Example Exercise 8.1 Evidence for a Reaction

Which of the following is experimental evidence for a chemical reaction?

(a) Pouring vinegar on baking soda gives foamy bubbles.
(b) Mixing two solutions produces insoluble particles.
(c) Mixing two colorless solutions gives a yellow solution.
(d) Mixing two solutions produces a temperature increase.

Solution

We can analyze each of these observations based on the criteria for a chemical reaction.

(a) The bubbles produced indicate a chemical reaction is occurring.
(b) The insoluble particles formed indicate a chemical reaction.
(c) The yellow color produced indicates a chemical reaction.
(d) The temperature increase indicates heat energy is being released and, thus, an exothermic chemical reaction.

Practice Exercise

What are four observations that a chemical reaction has occurred?

Answers: (a) a gas is released; (b) a precipitate is produced; (c) a permanent color change is observed; (d) an energy change is noted

Concept Exercise

What four observations are evidence for a chemical reaction?

Answer: See Appendix G.

Example Exercise 8.2 Writing Chemical Equations

Write a chemical equation for each of the following chemical reactions:

(a) Mercury liquid and fluorine gas react to give solid mercury(II) fluoride.

(b) Zinc metal reacts with sulfuric acid to give aqueous zinc sulfate and hydrogen gas.

Solution

To write the chemical equation, we must provide formulas and symbols for each substance. We can describe each of the preceding chemical reactions as follows:

(a) $Hg(l) + F_2(g) \rightarrow HgF_2(s)$

(b) $Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$

Practice Exercise

Write a chemical equation for each of the following chemical reactions:

(a) Aqueous solutions of sodium iodide and silver nitrate yield silver iodide precipitate and aqueous sodium nitrate.

(b) Acetic acid reacts with aqueous potassium hydroxide to give aqueous potassium acetate plus water.

Answers:

(a) $NaI(aq) + AgNO_3(aq) \rightarrow AgI(s) + NaNO_3(aq)$

(b) $HC_2H_3O_2(aq) + KOH(aq) \rightarrow KC_2H_3O_2(aq) + H_2O(l)$

Concept Exercise

Which seven nonmetals occur naturally as diatomic molecules?

Answer: See Appendix G.

Example Exercise 8.3 Balancing Chemical Equations

Aqueous solutions of calcium nitrate and sodium carbonate react to give a white precipitate of calcium carbonate and aqueous sodium nitrate. Write a balanced chemical equation given

$$Ca(NO_3)_2(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + NaNO_3(aq)$$

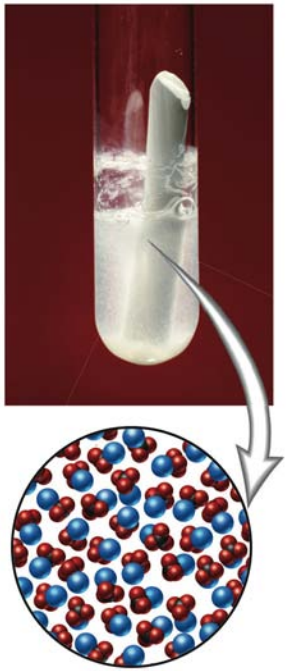
Solution

We see that $Ca(NO_3)_2$ has two NO_3^- ions in the formula. There is only one NO_3^- ion on the right side, so we insert the coefficient 2 as follows:

$$Ca(NO_3)_2(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + 2NaNO_3(aq)$$

The coefficient 2 in front of $NaNO_3$ generates two Na on the right side, and we have two Na on the left side. Notice we have one CO_3 on each side, and one Ca on each side. Finally, we can check off each element and polyatomic ion to verify that the chemical equation is balanced.

$$\underset{\surd\ \surd}{Ca(NO_3)_2(aq)} + \underset{\surd\ \surd}{Na_2CO_3(aq)} \rightarrow \underset{\surd\ \surd}{CaCO_3(s)} + 2\ \underset{\surd\ \surd}{NaNO_3(aq)}$$



Insoluble Calcium Carbonate Chalk, calcium carbonate, $CaCO_3$, is insoluble in an aqueous solution.

