UNIT 2 QUANTITIES IN CHEMISTRY

2.1 EXTENSION EXERCISE

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RATIOS IN CHEMICAL EQUATIONS—ADDITIONAL PRACTICE

1. bun = Bu, patty = Hp, cheese = Ch, bacon = Ba
   Bu + 2 Hp + Ch + 3 Ba $\rightarrow$ $BuHp_2ChBa_3$
2. (a) 5
   (b) 6
   (c) 6
3. (a) 1
   (b) 2
   (c) 10
   (d) 1 dozen
   (e) 1 mol
4. (a) $N_{2(g)} + 2\ O_{2(g)} \rightarrow 2\ NO_{2(g)}$
   (b) 4 molecules
   (c) 4 dozen molecules
   (d) 4 mol of molecules
5. (a) 4 mol
   (b) 20 mol
   (c) 0.4 mol
   (d) 6 mol

2.1 EXTENSION EXERCISE

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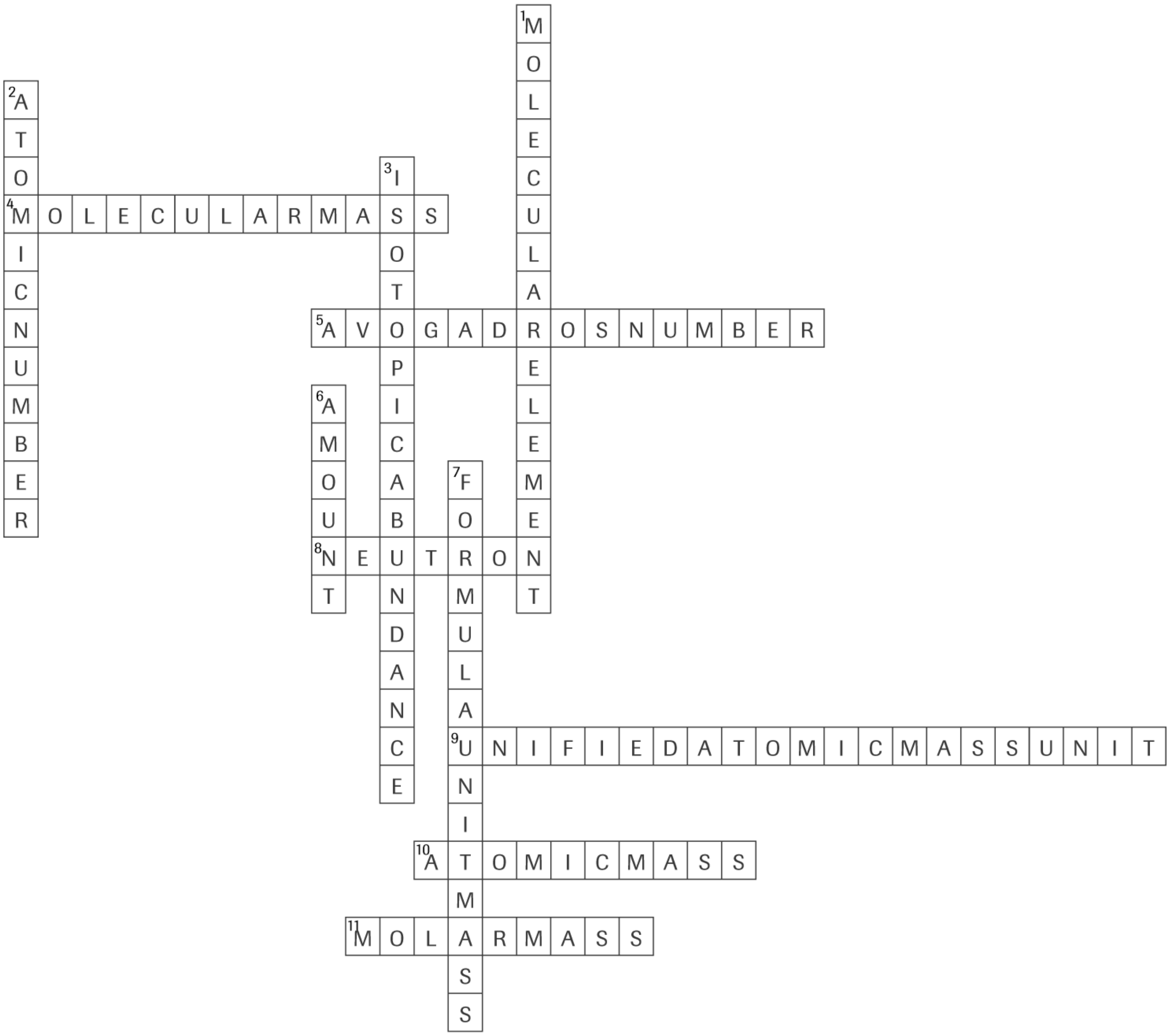
AMOUNTS IN CHEMISTRY—ADDITIONAL PRACTICE



