Solved Problems

INTRODUCTION

8.1. How many oxygen atoms are there in each of the following, perhaps part of a balanced chemical equation? (*a*) 7 H_2O, (*b*) 4 $Ba(NO_3)_2$, (*c*) 2 $CuSO_4 \cdot 5H_2O$, and (*d*) 4 $VO(ClO_3)_2$.

Ans. (*a*) 7, (*b*) 24, (*c*) 18, and (*d*) 28.

BALANCING SIMPLE EQUATIONS

8.2. Balance the following equation: $C + Cu_2O \xrightarrow{\text{heat}} CO + Cu$

Ans. $C + Cu_2O \longrightarrow CO + 2\ Cu$

8.3. Balance the following equation:

$$Ca(HCO_3)_2 + H_3PO_4 \longrightarrow Ca_3(PO_4)_2 + H_2O + CO_2$$

Ans.

$$?\ Ca(HCO_3)_2 + ?\ H_3PO_4 \longrightarrow 1\ Ca_3(PO_4)_2 + ?\ H_2O + ?\ CO_2$$

$$\underset{\textit{2nd}}{3}\ Ca(HCO_3)_2 + \underset{\textit{2nd}}{2}\ H_3PO_4 \longrightarrow 1\ Ca_3(PO_4)_2 + \underset{\textit{3rd}}{6}\ H_2O + \underset{\textit{3rd}}{6}\ CO_2$$

$$3\ Ca(HCO_3)_2 + 2\ H_3PO_4 \longrightarrow Ca_3(PO_4)_2 + 6\ H_2O + 6\ CO_2$$

8.4. Balance the following equation:

$$NH_4Cl + KOH \longrightarrow NH_3 + H_2O + KCl$$

Ans.

	$1\ NH_4Cl + ?\ KOH \longrightarrow ?\ NH_3 + ?\ H_2O + ?\ KCl$
Balance N and Cl :	$1\ NH_4Cl + ?\ KOH \longrightarrow 1\ NH_3 + ?\ H_2O + 1\ KCl$
Balance K :	$1\ NH_4Cl + 1\ KOH \longrightarrow 1\ NH_3 + ?\ H_2O + 1\ KCl$
Balance H :	$1\ NH_4Cl + 1\ KOH \longrightarrow 1\ NH_3 + 1\ H_2O + 1\ KCl$
Eliminate 1s :	$NH_4Cl + KOH \longrightarrow NH_3 + H_2O + KCl$

8.5. Balance the following equation

$$NH_4Cl + NaOH + AgCl \longrightarrow Ag(NH_3)_2Cl + NaCl + H_2O$$

Ans.

$$?\ NH_4Cl + ?\ NaOH + ?\ AgCl \longrightarrow 1\ Ag(NH_3)_2Cl + ?\ NaCl + ?\ H_2O$$

$$\underset{\textit{2nd}}{2}\ NH_4Cl + \underset{\textit{4th}}{2}\ NaOH + \underset{\textit{2nd}}{1}\ AgCl \longrightarrow 1\ Ag(NH_3)_2Cl + \underset{\textit{3rd}}{2}\ NaCl + \underset{\textit{5th}}{2}\ H_2O$$

$$2\ NH_4Cl + 2\ NaOH + AgCl \longrightarrow Ag(NH_3)_2Cl + 2\ NaCl + 2\ H_2O$$

8.6. Balance the following chemical equations:

(*a*) $NCl_3 + H_2O \longrightarrow HClO + NH_3$

(*b*) $NaOH + H_3PO_4 \longrightarrow Na_2HPO_4 + H_2O$

(*c*) $Al + HCl \longrightarrow AlCl_3 + H_2$

(*d*) $HCl + Mg \longrightarrow MgCl_2 + H_2$

(*e*) $SrCO_3 + HClO_4 \longrightarrow Sr(ClO_4)_2 + CO_2 + H_2O$

(*f*) $KC_2H_3O_2 + HBr \longrightarrow KBr + HC_2H_3O_2$

(*g*) $Ba(OH)_2 + H_3PO_4 \longrightarrow BaHPO_4 + H_2O$

(*h*) $HCl + Na_3PO_4 \longrightarrow NaCl + NaH_2PO_4$

Ans. (*a*) $NCl_3 + 3\ H_2O \longrightarrow 3\ HClO + NH_3$

(*b*) $2\ NaOH + H_3PO_4 \longrightarrow Na_2HPO_4 + 2\ H_2O$

(c) $2\,Al + 6\,HCl \longrightarrow 2\,AlCl_3 + 3\,H_2$
(d) $2\,HCl + Mg \longrightarrow MgCl_2 + H_2$
(e) $SrCO_3 + 2\,HClO_4 \longrightarrow Sr(ClO_4)_2 + CO_2 + H_2O$
(f) $KC_2H_3O_2 + HBr \longrightarrow KBr + HC_2H_3O_2$
(g) $Ba(OH)_2 + H_3PO_4 \longrightarrow BaHPO_4 + 2\,H_2O$
(h) $2\,HCl + Na_3PO_4 \longrightarrow 2\,NaCl + NaH_2PO_4$

8.7. Write balanced equations for each of the following reactions:

(a) Sodium plus oxygen yields sodium peroxide.
(b) Mercury(II) oxide, when heated, yields mercury and oxygen.
(c) Carbon plus oxygen yields carbon monoxide.
(d) Sulfur plus oxygen yields sulfur dioxide.
(e) Propane (C_3H_8) plus oxygen yields carbon dioxide plus water.
(f) Ethane (C_2H_6) plus oxygen yields carbon monoxide plus water.
(g) Ethylene (C_2H_4) plus oxygen yields carbon dioxide plus water.

Ans. (a) $2\,Na + O_2 \longrightarrow Na_2O_2$
(b) $2\,HgO \xrightarrow{\text{heat}} 2\,Hg + O_2$
(c) $2\,C + O_2 \longrightarrow 2\,CO$
(d) $S + O_2 \longrightarrow SO_2$
(e) $C_3H_8 + 5\,O_2 \longrightarrow 3\,CO_2 + 4\,H_2O$
(f) $2\,C_2H_6 + 5\,O_2 \longrightarrow 4\,CO + 6\,H_2O$
(g) $C_2H_4 + 3\,O_2 \longrightarrow 2\,CO_2 + 2\,H_2O$

8.8. Write balanced chemical equations for the following reactions:

(a) Sodium plus fluorine yields sodium fluoride.
(b) Potassium chlorate, when heated, yields potassium chloride plus oxygen.
(c) Zinc plus copper(II) nitrate yields zinc nitrate plus copper.
(d) Magnesium hydrogen carbonate plus heat yields magnesium carbonate plus carbon dioxide plus water.
(e) Magnesium hydrogen carbonate plus hydrobromic acid yields magnesium bromide plus carbon dioxide plus water.
(f) Lead(II) acetate plus sodium chromate yields lead(II) chromate plus sodium acetate.

Ans. (a) $2\,Na + F_2 \longrightarrow 2\,NaF$ (Remember that free fluorine is F_2.)
(b) $2\,KClO_3 \longrightarrow 2\,KCl + 3\,O_2$ (Remember that free oxygen is O_2.)
(c) $Zn + Cu(NO_3)_2 \longrightarrow Zn(NO_3)_2 + Cu$
(d) $Mg(HCO_3)_2 \longrightarrow MgCO_3 + H_2O + CO_2$
(e) $Mg(HCO_3)_2 + 2\,HBr \longrightarrow MgBr_2 + 2\,H_2O + 2\,CO_2$
(f) $Pb(C_2H_3O_2)_2 + Na_2CrO_4 \longrightarrow PbCrO_4 + 2\,NaC_2H_3O_2$

8.9. Balance the following equation: $Ba(ClO_4)_2 + Na_2SO_4 \longrightarrow BaSO_4 + NaClO_4$

Ans. $Ba(ClO_4)_2 + Na_2SO_4 \longrightarrow BaSO_4 + 2\,NaClO_4$
The oxygen atoms need not be considered individually if the ClO_4^- and SO_4^{2-} ions are considered as groups. (See step 3, Sec. 8.2.)

8.10. Write balanced chemical equations for the following reactions:
(a) Phosphorus pentachloride plus water yields phosphoric acid plus hydrogen chloride.
(b) Sodium hydroxide plus sulfuric acid yields sodium hydrogen sulfate plus water.
(c) Ethane, C_2H_6, plus oxygen yields carbon dioxide plus water.
(d) Octane, C_8H_{18}, plus oxygen yields carbon monoxide plus water.

(*e*) Copper(II) chloride plus hydrosulfuric acid yields copper(II) sulfide plus hydrochloric acid.

(*f*) Barium hydroxide plus chloric acid yields barium chlorate plus water.

(*g*) Copper(II) sulfate plus water yields copper(II) sulfate pentahydrate.

(*h*) Copper(II) chloride plus sodium iodide yields copper(I) iodide plus iodine plus sodium chloride.

Ans. (*a*) $PCl_5 + 4\,H_2O \longrightarrow H_3PO_4 + 5\,HCl$

(*b*) $NaOH + H_2SO_4 \longrightarrow NaHSO_4 + H_2O$

(*c*) $2\,C_2H_6 + 7\,O_2 \longrightarrow 4\,CO_2 + 6\,H_2O$

(*d*) $2\,C_8H_{18} + 17\,O_2 \longrightarrow 16\,CO + 18\,H_2O$

(*e*) $CuCl_2 + H_2S \longrightarrow CuS + 2\,HCl$

(*f*) $Ba(OH)_2 + 2\,HClO_3 \longrightarrow Ba(ClO_3)_2 + 2\,H_2O$

(*g*) $CuSO_4 + 5\,H_2O \longrightarrow CuSO_4{\cdot}5H_2O$

(*h*) $2\,CuCl_2 + 4\,NaI \longrightarrow 2\,CuI + I_2 + 4\,NaCl$

8.11. Balance the following equation: $Cr + CrCl_3 \longrightarrow CrCl_2$

Ans. Balance the Cl first, since the Cr appears in two reactants. Here, the Cr happens to be balanced automatically.

$$Cr + 2\,CrCl_3 \longrightarrow 3\,CrCl_2$$

8.12. Write balanced chemical equations for the following reactions: (*a*) Hydrogen chloride is produced by the reaction of hydrogen and chlorine. (*b*) Hydrogen combines with chlorine to yield hydrogen chloride. (*c*) Chlorine reacts with hydrogen to give hydrogen chloride.

Ans. (*a*), (*b*), and (*c*). $H_2 + Cl_2 \longrightarrow 2\,HCl$

8.13. Write balanced chemical equations for the following reactions: (*a*) Hydrogen fluoride is produced by the reaction of hydrochloric acid and sodium fluoride. (*b*) Hydrochloric acid combines with sodium fluoride to yield hydrogen fluoride. (*c*) Sodium fluoride reacts with hydrochloric acid to give hydrofluoric acid.

Ans. (*a*), (*b*), and (*c*). $HCl + NaF \longrightarrow NaCl + HF$

8.14. Balance the following chemical equations:

(*a*) $Na_2CO_3 + HClO_3 \longrightarrow NaClO_3 + CO_2 + H_2O$

(*b*) $Ca(HCO_3)_2 + HCl \longrightarrow CaCl_2 + CO_2 + H_2O$

(*c*) $BiCl_3 + H_2O \longrightarrow BiOCl + HCl$

(*d*) $H_2S + O_2 \longrightarrow H_2O + SO_2$

(*e*) $Cu_2S + O_2 \longrightarrow Cu + SO_2$

(*f*) $NH_3 + O_2 \longrightarrow NO + H_2O$

(*g*) $H_2O_2 \longrightarrow H_2O + O_2$

Ans. (*a*) $Na_2CO_3 + 2\,HClO_3 \longrightarrow 2\,NaClO_3 + CO_2 + H_2O$

(*b*) $Ca(HCO_3)_2 + 2\,HCl \longrightarrow CaCl_2 + 2\,CO_2 + 2\,H_2O$

(*c*) $BiCl_3 + H_2O \longrightarrow BiOCl + 2\,HCl$

(*d*) $2\,H_2S + 3\,O_2 \longrightarrow 2\,H_2O + 2\,SO_2$

(*e*) $Cu_2S + O_2 \longrightarrow 2\,Cu + SO_2$

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

(*g*) $2\,H_2O_2 \longrightarrow 2\,H_2O + O_2$

8.15. Balance the following chemical equations:

(*a*) $Pb(NO_3)_2 + KI \longrightarrow PbI_2 + KNO_3$
(*b*) $H_2S + CuCl_2 \longrightarrow HCl + CuS$
(*c*) $Hg_2Cl_2 + NH_3 \longrightarrow HgNH_2Cl + Hg + NH_4Cl$
(*d*) $NH_3 + CuCl_2 \longrightarrow Cu(NH_3)_4Cl$
(*e*) $As_2S_3 + Na_2S \longrightarrow NaAsS_2$

Ans. (*a*) $Pb(NO_3)_2 + 2\,KI \longrightarrow PbI_2 + 2\,KNO_3$
(*b*) $H_2S + CuCl_2 \longrightarrow 2\,HCl + CuS$
(*c*) $Hg_2Cl_2 + 2\,NH_3 \longrightarrow HgNH_2Cl + Hg + NH_4Cl$
(*d*) $4\,NH_3 + CuCl_2 \longrightarrow Cu(NH_3)_4Cl$
(*e*) $As_2S_3 + Na_2S \longrightarrow 2\,NaAsS_2$

8.16. Why is the catalyst not merely placed on both sides of the arrow, since it comes out of the reaction with the same composition as it started with?

Ans. That would imply a certain mole ratio to the other reactants and products, which is not correct.