Example Exercise 8.3 Balancing Chemical Equations

Continued

Practice Exercise

Aqueous solutions of aluminum sulfate and barium nitrate react to yield a white precipitate of barium sulfate and aqueous aluminum nitrate. Write a balanced chemical equation given

$$Al_2(SO_4)_3(aq) + Ba(NO_3)_2(aq) \rightarrow BaSO_4(s) + Al(NO_3)_3(aq)$$

Answer:

$$\underset{\surd\ \surd}{Al_2(SO_4)_3(aq)} + 3\ \underset{\surd\ \surd}{Ba(NO_3)_2(aq)} \rightarrow 3\ \underset{\surd\ \surd}{BaSO_4(s)} + 2\ \underset{\surd\ \surd}{Al(NO_3)_3(aq)}$$

Concept Exercise

Do you change a subscript in a chemical formula to balance an equation?

Answer: See Appendix G.

Example Exercise 8.4 Balancing Chemical Equations

Sulfuric acid reacts with aqueous sodium hydroxide to give aqueous sodium sulfate and water. Write a balanced chemical equation given

$$H_2SO_4(aq) + NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$$

Solution

Let's start with Na_2SO_4, which contains the same number of atoms as H_2SO_4. There is one SO_4 on each side of the equation, and so SO_4 is balanced. However, there are two Na on the right side of the equation and one Na on the left. We must place the coefficient 2 in front of NaOH.

$$H_2SO_4(aq) + 2\ NaOH(aq) \rightarrow Na_2SO_4(aq) + HOH(l)$$

To balance this reaction more easily, we can write the formula for water as HOH. Notice that we now have two OH on the left side of the equation, and one OH on the right side. By placing a 2 in front of the HOH, we can balance the OH. The two H on the right side are balanced by the two H in H_2SO_4. Finally, we check off each atom and polyatomic ion to verify that we have a balanced chemical equation.

$$\underset{\surd\ \surd}{H_2SO_4(aq)} + 2\ \underset{\surd\ \surd}{NaOH(aq)} \rightarrow \underset{\surd\ \surd}{Na_2SO_4(aq)} + 2\ \underset{\surd\ \surd}{HOH(l)}$$

Example Exercise 8.4 Balancing Chemical Equations

Continued

Practice Exercise

Nitric acid reacts with aqueous barium hydroxide to give aqueous barium nitrate and water. Write a balanced chemical equation given

$$HNO_3(aq) + Ba(OH)_2(aq) \rightarrow Ba(NO_3)_2(aq) + HOH(l)$$

Answer:

$$\underset{\surd\ \surd}{2\ HNO_3(aq)} + \underset{\surd\ \surd}{Ba(OH)_2(aq)} \rightarrow \underset{\surd\ \surd}{Ba(NO_3)_2(aq)} + \underset{\surd\ \surd}{2\ HOH(l)}$$

Concept Exercise

Why write water as HOH for the product of a neutralization reaction?

Answer: See Appendix G.

Example Exercise 8.5 Classifying Chemical Reactions

Classify each of the following reactions as combination, decomposition, single-replacement, double-replacement, or neutralization.

(a) Copper metal heated with oxygen gas produces solid copper(II) oxide.

$$2\,Cu(s) + O_2(g) \xrightarrow{\Delta} 2\,CuO(s)$$

(b) Heating powdered iron(III) carbonate produces solid iron(III) oxide and carbon dioxidegas.

$$Fe_2(CO_3)_3(s) \xrightarrow{\Delta} Fe_2O_3(s) + 3\,CO_2(g)$$

(c) Aluminum metal reacts with aqueous manganese(II) sulfate to give aqueous aluminum sulfate and manganese metal.

$$2\,Al(s) + 3\,MnSO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3\,Mn(s)$$

(d) Aqueous sodium chromate reacts with aqueous barium chloride to give insoluble barium chromate and aqueous sodium chloride.

$$Na_2CrO_4(aq) + BaCl_2(aq) \rightarrow BaCrO_4(s) + 2\,NaCl(aq)$$

(e) Nitric acid reacts with aqueous potassium hydroxide to give aqueous potassium nitrate and water.

$$HNO_3(aq) + KOH(aq) \rightarrow KNO_3(aq) + H_2O(l)$$

Example Exercise 8.5 Classifying Chemical Reactions

Continued

Solution

We can classify the type of each reaction as follows:

(a) The two elements Cu and O_2 synthesize a single compound; this is an example of a *combination* reaction.

(b) The compound $Fe_2(CO_3)_3$ is heated and breaks down into a simpler compound and a gas; this is an example of a *decomposition* reaction.