2.2 EXTENSION EXERCISE

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CALCULATIONS INVOLVING THE MOLE—ADDITIONAL PRACTICE

1.

Symbol	Quantity	Unit
n	amount	mol
m	mass	mg, g, kg
M	molar mass	g/mol
N	number	atoms, ions, molecules
N_A	Avogadro's number	—

2. (a) n_{Na} = 0.38 mol Na
M_{Na} = 22.99 g/mol Na
1 mol Na = 22.99 g Na

$$m_{Na} = 0.38 \cancel{\text{ mol Na}} \times \frac{22.99 \text{ g Na}}{1 \cancel{\text{ mol Na}}}$$

$$m_{Na} = 8.7 \text{ g Na}$$

The mass of 0.38 mol sodium atoms is 8.7 g.

(b) n_C = 0.199 mol C
M_C = 12.01 g/mol C
1 mol C = 12.01 g C

$$m_C = 0.199 \cancel{\text{ mol C}} \times \frac{12.01 \text{ g C}}{1 \cancel{\text{ mol C}}}$$

$$m_C = 2.39 \text{ g C}$$

The mass of 0.199 mol carbon is 2.39 g.

(c) n_{Cu} = 0.043 mol Cu
M_{Cu} = 63.55 g/mol Cu
1 mol Cu = 63.55 g Cu

$$m_{Cu} = 0.043 \cancel{\text{ mol Cu}} \times \frac{63.55 \text{ g Cu}}{1 \cancel{\text{ mol Cu}}}$$

$$m_{Cu} = 2.7 \text{ g Cu}$$

The mass of 0.043 mol copper is 2.7 g.

(d) n_{He} = 30.8 mol He
M_{He} = 4.00 g/mol He
1 mol He = 4.00 g He

$$m_{He} = 30.8 \cancel{\text{ mol He}} \times \frac{4.00 \text{ g He}}{1 \cancel{\text{ mol He}}}$$

$$m_{He} = 123 \text{ g He}$$

The mass of 30.8 mol helium gas is 123 g.

3. (a) m_{Hg} = 4.5 g Hg
M_{Hg} = 200.59 g/mol Hg
1 mol Hg = 200.59 g Hg

$$n_{Hg} = 4.5\ \cancel{g\ Hg} \times \frac{1\ \text{mol Hg}}{200.59\ \cancel{g\ Hg}}$$

$$n_{Hg} = 0.022\ \text{mol Hg}$$

There is 0.022 mol mercury in 4.5 g of mercury.

(b) m_{Ni} = 6.41 g Ni
M_{Ni} = 58.69 g/mol Ni
1 mol Ni = 58.69 g Ni

$$n_{Ni} = 6.41\ \cancel{g\ Ni} \times \frac{1\ \text{mol Ni}}{58.69\ \cancel{g\ Ni}}$$

$$n_{Ni} = 0.109\ \text{mol Ni}$$

There is 0.109 mol nickel in 6.41 g of nickel.

(c) m_{Na} = 552 mg Na
M_{Na} = 22.99 g/mol Na
1 mol Na = 22.99 g Na

$$n_{Na} = 552\ \cancel{mg\ Na} \times \frac{1\ \cancel{g\ Na}}{1000\ \cancel{mg\ Na}} \times \frac{1\ \text{mol Na}}{22.99\ \cancel{g\ Na}}$$

$$n_{Na} = 0.0240\ \text{mol Na}$$

There is 0.0240 mol sodium in 552 mg of sodium.