PREDICTING THE PRODUCTS OF A REACTION

8.17. In the list of reactivities of metals, Table 8-1, are all alkali metals more reactive than all alkaline earth metals, or are all elements of both groups of metals more active than any other metals?

Ans. Both groups of metals are more active than any other metals. Actually, some alkaline earth metals are more active than some alkali metals, and vice versa.

8.18. (*a*) What type of reaction requires knowledge of reactivities of elements? (*b*) What type requires knowledge of solubility properties of compounds?

Ans. (*a*) Substitution reaction (*b*) Double-substitution reaction

8.19. Complete and balance the following equations:

(*a*) $CH_4 + O_2$(limited amount) $\longrightarrow$
(*b*) $CH_4 + O_2$(excess amount) $\longrightarrow$

Ans. (*a*) $2\,CH_4 + 3\,O_2$(limited amount) $\longrightarrow 2\,CO + 4\,H_2O$
If suffient O_2 is available, CO_2 is the product.
(*b*) $CH_4 + 2\,O_2$(excess amount) $\longrightarrow CO_2 + 2\,H_2O$

8.20. What type of chemical reaction is represented by each of the following? Complete and balance the equation for each.

(*a*) $Cl_2 + AlBr_3 \longrightarrow$
(*b*) $Cl_2 + K \longrightarrow$
(*c*) $Na + AlCl_3 \longrightarrow$
(*d*) $FeCl_2 + AgC_2H_3O_2 \longrightarrow$
(*e*) $C_3H_8 + O_2$(limited) $\longrightarrow$

Ans.

(*a*)	Substitution	$3\,Cl_2 + 2\,AlBr_3 \longrightarrow 2\,AlCl_3 + 3\,Br_2$
(*b*)	Combination	$Cl_2 + 2\,K \longrightarrow 2\,KCl$
(*c*)	Substitution	$3\,Na + AlCl_3 \longrightarrow Al + 3\,NaCl$
(*d*)	Double substitution	$FeCl_2 + 2\,AgC_2H_3O_2 \longrightarrow Fe(C_2H_3O_2)_2 + 2\,AgCl$
(*e*)	Combustion	$2\,C_3H_8 + 7\,O_2 \longrightarrow 6\,CO + 8\,H_2O$

8.21. What type of chemical reaction is represented by each of the following? Complete and balance the equation for each.

(*a*) $Cl_2 + CrCl_2 \longrightarrow$
(*b*) $CO + O_2 \longrightarrow$
(*c*) $MgCO_3 \xrightarrow{\text{heat}}$
(*d*) $AlCl_3 + Cl_2 \longrightarrow$
(*e*) $C_5H_{12} + O_2$ (limited quantity) $\longrightarrow$

Ans.	(*a*)	Combination	$Cl_2 + 2\,CrCl_2 \longrightarrow 2\,CrCl_3$
	(*b*)	Combination (or combustion)	$2\,CO + O_2 \longrightarrow 2\,CO_2$
	(*c*)	Decomposition	$MgCO_3 \xrightarrow{\text{heat}} CO_2 + MgO$
	(*d*)	No reaction	$AlCl_3 + Cl_2 \longrightarrow NR$
	(*e*)	Combustion	$2\,C_5H_{12} + 11\,O_2 \longrightarrow 10\,CO + 12\,H_2O$

8.22. Which of the following is soluble in water, CuCl or $CuCl_2$?

Ans. $CuCl_2$ is soluble; CuCl is one of the four chlorides that are listed as insoluble (Table 8-2).

8.23. Complete and balance an equation for the reaction of excess HCl and Na_3PO_4.

Ans. $3\,HCl + Na_3PO_4 \longrightarrow H_3PO_4 + 3\,NaCl$
The phosphoric acid produced is weak, that is, mostly covalent, and the formation of the H_3PO_4 is the driving force for this reaction. (HCl is one of the seven strong acids listed in Table 8-3.)

8.24. Is F_2 soluble in water?

Ans. No, it reacts with water, liberating oxygen:

$$2\,F_2 + 2\,H_2O \longrightarrow 4\,HF + O_2$$

Supplementary Problems

8.25. What is the difference between dissolving and reacting?

Ans. Dissolving is a physical change, and no set ratio of substances is required.

8.26. How can you tell that the following are combination reactions rather than replacement or double-replacement reactions.

$$CoCl_2 + Cl_2 \longrightarrow \qquad HgCl_2 + Hg \longrightarrow$$
$$CO + O_2 \longrightarrow \qquad BaO + CO_2 \longrightarrow$$

Ans. The same element appears in both reactants.

8.27. State why the equation of Problem 8.2 is unusual.

Ans. It is a substitution reaction in which a nonmetal replaces a metal. Carbon, at high temperatures, can replace relatively inactive metals from their oxides.

8.28. Complete and balance each of the following. If no reaction occurs, write "NR."

(*a*) $SO_2 + H_2O \longrightarrow$
(*b*) $BaO + H_2O \longrightarrow$
(*c*) $Al + O_2 \longrightarrow$
(*d*) $Na + S \longrightarrow$
(*e*) $MgO + CO_2 \longrightarrow$
(*f*) $Al + Br_2 \longrightarrow$
(*g*) $Ag + ZnCl_2 \longrightarrow$
(*h*) $Cl_2 + KBr \longrightarrow$
(*i*) $BaSO_4 + NaCl \longrightarrow$
(*j*) $NaCl(l) \xrightarrow{\text{electricity}}$
(*k*) $KCl + HNO_3 \longrightarrow$
(*l*) $C + O_2$ (excess) $\longrightarrow$
(*m*) $KOH + HNO_3 \longrightarrow$
(*n*) $HClO_3 + ZnO \longrightarrow$
(*o*) $BaCl_2 + Na_2SO_4 \longrightarrow$
(*p*) $AgNO_3 + KCl \longrightarrow$
(*q*) $NaOH + H_2SO_4 \longrightarrow$
(*r*) $Ba(OH)_2 + HClO_2 \longrightarrow$
(*s*) $C + O_2$(limited) $\longrightarrow$
(*t*) $C_5H_{10} + O_2$(excess) $\longrightarrow$
(*u*) $C_5H_{10} + O_2$(limited) $\longrightarrow$
(*v*) $C_5H_{10}O + O_2$(excess) $\longrightarrow$
(*w*) $C_5H_{10}O + O_2$(limited) $\longrightarrow$

Ans. (*a*) $SO_2 + H_2O \longrightarrow H_2SO_3$

(*b*) $BaO + H_2O \longrightarrow Ba(OH)_2$

(*c*) $4\ Al + 3\ O_2 \longrightarrow 2\ Al_2O_3$

(*d*) $2\ Na + S \longrightarrow Na_2S$

(*e*) $MgO + CO_2 \longrightarrow MgCO_3$

(*f*) $2\ Al + 3\ Br_2 \longrightarrow 2\ AlBr_3$

(*g*) $Ag + ZnCl_2 \longrightarrow NR$

(*h*) $Cl_2 + 2\ KBr \longrightarrow 2\ KCl + Br_2$

(*i*) $BaSO_4 + NaCl \longrightarrow NR$

(*j*) $2\ NaCl(l) \xrightarrow{\text{electricity}} 2\ Na + Cl_2$

(*k*) $KCl + HNO_3 \longrightarrow NR$

(*l*) $C + O_2$ (excess) $\longrightarrow CO_2$

(*m*) $KOH + HNO_3 \longrightarrow KNO_3 + H_2O$

(*n*) $2\ HClO_3 + ZnO \longrightarrow Zn(ClO_3)_2 + H_2O$

(*o*) $BaCl_2 + Na_2SO_4 \longrightarrow BaSO_4 + 2\ NaCl$

(*p*) $AgNO_3 + KCl \longrightarrow AgCl + KNO_3$

(*q*) $NaOH + H_2SO_4 \longrightarrow NaHSO_4 + H_2O$
or $2\ NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2\ H_2O$

(*r*) $Ba(OH)_2 + 2\ HClO_2 \longrightarrow Ba(ClO_2)_2 + 2\ H_2O$

(*s*) $2\ C + O_2$ (limited) $\longrightarrow 2\ CO$

(*t*) $2\ C_5H_{10} + 15\ O_2$ (excess) $\longrightarrow$
$10\ CO_2 + 10\ H_2O$

(*u*) $C_5H_{10} + 5\ O_2$ (limited) $\longrightarrow 5\ CO + 5\ H_2O$

(*v*) $C_5H_{10}O + 7\ O_2$ (excess) $\longrightarrow 5\ CO_2 + 5\ H_2O$

(*w*) $2\ C_5H_{10}O + 9\ O_2$ (limited) $\longrightarrow$
$10\ CO + 10\ H_2O$

Solved Problems

WRITING NET IONIC EQUATIONS

9.1. How many types of ions are generally found in any ionic compound?

Ans. Two—one type of cation and one type of anion. (Alums are an exception. They are composed of two different cations and sulfate ions.)

9.2. Which of the following compounds are ionic? Which are soluble? Which would be written as separate ions in an ionic equation as written for the first equation in this section? Write the species as they would appear in an ionic equation. (*a*) $CuCl$, (*b*) $NH_4C_2H_3O_2$, (*c*) Hg_2Cl_2, (*d*) $CoCl_2$, (*e*) Na_3PO_4, and (*f*) $CH_3OH(aq)$.

Ans.

	Ionic	**Soluble**	**Written Separately**	**Formulas in Ionic Equation**
(*a*) $CuCl$	Yes	No	No	$CuCl$
(*b*) $NH_4C_2H_3O_2$	Yes	Yes	Yes	$NH_4^+ + C_2H_3O_2^-$
(*c*) Hg_2Cl_2	Yes	No	No	Hg_2Cl_2
(*d*) $CoCl_2$	Yes	Yes	Yes	$Co^{2+} + 2\ Cl^-$
(*e*) Na_3PO_4	Yes	Yes	Yes	$3\ Na^+ + PO_4^{3-}$
(*f*) $CH_3OH(aq)$	No	Yes	No	CH_3OH

9.3. Write the formulas for the ions present in each of the following compounds: (*a*) $NaClO_4$, (*b*) $BaCl_2$, (*c*) $KClO$, (*d*) $Ba(NO_3)_2$, (*e*) $LiClO_3$, (*f*) $(NH_4)_3PO_4$, (*g*) $Co_3(PO_3)_2$, (*h*) $AgCl(s)$, and (*i*) $Mg(HCO_3)_2$.

Ans. (*a*) Na^+ and ClO_4^-
(*b*) Ba^{2+} and Cl^-
(*c*) K^+ and ClO^-
(*d*) Ba^{2+} and NO_3^-
(*e*) Li^+ and ClO_3^-
(*f*) NH_4^+ and PO_4^{3-}
(*g*) Co^{2+} and PO_3^{3-}
(*h*) Ag^+ and Cl^- (even though it is a solid)
(*i*) Mg^{2+} and HCO_3^-

9.4. Write a net ionic equation for the equation in each of the following parts:

(*a*) $NH_4I + AgClO_3 \longrightarrow AgI(s) + NH_4ClO_3$

(*b*) $H_2SO_4 + BaCl_2 \longrightarrow BaSO_4 + 2\ HCl$

Ans. (*a*) $I^- + Ag^+ \longrightarrow AgI$ (*b*) $SO_4^{2-} + Ba^{2+} \longrightarrow BaSO_4$

9.5. Write a net ionic equation for the equation in each of the following parts:

(*a*) $HNO_3 + NaHCO_3 \longrightarrow NaNO_3 + CO_2 + H_2O$

(*b*) $NaOH + NH_4ClO_3 \longrightarrow NH_3 + H_2O + NaClO_3$

(*c*) $HC_2H_3O_2 + KOH \longrightarrow KC_2H_3O_2 + H_2O$

(*d*) $Ba(OH)_2(aq) + 2\ HI \longrightarrow BaI_2 + 2\ H_2O$

Ans. (*a*) $H^+ + HCO_3^- \longrightarrow CO_2 + H_2O$ (HNO_3 is strong)
(*b*) $OH^- + NH_4^+ \longrightarrow NH_3 + H_2O$
(*c*) $HC_2H_3O_2 + OH^- \longrightarrow C_2H_3O_2^- + H_2O$ ($HC_2H_3O_2$ is weak.)
(*d*) $OH^- + H^+ \longrightarrow H_2O$

9.6. Given that $BaCO_3$ is insoluble in water and that NH_3 and H_2O are covalent compounds, write net ionic equations for the following processes:

(*a*) $NH_4Cl + NaOH \longrightarrow NH_3 + H_2O + NaCl$

(*b*) $BaCl_2 + Li_2CO_3 \longrightarrow BaCO_3 + 2\ LiCl$

Ans. (*a*) $NH_4^+ + OH^- \longrightarrow NH_3 + H_2O$ (*b*) $Ba^{2+} + CO_3^{2-} \longrightarrow BaCO_3$

9.7. Write a net ionic equation for the following overall equation:

$$Cr + 2\ Cr(NO_3)_3 \longrightarrow 3\ Cr(NO_3)_2$$

Ans.

$$Cr + 3\ Cr^{3+} \longrightarrow 3\ Cr^{2+}$$

Chromium ions appear on both sides of this equation, but they are not spectator ions since they are not identical. One is a 3+ ion and the other is a 2+ ion. The neutral atom is different from both of these.