(c) The metal Al displaces the metal Mn from aqueous $MnSO_4$; this is an example of a *single-replacement* reaction.

(d) The two compounds Na_2CrO_4 and $BaCl_2$ exchange anions; this is an example of a *double-replacement* reaction.

(e) The acid HNO_3 reacts with the base KOH to form KNO_3 and water; this is an example of a *neutralization* reaction.

Example Exercise 8.5 Classifying Chemical Reactions

Continued

Practice Exercise

Classify the following types of reactions as combination, decomposition, single-replacement, double-replacement, or neutralization:

(a) $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$

(b) $2\ Sr(s) + O_2(g) \rightarrow 2\ SrO(s)$

(c) $Cd(HCO_3)_2(s) \rightarrow CdCO_3(s) + H_2O(g) + CO_2(g)$

(d) $HC_2H_3O_2(aq) + NaOH(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l)$

(e) $AgNO_3(aq) + KCl(aq) \rightarrow AgCl(s) + KNO_3(aq)$

Answers: (a) single-replacement; (b) combination; (c) decomposition; (d) neutralization; (e) double-replacement

Concept Exercise

How can a decomposition reaction be easily distinguished from other types of chemical reactions?

Answer: See Appendix G.

Example Exercise 8.6 Combination Reaction of a Metal and Oxygen Gas

Write a balanced chemical equation for each of the following combination reactions:

(a) Zinc metal is heated with oxygen gas in air to yield solid zinc oxide.

(b) Chromium metal is heated with oxygen gas to give chromium(III) oxide.

Solution

A metal and oxygen react to produce a metal oxide.

(a) Zinc is a metal with a predictable charge, that is, Zn^{2+}. The formula of zinc oxide is ZnO. The balanced equation for the reaction is

$$2\,Zn(s) + O_2(g) \xrightarrow{\Delta} 2\,ZnO(s)$$

(b) Chromium is a metal with a variable charge. From the name chromium(III) oxide, we know the ion is Cr^{3+}. The formula of the oxide is, therefore, Cr_2O_3, and the balanced equation for the reaction is

$$4\,Cr(s) + 3\,O_2(g) \xrightarrow{\Delta} 2\,Cr_2O_3(s)$$

Example Exercise 8.6 Combination Reaction of a Metal and Oxygen Gas

Continued

Practice Exercise

Write a balanced chemical equation for each of the following combination reactions:
(a) Lead metal is heated with oxygen in air to yield solid lead(IV) oxide.
(b) Cobalt metal is heated with oxygen gas to give solid cobalt(III) oxide.

Answers:

(a) $Pb(s) + O_2(g) \xrightarrow{\Delta} PbO_2(s)$

(b) $4\,Co(s) + 3\,O_2(g) \xrightarrow{\Delta} 2\,Co_2O_3(s)$

Concept Exercise

What is the product from heating a metal and oxygen gas?

Answer: See Appendix G.

Example Exercise 8.7 Combination Reaction of a Nonmetal and Oxygen Gas

Write a balanced chemical equation for each of the following combination reactions:

(a) Carbon is heated with oxygen gas to produce carbon dioxide gas.

(b) Phosphorus and oxygen gas react to give solid diphosphorus pentaoxide.

Solution

A nonmetal and oxygen combine to produce a nonmetal oxide.

(a) The formula of the nonmetal oxide is unpredictable. We are given that the product is carbon dioxide and not carbon monoxide. The balanced equation for the reaction is

$$C(s) + O_2(g) \xrightarrow{\Delta} CO_2(g)$$

(b) The formula for the oxide of phosphorus is not predictable, but we have the name of the nonmetal oxide product. The formula for diphosphorus pentaoxide is P_2O_5. The balanced equation is

$$4\ P(s) + 5\ O_2(g) \rightarrow 2\ P_2O_5(s)$$

Example Exercise 8.7 Combination Reaction of a Nonmetal and Oxygen Gas

Continued

Practice Exercise

Write a balanced chemical equation for each of the following combination reactions:

(a) Nitrogen gas is heated with oxygen to give dinitrogen trioxide gas.

(b) Chlorine gas is heated with oxygen to give dichlorine monoxide gas.

