitate, yellow solution</td>
</tr>
<tr>
<td>2</td>
<td>A + C</td>
<td>Red precipitate forms</td>
</tr>
<tr>
<td>3</td>
<td>A + D</td>
<td>No precipitate, yellow solution</td>
</tr>
<tr>
<td>4</td>
<td>B + C</td>
<td>White precipitate forms</td>
</tr>
<tr>
<td>5</td>
<td>B + D</td>
<td>White precipitate forms</td>
</tr>
<tr>
<td>6</td>
<td>C + D</td>
<td>White precipitate forms</td>
</tr>
</tbody>
</table>

(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?

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) MgCO₃(s), (d) NaAl(CO₃)(OH)₂(s), (e) CaCO₃(s).

Salts of the sulfite ion, SO₃²⁻, 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) Na₂SO₃(aq), (ii) Ag₂SO₃(aq), (iii) KHSO₃(s), and (iv) ZnSO₃(aq).

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

\[ 4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g) \]
\[ 2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g) \]
\[ 3 \text{NO}_2(g) + \text{H}_2\text{O}(l) \rightarrow 2 \text{HNO}_3(aq) + \text{NO}(g) \]

(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) Pb²⁺(aq), (c) Mg²⁺(aq), (d) Fe²⁺(aq), (e) Cu²⁺(aq), (f) Al³⁺(aq). Write the balanced net ionic equation for each reaction that occurs.

4.97 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 solutions 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 Ca²⁺, Mg²⁺, and Fe²⁺, 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 × 10³ L of hard water contains 0.010 M Ca²⁺ and 0.0050 M Mg²⁺, how many moles of Na⁺ are needed to replace these ions?

4.102 Tartaric acid, H₂C₄H₄O₆, 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.

$$2 \text{MnO}_4^- (aq) + 5 \text{H}_2\text{O}_2 (aq) + 6 \text{H}^+ (aq) \rightarrow 2 \text{Mn}^{2+} (aq) + 5 \text{O}_2 (g) + 8 \text{H}_2\text{O}(l)$$

If it takes 16.8 mL of 0.124 M MnO₄⁻ 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?

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 chloride 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 × 10³ kg of concentrated sulfuric acid solution tips over and spills its load. If the sulfuric acid is 95.0% H₂SO₄ 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 HNO₃. (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, HNO₃, and Mg(NO₃)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% MgCl₂, and 17.0% Na₂SO₄ 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 AsO₄³⁻ by suitable chemical treatment. It was then titrated using Ag⁺ to form Ag₃AsO₄ as a precipitate. (a) What is the oxidation state of As in AsO₄³⁻? (b) Name Ag₃AsO₄ 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 arsenite 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 arsenite, AsO₄³⁻, what mass of sodium arsenite 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 NH₃ in the air in a work environment (that is, 50 molecules of NH₃(g) for every million molecules in the air). Air from a manufacturing operation was drawn through a solution containing 1.00 × 10⁻² M of 0.0105 M HCl. The NH₃ reacts with HCl as follows:

\[ \text{NH}_3(aq) + \text{HCl}(aq) \rightarrow \text{NH}_4\text{Cl}(aq) \]

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 NH₃ were drawn into the acid solution? (b) How many ppm of NH₃ 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?

**MEDIA EXERCISES**

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

4.117 The Electrometry and Non-Electrometry 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 C₁₂H₂₂O₁₁.) Where appropriate, use the double arrow notation.

4.118 In the Strong and Weak Electrometry 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: H₂CO₃, C₂H₅OH, NH₄Cl, CaF₂, and HF.

4.119 (a) Use the solubility rules to predict what precipitate, if any, will form as the result of each combination. (i) Na₂CO₃(aq) and Fe(NO₃)₃(aq), (ii) NH₃NO₃(aq) and K₂SO₄(aq), (iii) AlBr₃(aq) and Fe₂(SO₄)₃(aq), (iv) H₂SO₄(aq) and Pb(NO₃)₂(aq), (v) Na₂S(aq) and (NH₄)₂SO₄(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 NH₄Cl(aq) and Pb(NO₃)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