9.8. Write a net ionic equation for each of the following overall equations:

(*a*) $HNO_3 + NaOH \longrightarrow NaNO_3 + H_2O$

(*b*) $HCl + KOH \longrightarrow KCl + H_2O$

(*c*) $HClO_4 + LiOH \longrightarrow LiClO_4 + H_2O$

(*d*) $HNO_3 + RbOH \longrightarrow RbNO_3 + H_2O$

(*e*) $HClO_3 + KOH \longrightarrow KClO_3 + H_2O$

Ans. In each case, the net ionic equation is

$$H^+ + OH^- \longrightarrow H_2O$$

9.9. Write a net ionic equation for each of the following overall equations:

(*a*) $HClO_3 + LiOH \longrightarrow LiClO_3 + H_2O$

(*b*) $HClO_3 + RbOH \longrightarrow RbClO_3 + H_2O$

Ans. In each case, the net ionic equation is

$$H^+ + OH^- \longrightarrow H_2O$$

9.10. Write a net ionic equation for each of the following overall equations:

(*a*) $H_3PO_4 + 3\ NaOH \longrightarrow Na_3PO_4 + 3\ H_2O$

(*b*) $MgCO_3(s) + CO_2 + H_2O \longrightarrow Mg(HCO_3)_2$

(*c*) $KHCO_3 + NaOH \longrightarrow K_2CO_3 + H_2O$

Ans. (*a*) $H_3PO_4 + 3\ OH^- \longrightarrow PO_4{}^{3-} + 3\ H_2O$

(*b*) $MgCO_3 + CO_2 + H_2O \longrightarrow Mg^{2+} + 2\ HCO_3{}^-$

(*c*) $HCO_3{}^- + OH^- \longrightarrow CO_3{}^{2-} + H_2O$

9.11. Write a net ionic equation for each of the following overall equations:

(*a*) $2\ AgNO_3 + H_2S \longrightarrow Ag_2S(s) + 2\ HNO_3$

(*b*) $Zn + 2\ HCl \longrightarrow ZnCl_2 + H_2$

(*c*) $Cu + 2\ AgNO_3 \longrightarrow Cu(NO_3)_2 + 2\ Ag$

(*d*) $2\ Al + 3\ HgCl_2 \longrightarrow 2\ AlCl_3 + 3\ Hg$

(*e*) $Zn + FeCl_2 \longrightarrow ZnCl_2 + Fe$

Ans. (*a*) $2\ Ag^+ + H_2S \longrightarrow Ag_2S + 2\ H^+$

(*b*) $Zn + 2\ H^+ \longrightarrow Zn^{2+} + H_2$

(*c*) $Cu + 2\ Ag^+ \longrightarrow Cu^{2+} + 2\ Ag$

(*d*) $2\ Al + 3\ Hg^{2+} \longrightarrow 2\ Al^{3+} + 3\ Hg$
(Note the overall charge balance.)

(*e*) $Zn + Fe^{2+} \longrightarrow Fe + Zn^{2+}$

9.12. Write six more equations that can be represented by the net ionic equation of Example 9.1. Use the same reactants that are used in the equations in Example 9.1

Ans.

$$AgNO_3 + KCl \longrightarrow KNO_3 + AgCl(s)$$
$$AgClO_3 + NH_4Cl \longrightarrow NH_4ClO_3 + AgCl(s)$$
$$AgC_2H_3O_2 + NaCl \longrightarrow NaC_2H_3O_2 + AgCl(s)$$
$$AgNO_3 + NH_4Cl \longrightarrow NH_4NO_3 + AgCl(s)$$
$$AgClO_3 + NaCl \longrightarrow NaClO_3 + AgCl(s)$$
$$AgC_2H_3O_2 + KCl \longrightarrow KC_2H_3O_2 + AgCl(s)$$

9.13. A student used H_3PO_4 to prepare a test solution that was supposed to contain phosphate ions. Criticize this choice.

Ans. Phosphoric acid is weak, and relatively few ions are present. The student should have used an ionic phosphate—sodium phosphate or ammonium phosphate, for example.

9.14. Write one or more complete equations for each of the following net ionic equations:

(*a*) $NH_3 + H^+ \longrightarrow NH_4^+$

(*b*) $Cu^{2+} + S^{2-} \longrightarrow CuS$

(*c*) $CO_2 + 2\,OH^- \longrightarrow CO_3^{2-} + H_2O$

Ans. (*a*) $NH_3 + HNO_3 \longrightarrow NH_4NO_3$ or $NH_3 + HCl \longrightarrow NH_4Cl$
or ammonia plus any other strong acid to yield the ammonium salt.

(*b*) $CuSO_4 + K_2S \longrightarrow CuS + K_2SO_4$ or $Cu(NO_3)_2 + BaS \longrightarrow CuS + Ba(NO_3)_2$
or $CuSO_4 + (NH_4)_2S \longrightarrow CuS + (NH_4)_2SO_4$
or any soluble copper(II) salt with any soluble sulfide.

(*c*) $CO_2 + 2\,KOH \longrightarrow K_2CO_3 + H_2O$
or CO_2 plus any other soluble hydroxide to give a soluble carbonate. Note that the following equation cannot be used, because $BaCO_3$ is insoluble: $CO_2 + Ba(OH)_2 \longrightarrow BaCO_3 + H_2O$

9.15. What chemical would you use to prepare a solution to be used for a test requiring the presence of Ca^{2+} ions?

Ans. $Ca(NO_3)_2$, $CaCl_2$, or any other soluble calcium salt.

9.16. What chemical would you use to prepare a solution to be used for a test requiring the presence of Br^- ions?

Ans. NaBr, $BaBr_2$, HBr(aq), or any other soluble ionic bromide.

9.17. What chemical would you use to prepare a solution to be used for a test requiring the presence of SO_4^{2-} ions?

Ans. Na_2SO_4, $FeSO_4$, or any other soluble sulfate.

Supplementary Problems

9.18. Write a net equation for the following overall equation:

$$4\,Au + 16\,KCN + 6\,H_2O + 3\,O_2 \longrightarrow 4\,KAu(CN)_4(aq) + 12\,KOH$$

Ans.

$$4\,Au + 16\,CN^- + 6\,H_2O + 3\,O_2 \longrightarrow 4\,Au(CN)_4^- + 12\,OH^-$$

9.19. Write a net ionic equation for each of the following equations:

(*a*) $CdS(s) + I_2 \longrightarrow CdI_2(aq) + S$

(*b*) $4\,KOH + 4\,KMnO_4(aq) \longrightarrow 4\,K_2MnO_4(aq) + O_2 + 2\,H_2O$

(*c*) $2\,HI + 2\,HNO_2 \longrightarrow 2\,NO + 2\,H_2O + I_2$

(*d*) $AlCl_3 + 4\,NaOH \longrightarrow NaAl(OH)_4(aq) + 3\,NaCl$

Ans. (*a*) $CdS(s) + I_2 \longrightarrow Cd^{2+} + 2\,I^- + S$

(*b*) $4\,OH^- + 4\,MnO_4^- \longrightarrow 4\,MnO_4^{2-} + O_2 + 2\,H_2O$

(*c*) $2\,H^+ + 2\,I^- + 2\,HNO_2 \longrightarrow 2\,NO + 2\,H_2O + I_2$ (HNO_2 is weak.)

(*d*) $Al^{3+} + 4\,OH^- \longrightarrow Al(OH)_4^-$

9.20. Balance the following net ionic equations:

(*a*) $Ag^+ + Fe \longrightarrow Fe^{2+} + Ag$
(*b*) $Fe^{3+} + I^- \longrightarrow Fe^{2+} + I_2$
(*c*) $Cu^{2+} + I^- \longrightarrow CuI + I_2$
(*d*) $Cd + Cr^{3+} \longrightarrow Cr^{2+} + Cd^{2+}$

Ans. In each part, the net charge as well as the number of each type of atom must balance.

(*a*) $2\ Ag^+ + Fe \longrightarrow Fe^{2+} + 2\ Ag$
(*b*) $2\ Fe^{3+} + 2\ I^- \longrightarrow 2\ Fe^{2+} + I_2$
(*c*) $2\ Cu^{2+} + 4\ I^- \longrightarrow 2\ CuI + I_2$
(*d*) $Cd + 2\ Cr^{3+} \longrightarrow 2\ Cr^{2+} + Cd^{2+}$

9.21. Try to write a complete equation corresponding to the unbalanced and the balanced net ionic equations of the prior problem. What do you find?

Ans. You cannot write a complete equation for an unbalanced net ionic equation. [In part (*a*), for example, you might have one acetate ion on the left and two on the right.] One complete equation for the balanced net ionic equation might be

$$2\ AgC_2H_3O_2 + Fe \longrightarrow Fe(C_2H_3O_2)_2 + 2\ Ag$$

9.22. Would the following reaction yield 56 kJ of heat per mole of water formed, as the reactions in Example 9.4 do? Explain.

$$HC_2H_3O_2 + NaOH \longrightarrow NaC_2H_3O_2 + H_2O$$

Ans. No. Since $HC_2H_3O_2$ is a weak acid, there is a different net ionic equation and thus a different amount of heat:

$$HC_2H_3O_2 + OH^- \longrightarrow C_2H_3O_2{}^- + H_2O$$

9.23. Per mole of water formed, how much heat is generated by the reaction of Example 9.5?

Ans. 56 kJ. It is the same reaction as that of Example 9.4.

9.24. Would 56 kJ per mole of water formed by generated by the following reaction? Compare your answer with that of the prior problem.

$$Ba(OH)_2(s) + 2\ HCl \longrightarrow BaCl_2 + 2\ H_2O$$

Ans. No. It is not represented by the same net ionic equation. Some heat is involved in dissolving the solid $Ba(OH)_2$.

9.25. Write a net ionic equation for each of the following overall equations:

(*a*) $Ca(OH)_2(s) + 2\ HClO_3 \longrightarrow Ca(ClO_3)_2 + 2\ H_2O$
(*b*) $CuSO_4(aq) + H_2S \longrightarrow CuS(s) + H_2SO_4$
(*c*) $ZnS(s) + 2\ HBr \longrightarrow H_2S + ZnBr_2$

Ans. (*a*) $Ca(OH)_2(s) + 2\ H^+ \longrightarrow Ca^{2+} + 2\ H_2O$
(*b*) $Cu^{2+} + H_2S \longrightarrow CuS + 2\ H^+$
(*c*) $ZnS(s) + 2\ H^+ \longrightarrow H_2S + Zn^{2+}$

9.26. Write 12 more equations represented by the net ionic equation given in Example 9.4, using only the reactants used in that example.

Ans.

$NaOH + HCl \longrightarrow NaCl + H_2O$
$RbOH + NHO_3 \longrightarrow RbNO_3 + H_2O$
$RbOH + HBr \longrightarrow RbBr + H_2O$
$NaOH + HI \longrightarrow NaI + H_2O$
$RbOH + HCl \longrightarrow RbCl + H_2O$
$LiOH + HNO_3 \longrightarrow LiNO_3 + H_2O$
$NaOH + HBr \longrightarrow NaBr + H_2O$
$KOH + HI \longrightarrow KI + H_2O$
$LiOH + HCl \longrightarrow LiCl + H_2O$
$KOH + HNO_3 \longrightarrow KNO_3 + H_2O$
$KOH + HBr \longrightarrow KBr + H_2O$
$LiOH + HI \longrightarrow LiI + H_2O$

9.27. Indicate how you could choose different compounds to enable you to write 100 additional equations in response to Problem 9.12.

Ans. Choose 34 or more soluble, ionic chlorides—the other alkali metal chlorides (4), the alkaline earth chlorides (6), the first transition metal chlorides, most of the metals with two different charges (14), many second and third transition metal chlorides (about 10), aluminum and tin(II) chloride (2). Combine each of these with each of the three silver salts that you know are soluble (given in the example), and you have over 100 overall equations.

EXAMPLE 10.20. What rise in temperature will occur if 24.5 kJ of heat is added to 175 g of a dilute aqueous solution of sodium chloride [$c = 4.10$ J/g·°C)] (*a*) by heating with a bunsen burner and (*b*) by means of a chemical reaction?

Ans. (*a* and *b*) The source of the heat does not matter; the temperature rise will be the same in either case. Watch out for the units!

$$\Delta t = \frac{\text{heat}}{(m)(c)} = \frac{24\,500\ \text{J}}{(175\ \text{g})[4.10\ \text{J/(g·°C)}]} = 34.1°\text{C}$$

EXAMPLE 10.21. Calculate the heat of reaction per mole of water formed if 0.0500 mol of HCl and 0.0500 mol of NaOH are added to 15.0 g of water, all at 18.0°C. The solution formed is heated from 18.0°C to 54.3°C. The specific heat of the solution is 4.10 J/(g·°C).

Ans. The law of conservation of mass allows us to calculate the mass of the solution:

$$15.0\ \text{g} + 1.82\ \text{g} + 2.00\ \text{g} = 18.8\ \text{g}$$
$$\text{Heat} = mc\Delta t = (18.8\ \text{g})[4.10\ \text{J/(g·°C)}](36.3°\text{C}) = 2800\ \text{J}$$
$$2.80\ \text{kJ/(0.0500 mol water formed)} = 56.0\ \text{kJ/mol}$$

Solved Problems

MOLE-TO-MOLE CALCULATIONS

10.1. Can the balanced chemical equation dictate to a chemist how much of each reactant to place in a reaction vessel?

Ans. The chemist can put in as little as is weighable or as much as the vessel will hold. For example, the fact that a reactant has a coefficient of 2 in the balanced chemical equation does not mean that the chemist must put 2 mol into the reaction vessel. The chemist might decide to add the reactants in the ratio of the balanced chemical equation, but that is not required. And even in that case, the numbers of moles of each reactant might be twice the respective coefficients or one-tenth those values, etc. The equation merely states the *reacting ratio*.