Answers:

(a) $2\,N_2(g) + 3\,O_2(g) \xrightarrow{\Delta} 2\,N_2O_3(g)$

(b) $2\,Cl_2(g) + O_2(g) \xrightarrow{\Delta} 2\,Cl_2O(g)$

Concept Exercise

What is the product from heating a nonmetal and oxygen gas?

Answer: See Appendix G.

Example Exercise 8.8 Combination Reaction of a Metal and a Nonmetal

Write a balanced chemical equation for each of the following combination reactions:

(a) Aluminum metal is heated with sulfur and gives a solid product.

(b) Chromium metal is heated with iodine and produces powdered chromium(III) iodide.

Solution

A metal and a nonmetal react to produce a binary ionic compound.

(a) The formula of the product is predictable. Aluminum combines with sulfur to give aluminum sulfide, Al_2S_3. The balanced equation for the reaction is

$$2\,Al(s) + 3\,S(s) \xrightarrow{\Delta} Al_2S_3(s)$$

(b) Chromium is a transition metal, and so we cannot predict the formula for the product. We are given the name of the compound, chromium(III) iodide, and so the formula is CrI_3. The equation is

$$2\,Cr(s) + 3\,I_2(s) \xrightarrow{\Delta} 2\,CrI_3(s)$$

Example Exercise 8.8 Combination Reaction of a Metal and a Nonmetal

Continued

Practice Exercise

Write a balanced chemical equation for each of the following combination reactions:

(a) Calcium metal is heated with fluorine gas to yield solid calcium fluoride.

(b) Manganese metal reacts with bromine vapor to give crystalline manganese(IV) bromide.

Answers:

(a) $Ca(s) + F_2(g) \xrightarrow{\Delta} CaF_2(s)$

(b) $Mn(s) + 2\,Br_2(g) \rightarrow MnBr_4(s)$

Concept Exercise

What is the product from heating a metal and nonmetal?

Answer: See Appendix G.

Example Exercise 8.9 Decomposition Reaction of a Hydrogen Carbonate

Write a balanced chemical equation for each of the following decomposition reactions:

(a) Lithium hydrogen carbonate decomposes on heating.

(b) Lead(II) hydrogen carbonate decomposes on heating.

Solution

A metal hydrogen carbonate decomposes with heat to give a metal carbonate, water, and carbon dioxide gas.

(a) All the formulas are predictable, including that of the product, Li_2CO_3. The balanced equation for the reaction is

$$2LiHCO_3(s) \xrightarrow{\Delta} Li_2CO_3(s) + H_2O(g) + CO_2(g)$$

(b) Although the ionic charge of lead is variable, we are given that lead(II) hydrogen carbonate is the reactant. Therefore, the product is lead(II) carbonate, $PbCO_3$. The balanced equation for the reaction is

$$Pb(HCO_3)_2(s) \xrightarrow{\Delta} PbCO_3(s) + H_2O(g) + CO_2(g)$$

Example Exercise 8.9 Decomposition Reaction of a Hydrogen Carbonate

Continued

Practice Exercise

Write a balanced chemical equation for each of the following decomposition reactions:

(a) Barium hydrogen carbonate is decomposed with heat.

(b) Copper(I) hydrogen carbonate is decomposed with heat.

Answers:

(a) $Ba(HCO_3)_2(s) \xrightarrow{\Delta} BaCO_3(s) + H_2O(g) + CO_2(g)$

(b) $2\,CuHCO_3(s) \xrightarrow{\Delta} Cu_2CO_3(s) + H_2O(g) + CO_2(g)$

Concept Exercise

What is the product from heating a metal hydrogen carbonate?

Answer: See Appendix G.

Example Exercise 8.10 Decomposition Reaction of a Carbonate

Write a balanced chemical equation for each of the following decomposition reactions:
(a) Magnesium carbonate decomposes on heating.
(b) Copper(I) carbonate decomposes on heating.

Solution

A metal carbonate decomposes with heat to a metal oxide and carbon dioxide gas.
(a) All the formulas are predictable including that of the metal oxide, MgO. The balanced equation for the reaction is

$$MgCO_3(s) \xrightarrow{\Delta} MgO(s) + CO_2(g)$$

(b) The ionic charge of copper can be either 1+ or 2+. Since the reactant is copper(I) carbonate, the product is copper(I) oxide, that is, Cu_2O. Thus, the balanced equation for the reaction is

$$Cu_2CO_3(s) \xrightarrow{\Delta} Cu_2O(s) + CO_2(g)$$

Example Exercise 8.10 Decomposition Reaction of a Carbonate

Continued

Practice Exercise

Write a balanced chemical equation for each of the following decomposition reactions:

(a) Aluminum carbonate is decomposed on heating.