(d) m_V = 15 μg V
M_V = 50.94 g/mol V
1 mol V = 50.94 g V

$$n_V = 15\ \cancel{\mu g\ V} \times \frac{1\ \cancel{g\ V}}{1 \times 10^6\ \cancel{\mu g\ V}} \times \frac{1\ \text{mol V}}{50.94\ \cancel{g\ V}}$$

$$n_V = 2.9 \times 10^{-7}\ \text{mol V}$$

There is 2.9×10^{-7} mol vanadium in 15 μg of vanadium.

4. (a) m_{Al} = 550 g Al
M_{Al} = 26.98 g/mol Al
1 mol Al = 26.98 g Al
1 mol Al = 6.02×10^{23} atoms Al

$$N_{Al} = 550\ \cancel{g\ Al} \times \frac{1\ \cancel{mol\ Al}}{26.98\ \cancel{g\ Al}} \times \frac{6.02 \times 10^{23}\ \text{atoms Al}}{1\ \cancel{mol\ Al}}$$

$$N_{Al} = 1.2 \times 10^{25}\ \text{atoms Al}$$

There are 1.2×10^{25} atoms of aluminum in a 550-g aluminum saucepan.

(b) m_{Cu} = 30.5 mg Cu
M_{Cu} = 63.55 g/mol Cu
1 mol Cu = 63.55 g Cu
1 mol Cu = 6.02×10^{23} atoms Cu

$$N_{Cu} = 30.5\ \cancel{mg\ Cu} \times \frac{1\ \cancel{g\ Cu}}{1000\ \cancel{mg\ Cu}} \times \frac{1\ \cancel{mol\ Cu}}{63.55\ \cancel{g\ Cu}} \times \frac{6.02 \times 10^{23}\ \text{atoms Cu}}{1\ \cancel{mol\ Cu}}$$

$$N_{Cu} = 2.89 \times 10^{20}\ \text{atoms Cu}$$

There are 2.89×10^{20} atoms of copper in 30.5 mg of copper wire.

5. (a) $M_{AlCl_3} = 1(M_{Al}) + 3(M_{Cl})$

$= 1(26.98 \text{ g/mol}) + 3(35.45 \text{ g/mol})$

$= 26.98 \text{ g/mol} + 106.35 \text{ g/mol}$

$M_{AlCl_3} = 133.33 \text{ g/mol}$

The molar mass of $AlCl_{3(s)}$ is 133.33 g/mol.

(b) $M_{KH_2PO_4} = 1(M_K) + 2(M_H) + 1(M_P) + 4(M_O)$

$= 1(39.10 \text{ g/mol}) + 2(1.01 \text{ g/mol}) + 1(30.97 \text{ g/mol}) + 4(16.00 \text{ g/mol})$

$= 39.10 \text{ g/mol} + 2.02 \text{ g/mol} + 30.97 \text{ g/mol} + 64.00 \text{ g/mol}$

$M_{KH_2PO_4} = 136.09 \text{ g/mol}$

The molar mass of $KH_2PO_{4(s)}$ is 136.09 g/mol.

(c) $M_{Ca(NO_3)_2} = 1(M_{Ca}) + 2(M_N) + 6(M_O)$

$= 1(40.08 \text{ g/mol}) + 2(14.01 \text{ g/mol}) + 6(16.00 \text{ g/mol})$

$= 40.08 \text{ g/mol} + 28.02 \text{ g/mol} + 96.00 \text{ g/mol}$

$M_{Ca(NO_3)_2} = 164.10 \text{ g/mol}$

The molar mass of $Ca(NO_3)_{2(s)}$ is 164.10 g/mol.

(d) $M_{Ta_2O_5} = 2(M_{Ta}) + 5(M_O)$

$= 2(180.95 \text{ g/mol}) + 5(16.00 \text{ g/mol})$

$= 361.90 \text{ g/mol} + 80.00 \text{ g/mol}$

$M_{Ta_2O_5} = 441.90 \text{ g/mol}$

The molar mass of $Ta_2O_{5(s)}$ is 441.90 g/mol.