10.2. How many factor labels can be used corresponding to each of the following balanced equations?

(*a*) $2\ K + Cl_2 \longrightarrow 2\ KCl$

(*b*) $NCl_3 + 3\ H_2O \longrightarrow 3\ HOCl + NH_3$

Ans. (*a*) 6:

$$\frac{2\ \text{mol K}}{1\ \text{mol Cl}_2} \quad \frac{2\ \text{mol K}}{2\ \text{mol KCl}} \quad \frac{1\ \text{mol Cl}_2}{2\ \text{mol K}} \quad \frac{1\ \text{mol Cl}_2}{2\ \text{mol KCl}} \quad \frac{2\ \text{mol KCl}}{2\ \text{mol K}} \quad \frac{2\ \text{mol KCl}}{1\ \text{mol Cl}_2}$$

(*b*) 12: Each of the four compounds as numerators with the three others as denominators—$4 \times 3 = 12$.

10.3. Which of the factors of Problem 10.2*a* would be used to convert (*a*) the number of moles of Cl_2 to the number of moles of KCl, (*b*) K to Cl_2, and (*c*) Cl_2 to K?

Ans. (*a*) $\frac{2\ \text{mol KCl}}{1\ \text{mol Cl}_2}$ (*b*) $\frac{1\ \text{mol Cl}_2}{2\ \text{mol K}}$ (*c*) $\frac{2\ \text{mol K}}{1\ \text{mol Cl}_2}$

10.4. How many moles of $AlCl_3$ can be prepared from 7.5 mol Cl_2 and sufficient Al?

Ans.

$$2\ Al + 3\ Cl_2 \longrightarrow 2\ AlCl_3$$
$$7.5\ \text{mol Cl}_2\left(\frac{2\ \text{mol AlCl}_3}{3\ \text{mol Cl}_2}\right) = 5.0\ \text{mol AlCl}_3$$

10.5. How many moles of H_2O will react with 2.25 mol PCl_5 to form HCl and H_3PO_4?

Ans.

$$4\ H_2O + PCl_5 \longrightarrow 5\ HCl + H_3PO_4$$
$$2.25\ \text{mol PCl}_5\left(\frac{4\ \text{mol H}_2\text{O}}{1\ \text{mol PCl}_5}\right) = 9.00\ \text{mol H}_2\text{O}$$

10.6. Balance the following equation. Calculate the number of moles of CO_2 that can be prepared by the reaction of 2.50 mol of $Mg(HCO_3)_2$.

$$Mg(HCO_3)_2 + HCl \longrightarrow MgCl_2 + CO_2 + H_2O$$

Ans.

$$Mg(HCO_3)_2 + 2\ HCl \longrightarrow MgCl_2 + 2\ CO_2 + 2\ H_2O$$

$$2.50 \text{ mol } Mg(HCO_3)_2\left[\frac{2 \text{ mol } CO_2}{1 \text{ mol } Mg(HCO_3)_2}\right] = 5.00 \text{ mol } CO_2$$

10.7. (*a*) How many moles of $CaCl_2$ can be prepared by the reaction of 2.50 mol HCl with excess $Ca(OH)_2$? (*b*) How many moles of NaCl can be prepared by the reaction of 2.50 mol HCl with excess NaOH?

Ans. (*a*) $Ca(OH)_2 + 2\ HCl \longrightarrow CaCl_2 + 2\ H_2O$

$$2.50 \text{ mol HCl}\left(\frac{1 \text{ mol } CaCl_2}{2 \text{ mol HCl}}\right) = 1.25 \text{ mol } CaCl_2$$

(*b*) $NaOH + HCl \longrightarrow NaCl + H_2O$

$$2.50 \text{ mol HCl}\left(\frac{1 \text{ mol NaCl}}{1 \text{ mol HCl}}\right) = 2.50 \text{ mol NaCl}$$

10.8. How many moles of H_2O are prepared along with 0.750 mol Na_3PO_4 in a reaction of NaOH and H_3PO_4?

Ans.

$$H_3PO_4 + 3\ NaOH \longrightarrow Na_3PO_4 + 3\ H_2O$$

$$0.750 \text{ mol } Na_3PO_4\left(\frac{3 \text{ mol } H_2O}{1 \text{ mol } Na_3PO_4}\right) = 2.25 \text{ mol } H_2O$$

10.9. Consider the following equation:

$$KMnO_4 + 5\ FeCl_2 + 8\ HCl \longrightarrow MnCl_2 + 5\ FeCl_3 + 4\ H_2O + KCl$$

How many moles of $FeCl_3$ will be produced by the reaction of 0.968 mol of HCl?

Ans. No matter how complicated the equation, the reacting ratio is still given by the coefficients. The coefficients of interest are 8 for HCl and 5 for $FeCl_3$.

$$0.968 \text{ mol HCl}\left(\frac{5 \text{ mol } FeCl_3}{8 \text{ mol HCl}}\right) = 0.605 \text{ mol } FeCl_3$$

Note: The hard part of this problem is balancing the equation, which will be presented in Chap. 14. Since the balanced equation was given in the statement of the problem, the problem is as easy to solve as the previous ones.

CALCULATIONS INVOLVING OTHER QUANTITIES

10.10. Figure 10-2 is a combination of which two earlier figures?

Ans. Figures 10-1 and 7-2.

10.11. Which earlier sections must be understood before mass-to-mass conversions can be studied profitably?

Ans. Section 2.2, factor-label method; Sec. 7.3, calculation of formula masses; Sec. 7.4, changing moles to grams and vice versa; Sec. 7.4, Avogadro's number; and/or Sec. 8.2, balancing chemical equations.

10.12. In a stoichiometry problem, (*a*) if the mass of a reactant is given, what conversions (if any) should be made? (*b*) If a number of molecules is given, what conversions (if any) should be made? (*c*) If a number of moles is given, what conversions (if any) should be made?

Ans. (*a*) The mass should be converted to moles. (*b*) The number of molecules should be converted to moles. (*c*) No conversion need be done; the quantity is given in moles.

10.13. Phosphoric acid reacts with sodium hydroxide to produce sodium phosphate and water. (*a*) Write a balanced chemical equation for the reaction. (*b*) Determine the number of moles of phosphoric acid in 50.0 g of the acid. (*c*) How many moles of sodium phosphate will be produced by the reaction of this number of moles of phosphoric acid? (*d*) How many grams of sodium phosphate will be produced? (*e*) How many moles of sodium hydroxide will it take to react with this quantity of phosphoric acid? (*f*) How many grams of sodium hydroxide will be used up?

Ans. (*a*) $H_3PO_4 + 3\ NaOH \longrightarrow Na_3PO_4 + 3\ H_2O$

(*b*) $50.0\ g\ H_3PO_4\left(\frac{1\ mol\ H_3PO_4}{98.0\ g\ H_3PO_4}\right) = 0.510\ mol\ H_3PO_4$

(*c*) $0.510\ mol\ H_3PO_4\left(\frac{1\ mol\ Na_3PO_4}{1\ mol\ H_3PO_4}\right) = 0.510\ mol\ Na_3PO_4$

(*d*) $0.510\ mol\ Na_3PO_4\left(\frac{164\ g\ Na_3PO_4}{1\ mol\ Na_3PO_4}\right) = 83.6\ g\ Na_3PO_4$

(*e*) $0.510\ mol\ H_3PO_4\left(\frac{3\ mol\ NaOH}{1\ mol\ Na_3PO_4}\right) = 1.53\ mol\ NaOH$

(*f*) $1.53\ mol\ NaOH\left(\frac{40.0\ g\ NaOH}{1\ mol\ NaOH}\right) = 61.2\ g\ NaOH$

10.14. (*a*) Write the balanced chemical equation for the reaction of sodium with chlorine. (*b*) How many moles of Cl_2 are there in 7.650 g chlorine? (*c*) How many moles of NaCl will that number of moles of chlorine produce? (*d*) What mass of NaCl is that number of moles of NaCl?

Ans. (*a*) $2\ Na + Cl_2 \longrightarrow 2\ NaCl$

(*b*) $7.650\ g\ Cl_2\left(\frac{1\ mol\ Cl_2}{70.90\ g\ Cl_2}\right) = 0.1079\ mol\ Cl_2$

(*c*) $0.1079\ mol\ Cl_2\left(\frac{2\ mol\ NaCl}{1\ mol\ Cl_2}\right) = 0.2158\ mol\ NaCl$

(*d*) $0.2158\ mol\ NaCl\left(\frac{58.45\ g\ NaCl}{1\ mol\ NaCl}\right) = 12.61\ g\ NaCl$

10.15. How many formula units of sodium hydroxide, along with H_2SO_4, does it take to make 7.50×10^{22} formula units of Na_2SO_4?

Ans.

$$2\ NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2\ H_2O$$

$$7.50 \times 10^{22}\ units\ Na_2SO_4\left(\frac{1\ mol\ Na_2SO_4}{6.02 \times 10^{23}\ units\ Na_2SO_4}\right)\left(\frac{2\ mol\ NaOH}{1\ mol\ Na_2SO_4}\right)\left(\frac{6.02 \times 10^{23}\ units\ NaOH}{1\ mol\ NaOH}\right)$$
$$= 1.50 \times 10^{23}\ units\ NaOH$$

Since the balanced chemical equation also relates the numbers of formula units of reactants and products, the problem can be solved by converting directly with the factor label from the balanced equation:

$$7.50 \times 10^{22}\ units\ Na_2SO_4\left(\frac{2\ units\ NaOH}{1\ unit\ Na_2SO_4}\right) = 1.50 \times 10^{23}\ units\ NaOH$$

10.16. How many grams of barium hydroxide will be used up in the reaction with hydrogen chloride (hydrochloric acid) to produce 16.70 g of barium chloride plus some water?

Ans.

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

$$16.70\ g\ BaCl_2\left(\frac{1\ mol\ BaCl_2}{208.2\ g\ BaCl_2}\right)\left(\frac{1\ mol\ Ba(OH)_2}{1\ mol\ BaCl_2}\right)\left(\frac{171.3\ g\ Ba(OH)_2}{1\ mol\ Ba(OH)_2}\right) = 13.74\ g\ Ba(OH)_2$$

10.17. Draw a figure like Fig. 10-2 for Problem 10.15.

Ans. See Fig. 10-4.

10.18. (*a*) What reactant may be treated with phosphoric acid to produce 6.00 mol of potassium hydrogen phosphate (plus some water)? (*b*) How many moles of phosphoric acid will it take? (*c*) How many moles of the other reactant are required? (*d*) How many grams?

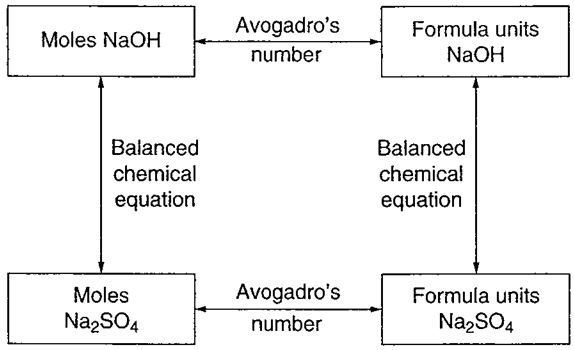

Fig. 10-4. Conversion of formula units of a reactant to formula units of a product

Ans. (*a*) KOH may be used: $H_3PO_4 + 2\ KOH \longrightarrow K_2HPO_4 + 2\ H_2O$

(*b*) $6.00\ \text{mol}\ K_2HPO_4\left(\frac{1\ \text{mol}\ H_3PO_4}{1\ \text{mol}\ K_2HPO_4}\right) = 6.00\ \text{mol}\ H_3PO_4$

(*c*) $6.00\ \text{mol}\ K_2HPO_4\left(\frac{2\ \text{mol KOH}}{1\ \text{mol}\ K_2HPO_4}\right) = 12.0\ \text{mol KOH}$

(*d*) $12.0\ \text{mol KOH}\left(\frac{56.1\ \text{g KOH}}{1\ \text{mol KOH}}\right) = 673\ \text{g KOH}$

10.19. Determine the number of grams of hydrochloric acid that will just react with 20.0 g of calcium carbonate to produce carbon dioxide, water, and calcium chloride.

Ans. $CaCO_3 + 2\ HCl \longrightarrow CaCl_2 + H_2O + CO_2$

$$20.0\ \text{g}\ CaCO_3\left(\frac{1\ \text{mol}\ CaCO_3}{100\ \text{g}\ CaCO_3}\right)\left(\frac{2\ \text{mol HCl}}{1\ \text{mol}\ CaCO_3}\right)\left(\frac{36.5\ \text{g HCl}}{1\ \text{mol HCl}}\right) = 14.6\ \text{g HCl}$$

10.20. How many grams of Hg_2Cl_2 can be prepared from 15.0 mL of mercury (density 13.6 g/mL)?

Ans. $2\ Hg + Cl_2 \longrightarrow Hg_2Cl_2$

$$15.0\ \text{mL Hg}\left(\frac{13.6\ \text{g Hg}}{1\ \text{mL Hg}}\right)\left(\frac{1\ \text{mol Hg}}{200.6\ \text{g Hg}}\right)\left(\frac{1\ \text{mol}\ Hg_2Cl_2}{2\ \text{mol Hg}}\right)\left(\frac{471\ \text{g}\ Hg_2Cl_2}{1\ \text{mol}\ Hg_2Cl_2}\right) = 239\ \text{g}\ Hg_2Cl_2$$

10.21. How many grams of methyl alcohol, CH_3OH, can be obtained in an industrial process from 5.00 metric tons (5.00×10^6 g) of CO plus hydrogen gas? To calculate the answer: (*a*) Write a balanced chemical equation for the process. (*b*) Calculate the number of moles of CO in 5.00×10^6 g CO. (*c*) Calculate the number of moles of CH_3OH obtainable from that number of moles of CO. (*d*) Calculate the number of grams of CH_3OH obtainable.