(b) Iron(II) carbonate is decomposed on heating.

Answers:

(a) $Al_2(CO_3)_3(s) \xrightarrow{\Delta} Al_2O_3(s) + 3\,CO_2(g)$

(b) $FeCO_3(s) \xrightarrow{\Delta} FeO(s) + CO_2(g)$

Concept Exercise

What is the product from heating a metal carbonate?

Answer: See Appendix G.

Example Exercise 8.11 Decomposition Reaction Producing Oxygen Gas

Write a balanced chemical equation for each of the following decomposition reactions:
(a) Solid potassium chlorate decomposes upon heating to give solid potassium chloride and oxygen gas.
(b) Solid sodium nitrate decomposes upon heating to give solid sodium nitrite and oxygen gas.

Solution

There is no general format for these reactions; however, we are given the names of the reactants and products.
(a) We can write the reaction for the decomposition of potassium chlorate and balance the chemical equation as follows:

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

(b) We can write the reaction for the decomposition of sodium nitrate and balance the chemical equation as follows:

$$2\,NaNO_3(s) \xrightarrow{\Delta} 2\,NaNO_2(s) + O_2(g)$$

Example Exercise 8.11 Decomposition Reaction Producing Oxygen Gas

Continued

Practice Exercise

Write a balanced chemical equation for each of the following decomposition reactions:

(a) Solid lead(IV) oxide decomposes upon heating to give solid lead(II) oxide and oxygen gas.

(b) Aqueous hydrogen peroxide, H2O2, decomposes upon heating to give water and oxygen gas.

Answers:

(a) $2\ PbO_2(s) \xrightarrow{\Delta} 2\ PbO(s) + O_2(g)$

(b) $2\ H_2O_2(aq) \xrightarrow{\Delta} 2\ H_2O(l) + O_2(g)$

Concept Exercise

What is the usual product from heating an oxygen-containing compound?

Answer: See Appendix G.

Example Exercise 8.12 Predictions Based on the Activity Series

Predict whether or not a reaction occurs for each of the following:

(a) Aluminum foil is added to an iron(II) sulfate solution.

(b) Iron wire is added to an aluminum sulfate solution.

(c) Manganese metal is added to acetic acid.

(d) Magnesium metal is added to water.

Solution

We refer to the activity series for the reactivity of each of the metals.

(a) Aluminum precedes iron in the activity series: Al > Fe. Thus, a reaction occurs, and Al displaces Fe from the solution.

(b) Conversely, iron follows aluminum in the activity series: Al > Fe. Thus, there is *no reaction*.

(c) Manganese precedes hydrogen in the activity series: Mn > (H). Thus, a reaction occurs, and Mn produces H_2 gas that bubbles from the solution.

(d) Magnesium is not an active metal. Therefore, magnesium does not react with water, and there is *no reaction*.

Example Exercise 8.12 Predictions Based on the Activity Series

Continued

Practice Exercise

Predict whether or not a reaction occurs for each of the following:

(a) A gold ring is dropped into sulfuric acid.
(b) A zinc granule is dropped into hydrochloric acid.
(c) A cadmium foil is put into a lead(II) nitrate solution.
(d) A chromium strip is put into water.

Answers:

(a) There is *no reaction* because Au follows (H) in the activity series.
(b) There is a reaction because Zn precedes (H) in the activity series.
(c) There is a reaction because Cd precedes Pb in the activity series.
(d) There is *no reaction* because Cr is not an active metal.

Concept Exercise

Which of the following metals reacts with aqueous silver nitrate: Zn, Cu, Au?

Answer: See Appendix G.

Gold in Acid A gold ring gives no reaction in an aqueous sulfuric acid, H_2SO_4, solution.

Example Exercise 8.13 Single-Replacement Reactions

Write a balanced chemical equation for each of the following single-replacement reactions.

(a) Nickel metal is placed in a tin(II) sulfate solution.

(b) Cobalt metal is put in a cadmium nitrate solution.

(c) Manganese chips are added to sulfuric acid.

(d) A chunk of potassium is dropped into water.