(e) $M_{NaH_2PO_4} = 1(M_{Na}) + 2(M_H) + 1(M_P) + 4(M_O)$

$= 1(22.99 \text{ g/mol}) + 2(1.01 \text{ g/mol}) + 1(30.97 \text{ g/mol}) + 4(16.00 \text{ g/mol})$

$= 22.99 \text{ g/mol} + 2.02 \text{ g/mol} + 30.97 \text{ g/mol} + 64.00 \text{ g/mol}$

$M_{NaH_2PO_4} = 119.98 \text{ g/mol}$

The molar mass of $NaH_2PO_{4(s)}$ is 119.98 g/mol.

(f) $M_{Al(MnO_4)_3} = 1(M_{Al}) + 3(M_{Mn}) + 12(M_O)$

$= 1(26.98 \text{ g/mol}) + 3(54.94 \text{ g/mol}) + 12(16.00 \text{ g/mol})$

$= 26.98 \text{ g/mol} + 164.82 \text{ g/mol} + 192.00 \text{ g/mol}$

$M_{Al(MnO_4)_3} = 383.80 \text{ g/mol}$

The molar mass of $Al(MnO_4)_{3(s)}$ is 383.80 g/mol.

(g) $M_{KAl(SO_4)_2} = 1(M_K) + 1(M_{Al}) + 2(M_S) + 8(M_O)$

$= 1(39.10 \text{ g/mol}) + 1(26.98 \text{ g/mol}) + 2(32.06 \text{ g/mol}) + 8(16.00 \text{ g/mol})$

$= 39.10 \text{ g/mol} + 26.98 \text{ g/mol} + 64.12 \text{ g/mol} + 128.00 \text{ g/mol}$

$M_{KAl(SO_4)_2} = 258.20 \text{ g/mol}$

The molar mass of $KAl(SO_4)_{2(s)}$ is 258.20 g/mol.

6. (a) $n_{CaCl_2} = 3.00 \text{ mol } CaCl_2$

$M_{CaCl_2} = 110.98 \text{ g/mol } CaCl_2$

$1 \text{ mol } CaCl_2 = 110.98 \text{ g } CaCl_2$

$$m_{CaCl_2} = 3.00 \cancel{\text{ mol } CaCl_2} \times \frac{110.98 \text{ g } CaCl_2}{1 \cancel{\text{ mol } CaCl_2}}$$

$$m_{CaCl_2} = 333 \text{ g } CaCl_2$$

The mass of 3.00 mol $CaCl_{2(s)}$ is 333 g.

(b) $n_{SO_2} = 2.05 \text{ mol } SO_2$

$M_{SO_2} = 64.06 \text{ g/mol } SO_2$

$1 \text{ mol } SO_2 = 64.06 \text{ g } SO_2$

$$m_{SO_2} = 2.05 \cancel{\text{ mol } SO_2} \times \frac{64.06 \text{ g } SO_2}{1 \cancel{\text{ mol } SO_2}}$$

$$m_{SO_2} = 131 \text{ g } SO_2$$

The mass of 2.05 mol $SO_{2(g)}$ is 131 g.

(c) $n_{H_2S} = 7.03 \text{ mol } H_2S$

$M_{H_2S} = 34.08 \text{ g/mol } H_2S$

$1 \text{ mol } H_2S = 34.08 \text{ g } H_2S$

$$m_{H_2S} = 7.03 \cancel{\text{ mol } H_2S} \times \frac{34.08 \text{ g } H_2S}{1 \cancel{\text{ mol } H_2S}}$$

$$m_{H_2S} = 240 \text{ g } H_2S$$

The mass of 7.03 mol $H_2S_{(g)}$ is 240 g.

(d) $n_{Na_2CO_3} = 0.040 \text{ mol } Na_2CO_3$

$M_{Na_2CO_3} = 105.99 \text{ g/mol } Na_2CO_3$

$1 \text{ mol } Na_2CO_3 = 105.99 \text{ g } Na_2CO_3$

$$m_{Na_2CO_3} = 0.040 \cancel{\text{ mol } Na_2CO_3} \times \frac{105.99 \text{ g } Na_2CO_3}{1 \cancel{\text{ mol } Na_2CO_3}}$$

$$m_{Na_2CO_3} = 4.2 \text{ g } Na_2CO_3$$

The mass of 0.040 mol $Na_2CO_{3(s)}$ is 4.2 g.