Ans. (*a*) $CO + 2\ H_2 \xrightarrow{\text{special conditions}} CH_3OH$

(*b*) $5.00 \times 10^6\ \text{g CO}\left(\frac{1\ \text{mol CO}}{28.0\ \text{g CO}}\right) = 1.79 \times 10^5\ \text{mol CO}$

(*c*) $1.79 \times 10^5\ \text{mol CO}\left(\frac{1\ \text{mol}\ CH_3OH}{1\ \text{mol CO}}\right) = 1.79 \times 10^5\ \text{mol}\ CH_3OH$

(*d*) $1.79 \times 10^5\ \text{mol}\ CH_3OH\left(\frac{32.0\ \text{g}\ CH_3OH}{1\ \text{mol}\ CH_3OH}\right) = 5.73 \times 10^6\ \text{g}\ CH_3OH$

10.22. Determine the number of grams of barium hydroxide it would take to neutralize (just react completely, with none left over) 14.7 g of phosphoric acid.

Ans.

$$3\ Ba(OH)_2 + 2\ H_3PO_4 \longrightarrow Ba_3(PO_4)_2 + 6\ H_2O$$

$$14.7\ g\ H_3PO_4\left(\frac{1\ mol\ H_3PO_4}{98.0\ g\ H_3PO_4}\right)\left(\frac{3\ mol\ Ba(OH)_2}{2\ mol\ H_3PO_4}\right)\left(\frac{171\ g\ Ba(OH)_2}{1\ mol\ Ba(OH)_2}\right) = 38.5\ g\ Ba(OH)_2$$

10.23. Calculate the number of moles of NaOH required to remove the SO_2 from 3.50 metric tons (3.50×10^6 g) of atmosphere if the SO_2 is 0.10% by mass. (Na_2SO_3 and water are the products.)

Ans.

$$2\ NaOH + SO_2 \longrightarrow Na_2SO_3 + H_2O$$

$$3.50 \times 10^6\ g\ atm\left(\frac{0.10\ g\ SO_2}{100\ g\ atm}\right)\left(\frac{1\ mol\ SO_2}{64.0\ g\ SO_2}\right)\left(\frac{2\ mol\ NaOH}{1\ mol\ SO_2}\right) = 110\ mol\ NaOH$$

10.24. Calculate the number of moles of Al_2O_3 needed to prepare 4.00×10^6 g of Al metal in the Hall process:

$$Al_2O_3 + 3\ C \xrightarrow[\text{special solvent}]{\text{electricity}} 2\ Al + 3\ CO$$

Ans.

$$4.00 \times 10^6\ g\ Al\left(\frac{1\ mol\ Al}{27.0\ g\ Al}\right)\left(\frac{1\ mol\ Al_2O_3}{2\ mol\ Al}\right) = 7.41 \times 10^4\ mol\ Al_2O_3$$

10.25. How much AgCl can be prepared with 50.0 g $CaCl_2$ and excess $AgNO_3$?

Ans.

$$CaCl_2 + 2\ AgNO_3 \longrightarrow Ca(NO_3)_2 + 2\ AgCl$$

$$50.0\ g\ CaCl_2\left(\frac{1\ mol\ CaCl_2}{111\ g\ CaCl_2}\right)\left(\frac{2\ mol\ AgCl}{1\ mol\ CaCl_2}\right)\left(\frac{143\ g\ AgCl}{1\ mol\ AgCl}\right) = 129\ g\ AgCl$$

10.26. In chemistry recitation, a student hears (incorrectly) the instructor say, "Hydrogen chloride reacts with $Ba(OH)_2$" when the instructor has actually said, "Hydrogen fluoride reacts with $Ba(OH)_2$." The instructor then asked how much product is formed. The student answers the question correctly. Which section, 10.1 or 10.2, were they discussing? Explain.

Ans. They were discussing Sec. 10.1. Since the student got the answer correct despite hearing the wrong name, they must have been discussing the number of moles of reactants and products. The numbers of moles of HF and HCl would be the same in the reaction, but since they have different formula masses, their masses would be different.

10.27. Consider the equation

$$KMnO_4 + 5\ FeCl_2 + 8\ HCl \longrightarrow MnCl_2 + 5\ FeCl_3 + 4\ H_2O + KCl$$

How many grams of $FeCl_3$ will be produced by the reaction of 2.72 g of $KMnO_4$?

Ans. The reacting ratio is given by the coefficients. The coefficients of interest are 1 for $KMnO_4$ and 5 for $FeCl_3$.

$$2.72\ g\ KMnO_4\left(\frac{1\ mol\ KMnO_4}{158\ g\ KMnO_4}\right)\left(\frac{5\ mol\ FeCl_3}{1\ mol\ KMnO_4}\right)\left(\frac{162\ g\ FeCl_3}{1\ mol\ FeCl_3}\right) = 13.9\ g\ FeCl_3$$

10.28. How many grams of NaCl can be produced from 7.650 g chlorine?

Ans. This problem is the same as Problem 10.14. Problem 10.14 was stated in steps, and this problem is not, but you must do the same steps whether or not they are explicitly stated.

10.29. How much $KClO_3$ must be decomposed thermally to produce 14.6 g O_2?

Ans.

$$2\ KClO_3 \longrightarrow 2\ KCl + 3\ O_2$$

$$14.6\ g\ O_2\left(\frac{1\ mol\ O_2}{32.0\ g\ O_2}\right)\left(\frac{2\ mol\ KClO_3}{3\ mol\ O_2}\right)\left(\frac{122.6\ g\ KClO_3}{1\ mol\ KClO_3}\right) = 37.3\ g\ KClO_3\ \text{decomposed}$$

LIMITING QUANTITIES

10.30. How many sandwiches, each containing 1 slice of salami and 2 slices of bread, can you make with 42 slices of bread and 25 slices of salami?

Ans. With 42 slices of bread, the maximum number of sandwiches you can make is 21. The bread is the limiting quantity.

10.31. How can you recognize a limiting-quantities problem?

Ans. The quantities of two reactants (or products) are given in the problem. They might be stated in any terms—moles, mass, etc.—but they must be given for the problem to be a limiting-quantities problem.

10.32. How much sulfur dioxide is produced by the reaction of 5.00 g S and all the oxygen in the atmosphere of the earth?

Ans. In this problem, it is obvious that the oxygen in the entire earth's atmosphere is in excess, so that no preliminary calculation need be done.

$$S + O_2 \longrightarrow SO_2$$

$$5.00\text{ g S}\left(\frac{1\text{ mol S}}{32.06\text{ g S}}\right)\left(\frac{1\text{ mol }SO_2}{1\text{ mol S}}\right)\left(\frac{64.1\text{ g }SO_2}{1\text{ mol }SO_2}\right) = 10.0\text{ g }SO_2$$

10.33. (*a*) The price of pistachio nuts is \$5.00 per pound. If a grocer has 17 lb for sale and a buyer has \$45.00 to buy nuts with, what is the maximum number of pounds that can be sold? (*b*) Consider the reaction

$$KMnO_4 + 5\ FeCl_2 + 8\ HCl \longrightarrow MnCl_2 + 5\ FeCl_3 + 4\ H_2O + KCl$$

If 45.0 mol of $FeCl_2$ and 17.0 mol of $KMnO_4$ are mixed with excess HCl, how many moles of $MnCl_2$ can be formed?

Ans. (*a*) With \$45, the buyer can buy

$$45\text{ dollars}\left(\frac{1\text{ lb}}{5\text{ dollars}}\right) = 9.0\text{ lb}$$

Since the seller has more nuts than that, the money is in limiting quantity and controls the amount of the sale.

(*b*) With 45.0 mol $FeCl_2$,

$$45.0\text{ mol }FeCl_2\left(\frac{1\text{ mol }KMnO_4}{5\text{ mol }FeCl_2}\right) = 9.00\text{ mol }KMnO_4\text{ required}$$

Since the number of moles of $KMnO_4$ present (17.0 mol) exceeds that number, the limiting quantity is the number of moles of $FeCl_2$.

$$45.0\text{ mol }FeCl_2\left(\frac{1\text{ mol }MnCl_2}{5\text{ mol }FeCl_2}\right) = 9.00\text{ mol }MnCl_2$$

10.34. In each of the following cases, determine which reactant is present in excess, and tell how many moles in excess it is.

	Equation	Moles Present
(*a*)	$2\ Na + Cl_2 \longrightarrow 2\ NaCl$	1.20 mol Na, 0.400 mol Cl_2
(*b*)	$P_4O_{10} + 6\ H_2O \longrightarrow 4\ H_3PO_4$	0.25 mol P_4O_{10}, 1.5 mol H_2O
(*c*)	$HNO_3 + NaOH \longrightarrow NaNO_3 + H_2O$	0.90 mol acid, 0.85 mol base
(*d*)	$Ca(HCO_3)_2 + 2\ HCl \longrightarrow CaCl_2 + 2\ CO_2 + 2\ H_2O$	2.5 mol HCl, 1.0 mol $Ca(HCO_3)_2$
(*e*)	$H_3PO_4 + 3\ NaOH \longrightarrow Na_3PO_4 + 3\ H_2O$	0.70 mol acid, 2.2 mol NaOH

Ans. (*a*) $0.400 \text{ mol } Cl_2\left(\frac{2 \text{ mol Na}}{1 \text{ mol } Cl_2}\right) = 0.800 \text{ mol Na required}$

There is 0.40 mol more Na present than is required.

(*b*) $0.25 \text{ mol } P_4O_{10}\left(\frac{6 \text{ mol } H_2O}{1 \text{ mol } P_4O_{10}}\right) = 1.5 \text{ mol } H_2O \text{ required}$

Neither reagent is in excess; there is just enough H_2O to react with all the P_4O_{10}.

(*c*) $0.85 \text{ mol NaOH}\left(\frac{1 \text{ mol } HNO_3}{1 \text{ mol NaOH}}\right) = 0.85 \text{ mol } HNO_3 \text{ required}$

There is not enough NaOH present; HNO_3 is in excess.
There is 0.05 mol HNO_3 in excess.

(*d*) $1.0 \text{ mol } Ca(HCO_3)_2\left(\frac{2 \text{ mol HCl}}{1 \text{ mol } Ca(HCO_3)_2}\right) = 2.0 \text{ mol HCl required}$

There is 0.5 mol HCl in excess.

(*e*) $0.70 \text{ mol } H_3PO_4\left(\frac{3 \text{ mol NaOH}}{1 \text{ mol } H_3PO_4}\right) = 2.1 \text{ mol NaOH required}$

There is $2.2 - 2.1 = 0.1$ mol NaOH in excess.

10.35. For the following reaction,

$$2\,NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2\,H_2O$$

(*a*) How many moles of NaOH would react with 0.250 mol H_2SO_4? How many moles of Na_2SO_4 would be produced?

(*b*) If 0.250 mol of H_2SO_4 and 0.750 mol NaOH were mixed, how much NaOH would react?

(*c*) If 24.5 g H_2SO_4 and 30.0 g NaOH were mixed, how many grams of Na_2SO_4 would be produced?

Ans. (*a*)

$$0.250 \text{ mol } H_2SO_4\left(\frac{2 \text{ mol NaOH}}{1 \text{ mol } H_2SO_4}\right) = 0.500 \text{ mol NaOH}$$

$$0.250 \text{ mol } H_2SO_4\left(\frac{1 \text{ mol } Na_2SO_4}{1 \text{ mol } H_2SO_4}\right) = 0.250 \text{ mol } Na_2SO_4$$

(*b*) 0.500 mol NaOH, as calculated in part (*a*).

(*c*) This is really the same problem as part (*b*), except that it is stated in grams, because 24.5 g H_2SO_4 is 0.250 mol and 30.0 g NaOH is 0.750 mol NaOH.

To finish:
$$0.250 \text{ mol } Na_2SO_4\left(\frac{142 \text{ g } Na_2SO_4}{1 \text{ mol } Na_2SO_4}\right) = 35.5 \text{ g } Na_2SO_4$$

10.36. For the reaction

$$3\,HCl + Na_3PO_4 \longrightarrow H_3PO_4 + 3\,NaCl$$

a chemist added 2.55 mol of HCl and a certain quantity of Na_3PO_4 to a reaction vessel, which produced 0.750 mol H_3PO_4. Which one of the reactants was in excess?

Ans.
$$2.55 \text{ mol HCl}\left(\frac{1 \text{ mol } H_3PO_4}{3 \text{ mol HCl}}\right) = 0.850 \text{ mol } H_3PO_4$$

would be produced by reaction of all the HCl. Since the actual quantity of H_3PO_4 produced is 0.750 mol, not all the HCl was used up and the Na_3PO_4 must be the limiting quantity. The HCl was in excess.

10.37. (*a*) How many moles of Cl_2 will react with 1.22 mol Na to produce NaCl? (*b*) If 0.880 mol Cl_2 is treated with 1.22 mol Na, how much Cl_2 will react? (*c*) What is the limiting quantity in this problem?

Ans. (*a*)

$$2\ Na + Cl_2 \longrightarrow 2\ NaCl$$

$$1.22\ mol\ Na\left(\frac{1\ mol\ Cl_2}{2\ mol\ Na}\right) = 0.610\ mol\ Cl_2\ reacts$$

(*b*) We calculated in part (*a*) that 0.610 mol of Cl_2 is needed to react. As long as we have at least 0.610 mol present, 0.610 mol Cl_2 will react.