Solution

First, we will refer to the activity series for the relative positions of each of the metals. Then we will write the equations.

(a) Nickel is above tin in the activity series: Ni > Sn. Therefore, a reaction occurs and Ni displaces Sn from the solution.

$$Ni(s) + SnSO_4(aq) \rightarrow NiSO_4(aq) + Sn(s)$$

(b) Cobalt is below cadmium in the series: Cd > Co. Therefore, there is no reaction.

$$Co(s) + Cd(NO_3)_2(aq) \rightarrow NR$$

(c) Manganese is above hydrogen in the series: Mn > (H). Therefore, a reaction occurs, and Mn releases H2 gas bubbles from the solution.

$$Mn(s) + H_2SO_4(aq) \rightarrow MnSO_4(aq) + H_2(g)$$

(d) Potassium is a Group IA/1 active metal. Therefore, a reaction occurs, and K releases H2 gas from the solution.

$$2\ K(s) + 2\ H_2O(l) \rightarrow 2\ KOH(aq) + H_2(g)$$

Example Exercise 8.13 Single-Replacement Reactions

Continued

Practice Exercise

Write a balanced chemical equation for each of the following single-replacement reactions:

(a) Nickel metal is placed in a silver nitrate solution.
(b) Gold metal is placed in a silver nitrate solution.
(c) A chunk of cadmium metal is dropped into hydrochloric acid.
(d) A small piece of strontium metal is dropped into water.

Answers:

(a) $Ni(s) + 2\ AgNO_3(aq) \rightarrow 2\ Ag(s) + Ni(NO_3)_2(aq)$
(b) $Au(s) + AgNO_3(aq) \rightarrow NR$
(c) $Cd(s) + 2\ HCl(aq) \rightarrow CdCl_2(aq) + H_2(g)$
(d) $Sr(s) + 2\ H_2O(l) \rightarrow Sr(OH)_2(aq) + H_2(g)$

Concept Exercise

Which of the following metals reacts with an aqueous acid: Zn, Cu, Au?

Answer: See Appendix G.

Example Exercise 8.14 Applying Solubility Rules

State whether each of the following compounds is soluble or insoluble in water:

(a) sodium sulfate, Na_2SO_4
(b) aluminum nitrate, $Al(NO_3)_3$
(c) barium sulfate, $BaSO_4$
(d) lead(II) chromate, $PbCrO_4$
(e) ammonium sulfide, $(NH_4)_2S$

Solution

We refer to the solubility rules in Table 8.2.

(a) Sodium sulfate contains the alkali metal ion Na^+. According to Rule 1, Na_2SO_4 is *soluble*.

(b) Aluminum nitrate contains the nitrate ion NO_3^-. According to Rule 3, $Al(NO_3)_3$ is *soluble*.

(c) Barium sulfate contains the sulfate ion SO_4^{2-}. According to the Rule 5 exception, $BaSO_4$ is *insoluble*.

(d) Lead(II) chromate contains the chromate ion CrO_4^{2-}. According to Rule 7, $PbCrO_4$ is *insoluble*.

(e) Ammonium sulfide contains the ammonium ion NH_4^+. According to Rule 1, $(NH_4)_2S$ is *soluble*.

TABLE 8.2 SOLUBILITY RULES FOR IONIC COMPOUNDS

Compounds containing the following ions are generally *soluble* in water:

1. alkali metal ions and the ammonium ion, Li^+, Na^+, K^+, NH_4^+
2. acetate ion, $C_2H_3O_2^-$
3. nitrate ion, NO_3^-
4. halide ions (X = Cl^-, Br^-, I^-) (AgX, Hg_2X_2, and PbX_2 are exceptions and *insoluble*)
5. sulfate ion, an SO_4^{2-} ($SrSO_4$, $BaSO_4$, and $PbSO_4$ are exceptions and insoluble)

Compounds containing the following ions are generally *insoluble* in water:*

6. carbonate ion, CO_3^{2-} (see Rule 1 exceptions, which are *soluble*)
7. chromate ion, CrO_4^{2-} (see Rule 1 exceptions, which are *soluble*)
8. phosphate ion, PO_4^{3-} (see Rule 1 exceptions, which are *soluble*)
9. sulfide ion, S^{2-} (CaS, SrS, BaS, and Rule 1 exceptions are *soluble*)
10. hydroxide ion, OH^- [$Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$, and Rule 1 exceptions are *soluble*]

*These compounds are actually slightly soluble, or very slightly soluble, in water.