(*c*) Since we have more Cl_2 than that, the Na is in limiting quantity.

10.38. What mass of CO_2 can be produced by the complete combustion of 2.00 kg of octane, C_8H_{18}, a major component of gasoline, in 8.00 kg of oxygen?

Ans.

$$2\ C_8H_{18} + 25\ O_2 \longrightarrow 16\ CO_2 + 18\ H_2O$$

$$2.00\ kg\ C_8H_{18}\left(\frac{1000\ g}{1\ kg}\right)\left(\frac{1\ mol\ C_8H_{18}}{114\ g\ C_8H_{18}}\right) = 17.5\ mol\ C_8H_{18}\ present$$

$$8.00\ kg\ O_2\left(\frac{1000\ g}{1\ kg}\right)\left(\frac{1\ mol\ O_2}{32.0\ g\ O_2}\right) = 250\ mol\ O_2\ present$$

$$17.5\ mol\ C_8H_{18}\left(\frac{25\ mol\ O_2}{2\ mol\ C_8H_{18}}\right) = 219\ mol\ O_2\ required$$

Since 219 mol of O_2 is required and 250 mol O_2 is present, C_8H_{18} is in limiting quantity.

$$17.5\ mol\ C_8H_{18}\left(\frac{16\ mol\ CO_2}{2\ mol\ C_8H_{18}}\right)\left(\frac{44.0\ g\ CO_2}{1\ mol\ CO_2}\right) = 6160\ g = 6.16\ kg\ CO_2\ produced$$

10.39. If you were treating two chemicals, one very cheap and one expensive, to produce a product, which chemical would you use in excess, if one had to be in excess?

Ans. Economically, it would be advisable to use the cheap one in excess, since more product could be obtained per dollar by using up all the expensive reactant.

CALCULATIONS BASED ON NET IONIC EQUATIONS

10.40. What mass of each of the following silver salts would be required to react completely with a solution containing 35.5 g of chloride ion to form (insoluble) silver chloride? (*a*) $AgNO_3$, (*b*) Ag_2SO_4, and (*c*) $AgC_2H_3O_2$.

Ans.

$$35.5\ g\ Cl^-\left(\frac{1\ mol\ Cl^-}{35.5\ g\ Cl^-}\right)\left(\frac{1\ mol\ Ag^+}{1\ mol\ Cl^-}\right) = 1.00\ mol\ Ag^+$$

(*a*) $$1.00\ mol\ Ag^+\left(\frac{1\ mol\ AgNO_3}{1\ mol\ Ag^+}\right)\left(\frac{169.9\ g\ AgNO_3}{1\ mol\ AgNO_3}\right) = 170\ g\ AgNO_3$$

(*b*) $$1.00\ mol\ Ag^+\left(\frac{1\ mol\ Ag_2SO_4}{2\ mol\ Ag^+}\right)\left(\frac{311.8\ g\ Ag_2SO_4}{1\ mol\ Ag_2SO_4}\right) = 156\ Ag_2SO_4$$

(*c*) $$1.00\ mol\ Ag^+\left(\frac{1\ mol\ AgC_2H_3O_2}{1\ mol\ Ag^+}\right)\left(\frac{166.9\ g\ AgC_2H_3O_2}{1\ mol\ AgC_2H_3O_2}\right) = 167\ g\ AgC_2H_3O_2$$

HEAT CAPACITY AND HEAT OF REACTION

10.41. The student political science society decides to take a trip to Washington, D.C. The hostel rate is $20 per student each night. How much will it cost for 23 students to stay for three nights?

Ans.

$$23\ students\left(\frac{20\ dollars}{student \cdot night}\right)3\ nights = 1380\ dollars$$

10.42. A system is initially at 15°C. What will be the final temperature if the system (*a*) is warmed 35°C and (*b*) is warmed to 35°C? (*c*) What is the difference between final temperature and temperature change?

Ans. (*a*) 50°C (*b*) 35°C (*c*) The temperature difference is the final temperature minus the initial temperature. The final temperature is merely a single temperature. Be sure to read the problems carefully so that you do not mistake temperature change for initial or final temperature.

10.43. How much heat is required to raise 43.2 g of iron from 20.0°C to 35.1°C? [$c = 0.447\ \text{J/(g·°C)}$]

Ans.
$$\Delta t = 35.1°\text{C} - 20.0°\text{C} = 15.1°\text{C}$$
$$\text{Heat} = (m)(c)(\Delta t) = (43.2\ \text{g})\left(\frac{0.447\ \text{J}}{\text{g·°C}}\right)(15.1°\text{C}) = 292\ \text{J}$$

10.44. Calculate the heat produced by incomplete combustion of carbon, producing 45.7 g of CO according to the following equation:

$$2\ \text{C} + \text{O}_2 \longrightarrow 2\ \text{CO} + 220\ \text{kJ}$$

Ans.
$$45.7\ \text{g CO}\left(\frac{1\ \text{mol CO}}{28.0\ \text{g CO}}\right)\left(\frac{220\ \text{kJ}}{2\ \text{mol CO}}\right) = 180\ \text{kJ}$$

10.45. Calculate the temperature change produced by the addition of 225 J of heat to 15.3 g of water.

Ans.
$$t = \frac{225\ \text{J}}{[4.184\ \text{J/(g·°C)}](15.3\ \text{g})} = 3.51°\text{C}$$

10.46. Calculate the final temperature t_f if 225 J of energy is added to 15.3 g of water at 19.0°C.

Ans. Δt was calculated in the prior problem.

$$t_f = 19.0°\text{C} + 3.51°\text{C} = 22.5°\text{C}$$

10.47. Calculate the specific heat of a 125 g metal bar which rose in temperature from 18.0°C to 33.0°C on addition of 2.37 kJ of heat.

Ans.
$$c = \frac{\text{heat}}{(m)(t)} = \frac{2370\ \text{J}}{(125\ \text{g})(15.0°\text{C})} = 1.26\ \text{J/(g·°C)}$$

Supplementary Problems

10.48. Read each of the other supplementary problems and state which ones are limiting-quantities problems.

Ans. 10.57, 10.58, 10.59, 10.64, 10.65, 10.66, 10.67, 10.71.

10.49. Calculate the number of grams of methyl alcohol, CH_3OH, obtainable in an industrial process from 5.00 metric tons (5.00×10^6 g) of CO plus hydrogen gas.

Ans. See Problem 10.21.

10.50. Make up your own stoichiometry problem, using the equation

$$\text{CaCl}_2 + 2\ \text{AgNO}_3 \longrightarrow \text{Ca(NO}_3)_2 + 2\ \text{AgCl}$$

10.51. What percentage of 50.0 g of $KClO_3$ must be decomposed thermally to produce 14.6 g O_2?

Ans. The statement of the problem implies that not all the $KClO_3$ is decomposed; it must be in excess for the purpose of producing the 14.6 g O_2. Hence we can base the solution on the quantity of O_2. In Problem 10.29 we found that 37.3 g of $KClO_3$ decomposed. The percent $KClO_3$ decomposed is then

$$\frac{37.3\ \text{g}}{50.0\ \text{g}} \times 100\% = 74.6\%$$

10.52. Percent yield is defined as 100 times the amount of a product actually prepared during a reaction divided by the amount theoretically possible to be prepared according to the balanced chemical equation. (Some reactions are slow, and sometimes not enough time is allowed for their completion; some reactions are accompanied by side reactions which consume a portion of the reactants; some reactions never get to completion.) If 5.00 g $C_6H_{11}Br$ is prepared by treating 5.00 g C_6H_{12} with excess Br_2, what is the percent yield? The equation is

$$\text{C}_6\text{H}_{12} + \text{Br}_2 \longrightarrow \text{C}_6\text{H}_{11}\text{Br} + \text{HBr}$$

Ans.

$$5.00\text{ g }C_6H_{12}\left(\frac{1\text{ mol }C_6H_{12}}{84.2\text{ g }C_6H_{12}}\right)\left(\frac{1\text{ mol }C_6H_{11}Br}{1\text{ mol }C_6H_{12}}\right)\left(\frac{163\text{ g }C_6H_{11}Br}{1\text{ mol }C_6H_{11}Br}\right) = 9.68\text{ g }C_6H_{11}Br$$

$$\frac{5.00\text{ g }C_6H_{11}Br\text{ obtained}}{9.68\text{ g }C_6H_{11}Br\text{ possible}} \times 100\% = 51.7\%\text{ yield}$$

10.53. In a certain experiment, 225 g of ethane, C_2H_6, is burned. (*a*) Write a balanced chemical equation for the combustion of ethane to produce CO_2 and water. (*b*) Determine the number of moles of ethane in 225 g of ethane. (*c*) Determine the number of moles of CO_2 produced by the combustion of that number of moles of ethane. (*d*) Determine the mass of CO_2 that can be produced by the combustion of 225 g of ethane.

Ans. (*a*) $2\ C_2H_6 + 7\ O_2 \longrightarrow 4\ CO_2 + 6\ H_2O$

(*b*) $225\text{ g }C_2H_6\left(\frac{1\text{ mol }C_2H_6}{30.1\text{ g }C_2H_6}\right) = 7.48\text{ mol }C_2H_6$

(*c*) $7.48\text{ mol }C_2H_6\left(\frac{4\text{ mol }CO_2}{2\text{ mol }C_2H_6}\right) = 15.0\text{ mol }CO_2$

(*d*) $15.0\text{ mol }CO_2\left(\frac{44.0\text{ g }CO_2}{1\text{ mol }CO_2}\right) = 660\text{ g }CO_2$

10.54. Determine the number of kilograms of SO_3 produced by treating excess SO_2 with 50.0 g of oxygen.

Ans.

$$2\ SO_2 + O_2 \longrightarrow 2\ SO_3$$

$$50.0\text{ g }O_2\left(\frac{1\text{ mol }O_2}{32.0\text{ g }O_2}\right)\left(\frac{2\text{ mol }SO_3}{1\text{ mol }O_2}\right)\left(\frac{80.0\text{ g }SO_3}{1\text{ mol }SO_3}\right) = 250\text{ g }SO_3 = 0.250\text{ kg }SO_3$$

10.55. How many grams of K_2CO_3 will be produced by thermal decomposition of 4.00 g $KHCO_3$?

Ans.

$$2\ KHCO_3 \xrightarrow{\text{heat}} K_2CO_3 + CO_2 + H_2O$$

$$4.00\text{ g }KHCO_3\left(\frac{1\text{ mol }KHCO_3}{100\text{ g }KHCO_3}\right)\left(\frac{1\text{ mol }K_2CO_3}{2\text{ mol }KHCO_3}\right)\left(\frac{138\text{ g }K_2CO_3}{1\text{ mol }K_2CO_3}\right) = 2.76\text{ g }K_2CO_3$$

10.56. What is the difference in mass between reactions involving 2.25 g Cl^- and 2.25 g NaCl?

Ans. The former might be part of any ionic chloride, but more importantly, the former has a greater mass of chlorine, because 2.25 g NaCl has less than 2.25 g Cl^-.

10.57. How many moles of H_2 can be prepared by treating 5.00 g Na with 2.80 g H_2O? *Caution*: This reaction is very energetic and can even cause an explosion.

Ans.

$$2\ Na + 2\ H_2O \longrightarrow 2\ NaOH + H_2$$

$$5.00\text{ g Na}\left(\frac{1\text{ mol Na}}{23.0\text{ g Na}}\right) = 0.217\text{ mol Na}$$

$$2.80\text{ g }H_2O\left(\frac{1\text{ mol }H_2O}{18.0\text{ g }H_2O}\right) = 0.156\text{ mol }H_2O$$

Since they react in a 1 : 1 mole ratio, H_2O is obviously in limiting quantity.

$$0.156\text{ mol }H_2O\left(\frac{1\text{ mol }H_2}{2\text{ mol }H_2O}\right) = 0.0780\text{ mol }H_2$$

10.58. How many grams of NaCl can be prepared by treating 18.9 g $BaCl_2$ with 14.8 g Na_2SO_4?

Ans.

$$BaCl_2 + Na_2SO_4 \longrightarrow BaSO_4 + 2\ NaCl$$

$$18.9\text{ g }BaCl_2\left(\frac{1\text{ mol }BaCl_2}{208\text{ g }BaCl_2}\right) = 0.0909\text{ mol }BaCl_2$$

$$14.8\text{ g }Na_2SO_4\left(\frac{1\text{ mol }Na_2SO_4}{142\text{ g }Na_2SO_4}\right) = 0.104\text{ mol }Na_2SO_4$$

Since they react in a 1:1 mole ratio, $BaCl_2$ is obviously in limiting quantity.

$$0.0909 \text{ mol } BaCl_2\left(\frac{2 \text{ mol NaCl}}{1 \text{ mol } BaCl_2}\right)\left(\frac{58.5 \text{ g NaCl}}{1 \text{ mol NaCl}}\right) = 10.6 \text{ g NaCl}$$

10.59. If 4.00 g Cu is treated with 15.0 g $AgNO_3$, how many grams of Ag metal can be prepared?

$$2\ AgNO_3 + Cu \longrightarrow 2\ Ag + Cu(NO_3)_2$$

Ans.

$$4.00 \text{ g Cu}\left(\frac{1 \text{ mol Cu}}{63.5 \text{ g Cu}}\right) = 0.0630 \text{ mol Cu present}$$

$$15.0 \text{ g } AgNO_3\left(\frac{1 \text{ mol } AgNO_3}{170 \text{ g } AgNO_3}\right) = 0.0882 \text{ mol } AgNO_3 \text{ present}$$

$$\frac{0.0882 \text{ mol } AgNO_3}{2} = \cancel{0.0441 \text{ mol } AgNO_3}$$

$$\frac{0.0630 \text{ mol Cu}}{1} = \cancel{0.0630 \text{ mol Cu}}$$

$AgNO_3$ is present in limiting quantity, and we base the calculation on the $AgNO_3$ present.

$$0.0882 \text{ mol } AgNO_3\left(\frac{1 \text{ mol Ag}}{1 \text{ mol } AgNO_3}\right)\left(\frac{108 \text{ g Ag}}{1 \text{ mol Ag}}\right) = 9.53 \text{ g Ag}$$

10.60. What, if any, is the difference between the following three exam questions?

How much NaCl is produced by treating 10.00 g NaOH with excess HCl?

How much NaCl is produced by treating 10.00 g NaOH with sufficient HCl?

How much NaCl is produced by treating 10.00 g NaOH with HCl?

Ans. There is no difference.

10.61. What mass of water can be heated from 20.0°C to 45.0°C by the combustion of 4.00 g of carbon to carbon dioxide?

$$C + O_2 \longrightarrow CO_2 + 393 \text{ kJ}$$

Ans.

$$4.00 \text{ g C}\left(\frac{1 \text{ mol C}}{12.0 \text{ g C}}\right)\left(\frac{393 \text{ kJ}}{1 \text{ mol C}}\right) = 131 \text{ kJ produced}$$

Hence 131 kJ = 131 000 J is added to the water.

$$m = \frac{\text{heat}}{(c)(\Delta t)} = \frac{131\,000 \text{ J}}{[4.184 \text{ J/(g·°C)}](25.0\text{°C})} = 1250 \text{ g} = 1.25 \text{ kg}$$

Note that the heat *given off* by the reaction is *absorbed* by the water.

10.62. Some pairs of substances undergo different reactions if one or the other is in excess. For example,

With excess O_2: $C + O_2 \longrightarrow CO_2$

With excess C: $2\ C + O_2 \longrightarrow 2\ CO$

Does this fact make the limiting-quantities calculations in the text untrue for such pairs?

Ans. No. The principles are true for *each* possible reaction.

10.63. A manufacturer produces impure ammonium phosphate as a fertilizer. Treatment of 56.0 g of product with excess NaOH produces 18.3 g NH_3. What percentage of the fertilizer is pure $(NH_4)_3PO_4$? (Assume that any impurity contains no ammonium compound.)

Ans.

$$3\ NaOH + (NH_4)_3PO_4 \longrightarrow 3\ NH_3 + 3\ H_2O + Na_3PO_4$$

$$18.3 \text{ g } NH_3\left(\frac{1 \text{ mol } NH_3}{17.0 \text{ g } NH_3}\right)\left(\frac{1 \text{ mol } (NH_4)_3PO_4}{3 \text{ mol } NH_3}\right)\left(\frac{149 \text{ g } (NH_4)_3PO_4}{1 \text{ mol } (NH_4)_3PO_4}\right) = 53.5 \text{ g } (NH_4)_3PO_4$$

$$\left(\frac{53.5 \text{ g } (NH_4)_3PO_4}{56.0 \text{ g product}}\right) \times 100\% = 95.5\% \text{ pure}$$

10.64. (*a*) When 5.00 g NaOH reacts with 5.00 g HCl, how much NaCl is produced? (*b*) When 6.00 g NaOH reacts with 5.00 g HCl, how much NaCl is produced?

Ans.

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

(*a*)

$$5.00\text{ g HCl}\left(\frac{1\text{ mol HCl}}{36.5\text{ g HCl}}\right) = 0.137\text{ mol HCl}$$

$$5.00\text{ g NaOH}\left(\frac{1\text{ mol NaOH}}{40.0\text{ g NaOH}}\right) = 0.125\text{ mol NaOH}$$

Since the reactants react in a 1:1 ratio, NaOH is the limiting quantity:

$$0.125\text{ mol NaOH}\left(\frac{1\text{ mol NaCl}}{1\text{ mol NaOH}}\right)\left(\frac{58.5\text{ g NaCl}}{1\text{ mol NaCl}}\right) = 7.31\text{ g NaCl}$$

(*b*)

$$6.00\text{ g NaOH}\left(\frac{1\text{ mol NaOH}}{40.0\text{ g NaOH}}\right) = 0.150\text{ mol NaOH}$$

$$5.00\text{ g HCl}\left(\frac{1\text{ mol HCl}}{36.5\text{ g HCl}}\right) = 0.137\text{ mol HCl}$$

Since the reactants react in a 1:1 ratio, HCl is the limiting quantity:

$$0.137\text{ mol HCl}\left(\frac{1\text{ mol NaCl}}{1\text{ mol HCl}}\right)\left(\frac{58.5\text{ g NaCl}}{1\text{ mol NaCl}}\right) = 8.01\text{ g NaCl}$$

10.65. Calculate the number of moles of each solute in the final solution after 1.75 mol of aqueous $BaCl_2$ and 2.70 mol of aqueous $AgNO_3$ are mixed.

Ans.

	$BaCl_2$	$+\ 2\,AgNO_3$	$\longrightarrow Ba(NO_3)_2 + 2\,AgCl(s)$
Initial:	1.75 mol	2.70 mol	0.00 mol
Change:	1.35 mol	2.70 mol	1.35 mol
Final:	0.40 mol	0.00 mol	1.35 mol

10.66. Calculate the number of moles of each ion in the final solution after 1.75 mol of aqueous $BaCl_2$ and 2.70 mol of aqueous $AgNO_3$ are mixed.

Ans. The Ba^{2+} ion and the NO_3^- ion do not react (they are spectator ions), so there are 1.75 mol of Ba^{2+} ion and 2.70 mol of NO_3^- ion in the final solution. The silver ion and chloride ion concentrations are calculated using the net ionic equation:

	Cl^-	$+\ Ag^+$	$\longrightarrow AgCl(s)$
Initial:	3.50 mol	2.70 mol	
Change:	2.70 mol	2.70 mol	
Final:	0.80 mol	0.00 mol	

These results are the same as those of the prior problem.

10.67. Consider the reaction

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

If exactly 20.0 g of $Ba(OH)_2$ reacts according to this equation, do you know how much $Ba(OH)_2$ was added to the HCl? Do you know how much HCl was added to the $Ba(OH)_2$? Explain.

Ans. You cannot tell. Either reactant might have been in excess. The information given allows calculations of how much reacted and how much of the products were produced, but not how much was added in the first place.

10.68. Redo Problem 10.18 without bothering to solve for intermediate answers.

10.69. Determine the number of grams of SO_3 produced by treating excess SO_2 with 50.0 g of oxygen.

Ans. 250 g.

10.70. A sample of a hydrocarbon (a compound of carbon and hydrogen only) is burned, and 1.10 g CO_2 and 0.450 g H_2O are produced. What is the empirical formula of the hydrocarbon?

Ans. The empirical formula can be determined from the ratio of moles of carbon atoms to moles of hydrogen atoms. From the masses of products, we can get the numbers of moles of products, from which we can get the numbers of moles of C and H. The mole ratio of these two elements is the same in the products as in the original compound.

$$1.10 \text{ g } CO_2\left(\frac{1 \text{ mol } CO_2}{44.0 \text{ g } CO_2}\right) = 0.0250 \text{ mol } CO_2$$

$$0.450 \text{ g } H_2O\left(\frac{1 \text{ mol } H_2O}{18.0 \text{ g } H_2O}\right) = 0.0250 \text{ mol } H_2O$$

0.0250 mol CO_2 contains 0.0250 mol C

0.0250 mol H_2O contains 0.500 mol H

The mole ratio is 1:2, and the empirical formula is CH_2.

10.71. How many moles of each substance are present in solution after 0.100 mol of NaOH is added to 0.200 mol of $HC_2H_3O_2$?

Ans. The balanced equation is

$$NaOH + HC_2H_3O_2 \longrightarrow NaC_2H_3O_2 + H_2O$$

The limiting quantity is NaOH, and so 0.100 mol NaOH reacts with 0.100 mol $HC_2H_3O_2$ to produce 0.100 mol $NaC_2H_3O_2$ + 0.100 mol H_2O. There is also 0.100 mol excess $HC_2H_3O_2$ left in the solution.

10.72. Combine Figs. 7-5 and 10-4 to show all the conversions learned so far.

Ans. The answer is shown on the factor-label conversion figure, page 348. It includes the boxes numbered 3 to 8, 11 to 14, 16 and 17, plus all the conversion factors on the arrows between them.

EXAMPLE 11.15. (*a*) Calculate the concentration of Zn^{2+} produced when excess solid zinc is treated with 100.0 mL of 6.000 *M* HCl. Assume no change in volume. (*b*) Repeat the problem with solid aluminum.

Ans. (*a*)

$$Zn + 2\,H^+ \longrightarrow Zn^{2+} + H_2$$

$$100.0\text{ mL}\left(\frac{6.000\text{ mmol H}^+}{1\text{ mL}}\right)\left(\frac{1\text{ mmol Zn}^{2+}}{2\text{ mmol H}^+}\right) = 300.0\text{ mmol Zn}^{2+}$$

$$\frac{300.0\text{ mmol Zn}^{2+}}{100.0\text{ mL}} = 3.000\,M\text{ Zn}^{2+}$$

(*b*)

$$2\,Al + 6\,H^+ \longrightarrow 2\,Al^{3+} + 3\,H_2$$

$$100.0\text{ mL}\left(\frac{6.000\text{ mmol H}^+}{1\text{ mL}}\right)\left(\frac{2\text{ mmol Al}^{3+}}{6\text{ mmol H}^+}\right) = 200.0\text{ mmol Al}^{3+}$$

$$\frac{200.0\text{ mmol Al}^{3+}}{100.0\text{ mL}} = 2.000\,M\text{ Al}^{3+}$$

Solved Problems

INTRODUCTION

11.1. Which, if either, has more sugar in it, (*a*) a half cup of tea with one lump of sugar or (*b*) a whole cup of tea with two lumps of sugar?

Ans. Two lumps are more than one; the whole cup has more sugar. Note the difference between *quantity* of sugar and *concentration* of sugar.

11.2. Which, if either, of the following tastes sweeter, (*a*) a half cup of tea with one lump of sugar or (*b*) a whole cup of tea with two lumps of sugar?

Ans. They both taste equally sweet, since their concentrations are equal.

MOLARITY CALCULATIONS

11.3. Calculate the molarity of each of the following solutions: (*a*) 4.00 mol solute in 2.50 L of solution, (*b*) 0.200 mol solute in 0.240 L of solution, (*c*) 0.0500 mol solute in 25.0 mL of solution, and (*d*) 0.240 mol solute in 750.0 mL of solution.

Ans. (*a*) $\frac{4.00\text{ mol}}{2.50\text{ L}} = 1.60\,M$

(*b*) $\frac{0.200\text{ mol}}{0.240\text{ L}} = 0.833\,M$

(*c*) $\frac{0.0500\text{ mol}}{0.0250\text{ L}} = 2.00\,M$ or $\frac{50.0\text{ mmol}}{25.0\text{ mL}} = 2.00\,M$

(*d*) $\frac{0.240\text{ mol}}{0.750\text{ L}} = 0.320\,M$ or $\frac{240\text{ mmol}}{750.0\text{ mL}} = 0.320\,M$

(Note: moles per liter or millimoles per milliliter, not moles per milliliter)

11.4. Calculate the number of moles of solute in each of the following solutions: (*a*) 1.50 L of 0.800 *M* solution, (*b*) 1.66 L of 0.150 *M* solution, (*c*) 45.0 mL of 0.600 *M* solution, and (*d*) 25.0 mL of 2.00 *M* solution.

Ans. (*a*) $1.50\text{ L}\left(\frac{0.800\text{ mol}}{1\text{ L}}\right) = 1.20\text{ mol}$

(*b*) $1.66\text{ L}\left(\frac{0.150\text{ mol}}{1\text{ L}}\right) = 0.249\text{ mol}$

(*c*) $0.0450\text{ L}\left(\frac{0.600\text{ mol}}{1\text{ L}}\right) = 0.0270\text{ mol}$

(*d*) $0.0250\text{ L}\left(\frac{2.00\text{ mol}}{1\text{ L}}\right) = 0.0500\text{ mol}$

11.5. How can you make 2.25 L of 4.00 M sugar solution?

Ans. The solution will contain 9.00 mol sugar:

$$2.25\ \text{L}\left(\frac{4.00\ \text{mol}}{1\ \text{L}}\right) = 9.00\ \text{mol}$$

Thus, place 9.00 mol sugar in a liter or two of water, mix until dissolved, dilute the resulting solution to 2.25 L, and mix thoroughly.

11.6. Calculate the volume of 1.75 M solution required to contain 4.20 mol of solute.

Ans.
$$4.20\ \text{mol}\left(\frac{1\ \text{L}}{1.75\ \text{mol}}\right) = 2.40\ \text{L}$$

11.7. A 10.0-mL solution contains 2.40 mmol of solute. What is its molarity?

Ans.
$$\frac{2.40\ \text{mmol}}{10.0\ \text{mL}} = 0.240\ M$$

Molarity can be calculated by dividing millimoles by milliliters.