Example Exercise 8.14 Applying Solubility Rules

Continued

Practice Exercise

State whether each of the following compounds is soluble or insoluble in water:

(a) lead(II) acetate, $Pb(C_2H_3O_2)_2$
(b) mercury(II) bromide, $HgBr_2$
(c) magnesium carbonate, $MgCO_3$
(d) zinc phosphate, $Zn_3PO_4)_2$
(e) calcium hydroxide, $Ca(OH)_2$

Answers:

(a) soluble (Rule 2)
(b) soluble (Rule 4)
(c) insoluble (Rule 6)
(d) insoluble (Rule 8)
(e) soluble (Rule 10 exception)

Concept Exercise

Which of the following compounds is soluble in water: $Pb(NO_3)_2$, $PbCl_2$, $PbCO_3$?

Answer: See Appendix G.

Example Exercise 8.15 Double-Replacement Reactions

Write a balanced chemical equation for each of the following double-replacement reactions.
(a) Aqueous barium chloride is added to a potassium chromate solution.
(b) Aqueous strontium acetate is added to a lithium hydroxide solution.

Solution

For double-replacement reactions, we switch anions for the two compounds and check the solubility rules for an insoluble compound.
(a) Barium chloride and potassium chromate give barium chromate and potassium chloride. According to solubility Rule 7, we find that barium chromate is insoluble. The balanced equation is

$$BaCl_2(aq) + K_2CrO_2(aq) \rightarrow BaCrO_4(s) + 2\ KCl(aq)$$

(b) Strontium acetate and lithium hydroxide react as follows:

$$Sr(C_2H_3O_2)_2(aq) + 2\ LiOH(aq) \rightarrow Sr(OH)_2(aq) + 2\ LiC_2H_3O_2(aq)$$

However, the solubility rules indicate that $Sr(OH)_2$ and $LiC_2H_3O_2$ are soluble. Therefore, the equation is written

$$Sr(C_2H_3O2)2(aq) + LiOH(aq) \rightarrow NR$$

Example Exercise 8.15 Double-Replacement Reactions

Continued

Practice Exercise

Write a balanced chemical equation for each of the following double-replacement reactions:

(a) Aqueous zinc sulfate is added to a sodium carbonate solution.

(b) Aqueous manganese(II) nitrate is added to a potassium hydroxide solution.

Answers:

(a) $ZnSO_4(aq) + Na_2CO_3(aq) \rightarrow ZnCO_3(s) + Na_2SO_4(aq)$

(b) $Mn(NO_3)_2(aq) + 2\ KOH(aq) \rightarrow Mn(OH)_2(s) + 2\ KNO_3(aq)$

Concept Exercise

Identify the insoluble product from the reaction of silver nitrate and sodium chloride.

Answer: See Appendix G.

Example Exercise 8.16 Neutralization Reactions

Write a balanced chemical equation for each of the following neutralization reactions:
(a) Nitric acid neutralizes an ammonium hydroxide solution.
(b) Sulfuric acid neutralizes a potassium hydroxide solution.

Solution

A neutralization reaction produces a salt and water.
(a) Nitric acid and ammonium hydroxide produce ammonium nitrate and water. The balanced equation is

$$HNO_3(aq) + NH_4OH(aq) \rightarrow NH_4NO_3(aq) + HOH(l)$$

(b) Sulfuric acid and potassium hydroxide produce potassium sulfate and water. The balanced equation is

$$H_2SO_4(aq) + 2\ KOH(aq) \rightarrow K_2SO_4(aq) + 2\ HOH(l)$$

Practice Exercise

Write a balanced chemical equation for each of the following neutralization reactions:
(a) Chloric acid neutralizes a strontium hydroxide solution.
(b) Phosphoric acid neutralizes a sodium hydroxide solution.

Answers:
(a) $2\ HClO_3(aq) + Sr(OH)_2(aq) \rightarrow Sr(ClO_3)_2(aq) + 2\ HOH(l)$
(b) $H_3PO_4(aq) + 3\ NaOH \rightarrow Na_3PO_4(aq) + 3\ HOH(l)$

Concept Exercise

Identify the salt product from the reaction of hydrochloric acid and sodium hydroxide.

Answer: See Appendix G.