11.8. How many moles of solute are present in 29.4 mL of 0.606 M solution?

Ans.
$$(0.0294\ \text{L})(0.606\ \text{mol/L}) = 0.0178\ \text{mol}$$

11.9. Calculate the number of milliliters of 1.25 M solution required to contain 0.622 mol of solute.

Ans.
$$0.622\ \text{mol}\left(\frac{1\ \text{L}}{1.25\ \text{mol}}\right) = 0.498\ \text{L} = 498\ \text{mL}$$

11.10. What volume of 1.45 M NaCl solution contains 71.3 g NaCl?

Ans.
$$71.3\ \text{g NaCl}\left(\frac{1\ \text{mol NaCl}}{58.5\ \text{g NaCl}}\right) = 1.22\ \text{mol NaCl}$$

$$1.22\ \text{mol NaCl}\left(\frac{1\ \text{L solution}}{1.45\ \text{mol NaCl}}\right) = 0.841\ \text{L} = 841\ \text{mL}$$

11.11. What is the concentration of a solution prepared by dissolving 22.2 g NaCl in sufficient water to make 86.9 mL of solution?

Ans. Molarity is in moles per liter. We must change the grams of NaCl to moles and the milliliters of solution to liters.

$$22.2\ \text{g NaCl}\left(\frac{1\ \text{mol NaCl}}{58.5\ \text{g NaCl}}\right) = 0.379\ \text{mol}$$

$$0.379\ \text{mol}/0.0869\ \text{L} = 4.36\ M$$

11.12. How many grams of NaCl are present in 72.1 mL of 1.03 M NaCl?

Ans.
$$(0.0721\ \text{L})(1.03\ \text{mol/L}) = 0.0743\ \text{mol}$$

$$(0.0743\ \text{mol})(58.5\ \text{g NaCl/mol}) = 4.35\ \text{g NaCl}$$

11.13. Calculate the volume of 0.900 M solution required to contain 1.84 mol of solute.

Ans.
$$1.84\ \text{mol}\left(\frac{1\ \text{L}}{0.900\ \text{mol}}\right) = 2.04\ \text{L}$$

11.14. How many milligrams of NaOH are present in 35.0 mL of 2.18 M NaOH?

Ans.
$$35.0\ \text{mL}\left(\frac{2.18\ \text{mmol}}{1\ \text{mL}}\right)\left(\frac{40.0\ \text{mg}}{1\ \text{mmol}}\right) = 3050\ \text{mg}$$

11.15. What is the concentration of a solution prepared by diluting 3.0 L of 2.5 *M* solution to 8.0 L with water?

Ans. The number of moles of solute is not changed by addition of the water. The number of moles in the original solution is

$$3.0\ \text{L}\left(\frac{2.5\ \text{mol}}{1\ \text{L}}\right) = 7.5\ \text{mol}$$

That 7.5 mol is now dissolved in 8.0 L, and its concentration is

$$\frac{7.5\ \text{mol}}{8.0\ \text{L}} = 0.94\ M$$

11.16. What is the concentration of a solution prepared by diluting 0.500 L of 1.80 *M* solution to 1.50 L with solvent?

Ans. The number of moles of solute is not changed by addition of the solvent. The number of moles in the original solution is

$$0.500\ \text{L}\left(\frac{1.80\ \text{mol}}{1\ \text{L}}\right) = 0.900\ \text{mol}$$

That 0.900 mol is now dissolved in 1.50 L (compare Problem 11.17), and its concentration is

$$\frac{0.900\ \text{mol}}{1.50\ \text{L}} = 0.600\ M$$

11.17. What is the concentration of a solution prepared by diluting 0.500 L of 1.80 *M* solution with 1.50 L of solvent?

Ans. The number of moles of solute is not changed by addition of the solvent; it is 0.900 mol. What is the final volume of the solution? If we add 1.50 L of solvent, it will be about 2.00 L. Compare this wording with that of Problem 11.16. The 1.50 mol is now dissolved in 2.00 L, and its concentration is

$$\frac{0.900\ \text{mol}}{2.00\ \text{L}} = 0.450\ M$$

11.18. What is the concentration of a solution prepared by diluting 25.0 mL of 3.00 *M* solution to 60.0 mL?

Ans. The number of moles of solute is not changed by addition of the solvent. The number of moles in the original solution is

$$(0.0250\ \text{L})(3.00\ \text{mol/L}) = 0.0750\ \text{mol}$$

That 0.0750 mol is now dissolved in 0.0600 L, and its concentration is

$$\frac{0.0750\ \text{mol}}{0.0600\ \text{L}} = 1.25\ M$$

Alternatively, the number of millimoles is given by

$$(25.0\ \text{mL})(3.00\ \text{mmol/mL}) = 75.0\ \text{mmol}$$

The concentration is

$$\frac{75.0\ \text{mmol}}{60.0\ \text{mL}} = 1.25\ M$$

The use of millimoles and milliliters saves conversions of milliliters to liters.

11.19. What concentration of salt is obtained by mixing 20.0 mL of 3.0 *M* salt solution with 30.0 mL of 2.0 *M* salt solution?

Ans. The final concentration is the total number of millimoles divided by the total number of milliliters. The volume is 20.0 mL + 30.0 mL = 50.0 mL. The total number of millimoles is given by

$$(20.0\ \text{mL})(3.0\ \text{mmol/mL}) + (30.0\ \text{mL})(2.0\ \text{mmol/mL}) = 120\ \text{mmol}$$

The concentration is 120 mmol/50.0 mL = 2.4 *M*.

11.20. What concentration of salt is obtained by mixing 20.0 mL of 3.0 *M* salt solution with 30.0 mL of 2.0 *M* salt solution and diluting with water to 100.0 mL?

Ans. The final concentration is the total number of moles divided by the total number of liters. The volume is 100.0 mL. Since there is no solute in the water, the total number of moles is the same as that in the prior problem. The concentration is 120 mmol/100.0 mL = 1.2 *M*. The concentration is lower than that in Problem 11.19 despite the same number of moles of solute, because of the greater volume.

11.21. Calculate the concentration of sugar in a solution prepared by mixing 3.0 L of 2.0 *M* sugar with 2.5 L of 1.0 *M* salt.

Ans. The sugar concentration is given by dividing the number of moles of sugar by the total volume. The number of moles of salt makes no difference in this problem because the problem does not ask about salt concentration and the salt does not react. This is simply a dilution problem for the sugar.

$$(3.0\text{ L})(2.0\text{ mol/L}) = 6.0\text{ mol sugar}$$

$$\frac{6.0\text{ mol sugar}}{5.5\text{ L}} = 1.1\ M\text{ sugar}$$

TITRATION

11.22. (*a*) A solid acid containing one hydrogen atom per molecule is titrated with 1.000 *M* NaOH. If 27.21 mL of base is used in the titration, how many moles of base is present? (*b*) How many moles of acid? (*c*) If the mass of the acid was 3.494 g, what is the molar mass of the acid?

Ans. (*a*) (27.21 mL)(1.000 mmol/mL) = 27.21 mmol base

(*b*) Since the acid has one hydrogen atom per molecule, it will react in a 1:1 ratio with the base. The equation might be written as

$$HX + NaOH \longrightarrow NaX + H_2O$$

where X stands for the anion of the acid, whatever it might be (just as *x* is often used for an unknown in algebra). The quantity of acid is therefore 27.21 mmol, or 0.027 21 mol.

(*c*)
$$\text{Molar mass} = \frac{3.494\text{ g}}{0.027\,21\text{ mol}} = 128.4\text{ g/mol}$$

11.23. A 25.00-mL sample of 1.000 *M* HCl is titrated with 31.72 mL of NaOH. What is the concentration of the base?

Ans.
$$(25.00\text{ mL HCl})(1.000\text{ mmol/mL}) = 25.00\text{ mmol HCl}$$

Since the reagents react in a 1:1 ratio, there is 25.00 mmol NaOH in the 31.72 mL of base.

$$\frac{25.00\text{ mmol NaOH}}{31.72\text{ mL}} = 0.7881\ M\text{ NaOH}$$

11.24. A 25.00-mL sample of 2.000 *M* H_2SO_4 is titrated with 16.54 mL of NaOH until both hydrogen atoms of each molecule of the acid are just neutralized. What is the concentration of the base?

Ans.
$$(25.00\text{ mL } H_2SO_4)(2.000\text{ mmol/mL}) = 50.00\text{ mmol } H_2SO_4$$

$$H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + 2\ H_2O$$

$$50.00\text{ mmol } H_2SO_4\left(\frac{2\text{ mmol NaOH}}{1\text{ mmol } H_2SO_4}\right) = 100.0\text{ mmol NaOH}$$

$$\frac{100.0\text{ mmol NaOH}}{16.54\text{ mL}} = 6.046\ M\text{ NaOH}$$

STOICHIOMETRY IN SOLUTION

11.25. What mass of $H_2C_2O_4$ can react with 35.0 mL of 1.50 *M* $KMnO_4$ according to the following equation?

$$5\ H_2C_2O_4 + 2\ KMnO_4 + 3\ H_2SO_4 \longrightarrow 2\ MnSO_4 + K_2SO_4 + 10\ CO_2 + 8\ H_2O$$

Ans.

$$(0.0350\ \text{L})(1.50\ \text{mol/L}) = 0.0525\ \text{mol}\ KMnO_4$$

$$0.0525\ \text{mol}\ KMnO_4\left(\frac{5\ \text{mol}\ H_2C_2O_4}{2\ \text{mol}\ KMnO_4}\right)\left(\frac{90.0\ \text{g}\ H_2C_2O_4}{1\ \text{mol}\ H_2C_2O_4}\right) = 11.8\ \text{g}\ H_2C_2O_4$$

11.26. Calculate the number of grams of $BaSO_4$ that can be prepared by treating 35.0 mL of 0.479 *M* $BaCl_2$ with excess Na_2SO_4.

Ans.

$$BaCl_2 + Na_2SO_4 \longrightarrow BaSO_4 + 2\ NaCl$$

$$(35.0\ \text{mL})(0.479\ \text{mmol}\ BaCl_2/\text{mL}) = 16.8\ \text{mmol}\ BaCl_2$$

$$16.8\ \text{mmol}\ BaCl_2\left(\frac{1\ \text{mmol}\ BaSO_4}{1\ \text{mmol}\ BaCl_2}\right)\left(\frac{233\ \text{mg}\ BaSO_4}{1\ \text{mmol}\ BaSO_4}\right) = 3910\ \text{mg} = 3.91\ \text{g}\ BaSO_4$$

11.27. When 20.0 mL of 1.71 *M* $AgNO_3$ is added to 35.0 mL of 0.444 *M* $CuCl_2$, how many grams of AgCl will be produced?

Ans.

$$0.0200\ \text{L}\left(\frac{1.71\ \text{mol}\ AgNO_3}{1\ \text{L}}\right)\left(\frac{1\ \text{mol}\ Ag^+}{1\ \text{mol}\ AgNO_3}\right) = 0.0342\ \text{mol}\ Ag^+\ \text{present}$$

$$0.0350\ \text{L}\left(\frac{0.444\ \text{mol}\ CuCl_2}{1\ \text{L}}\right)\left(\frac{2\ \text{mol}\ Cl^-}{1\ \text{mol}\ CuCl_2}\right) = 0.0311\ \text{mol}\ Cl^-\ \text{present}$$

$$Ag^+ + Cl^- \longrightarrow AgCl$$

The chloride is limiting. It will produce 0.0311 mol AgCl.

$$(0.0311\ \text{mol AgCl})(143\ \text{g AgCl}/1\ \text{mol AgCl}) = 4.45\ \text{g AgCl}$$

11.28. What concentration of NaCl will be produced when 1.00 L of 1.11 *M* HCl and 250 mL of 4.05 *M* NaOH are mixed? Assume that the volume of the final solution is the sum of the two initial volumes.

Ans.

$$(1.00\ \text{L})(1.11\ \text{mol/L}) = 1.11\ \text{mol HCl}$$

$$(0.250\ \text{L})(4.05\ \text{mol/L}) = 1.01\ \text{mol NaOH}$$

$$NaOH + HCl \longrightarrow NaCl + H_2O$$

So 1.01 mol NaCl will be produced, in 1.25 L:

$$\frac{1.01\ \text{mol}}{1.25\ \text{L}} = 0.808\ M$$

Supplementary Problems

11.29. Describe in detail how you would prepare 250.0 mL of 4.000 *M* NaCl solution.

Ans. First, figure out how much NaCl you need:

$$(0.2500\ \text{L})(4.000\ \text{mol/L}) = 1.000\ \text{mol}$$

Since the laboratory balance does not weigh out in moles, convert this quantity to grams:

$$(1.000\ \text{mol NaCl})(58.45\ \text{g/mol}) = 58.45\ \text{g NaCl}$$

Weight out 58.45 g of NaCl and dissolve it in a portion of water in a 250-mL volumetric flask (Fig. 11-2). After the salt has dissolved, dilute the solution with water until the volume reaches the calibration mark on the flask (250.0 mL). Mix the solution thoroughly by inverting and shaking the stoppered flask several times.

11.30. What is the percent by mass of NaCl in 1.60 M NaCl solution? Assume that the solution has a density of 1.06 g/mL.

Ans. Percent by mass is the number of grams of NaCl in 100.0 g solution.

$$\frac{1.60 \text{ mol NaCl}}{1 \text{ L}}\left(\frac{58.5 \text{ g NaCl}}{1 \text{ mol NaCl}}\right)\left(\frac{1 \text{ L}}{1060 \text{ g solution}}\right) = \frac{0.0883 \text{ g NaCl}}{1 \text{ g solution}}$$

For 100.0 g of solution, multiply the numerator and denominator by 100:

$$\frac{0.0883 \text{ g NaCl}}{1 \text{ g solution}} = \frac{8.83 \text{ g NaCl}}{100 \text{ g solution}} = 8.83\% \text{ NaCl}$$

11.31. Which boxes of the conversion diagram (page 348) indicate the method of converting volumes of solutions to moles of reactants and/or products and vice versa?

Ans. Boxes 2, 6, 12, and 15 with the intervening arrows.