7. (a) $m_{HgS} = 168.0 \text{ g HgS}$

$M_{HgS} = 232.65 \text{ g/mol HgS}$

$1 \text{ mol HgS} = 232.65 \text{ g HgS}$

$$n_{HgS} = 168.0 \cancel{\text{ g HgS}} \times \frac{1 \text{ mol HgS}}{232.65 \cancel{\text{ g HgS}}}$$

$$n_{HgS} = 0.722 \text{ mol HgS}$$

The amount of cinnabar in a 168.0-g sample is 0.722 mol.

(b) $m_{NH_3} = 4.53 \text{ g } NH_3$

$M_{NH_3} = 17.04 \text{ g/mol } NH_3$

$1 \text{ mol } NH_3 = 17.04 \text{ g } NH_3$

$$n_{NH_3} = 4.53\ \cancel{g\ NH_3} \times \frac{1\ mol\ NH_3}{17.04\ \cancel{g\ NH_3}}$$

$$n_{NH_3} = 0.266\ mol\ NH_3$$

The amount of ammonia in a 4.53-g sample is 0.266 mol.

(c) $m_{CaCO_3} = 2.22\ g\ CaCO_3$

$M_{CaCO_3} = 100.09\ g/mol\ CaCO_3$

1 mol $CaCO_3$ = 100.09 g $CaCO_3$

$$n_{CaCO_3} = 2.22\ \cancel{g\ CaCO_3} \times \frac{1\ mol\ CaCO_3}{100.09\ \cancel{g\ CaCO_3}}$$

$$n_{CaCO_3} = 0.0222\ mol\ CaCO_3$$

The amount of calcium carbonate in a 2.22-g chunk of marble is 0.0222 mol.

(d) $m_{C_{14}H_{18}N_2O_5} = 33\ mg\ C_{14}H_{18}N_2O_5$

$M_{C_{14}H_{18}N_2O_5} = 294.34\ g/mol\ C_{14}H_{18}N_2O_5$

1 mol $C_{14}H_{18}N_2O_5$ = 294.34 g $C_{14}H_{18}N_2O_5$

$$n_{C_{14}H_{18}N_2O_5} = 33\ \cancel{mg\ C_{14}H_{18}N_2O_5} \times \frac{1\ \cancel{g\ C_{14}H_{18}N_2O_5}}{1000\ \cancel{mg\ C_{14}H_{18}N_2O_5}} \times \frac{1\ mol\ C_{14}H_{18}N_2O_5}{294.34\ \cancel{g\ C_{14}H_{18}N_2O_5}}$$

$$n_{C_{14}H_{18}N_2O_5} = 1.1 \times 10^{-4}\ mol\ C_{14}H_{18}N_2O_5$$

The amount of aspartame in 33 mg of aspartame is 1.1×10^{-4} mol.

8. (a) $m_{(NH_4)_3PO_4} = 0.170\ g\ (NH_4)_3PO_4$

$M_{(NH_4)_3PO_4} = 149.12\ g/mol\ (NH_4)_3PO_4$

1 mol $(NH_4)_3PO_4$ = 149.12 g $(NH_4)_3PO_4$

1 mol $(NH_4)_3PO_4$ = 6.02×10^{23} molecules $(NH_4)_3PO_4$

$$N_{(NH_4)_3PO_4} = 0.170\ \cancel{g\ (NH_4)_3PO_4} \times \frac{1\ \cancel{mol\ (NH_4)_3PO_4}}{149.12\ \cancel{g\ (NH_4)_3PO_4}} \times \frac{6.02 \times 10^{23}\ molecules\ (NH_4)_3PO_4}{1\ \cancel{mol\ (NH_4)_3PO_4}}$$

$$N_{(NH_4)_3PO_4} = 6.86 \times 10^{20}\ molecules\ (NH_4)_3PO_4$$

There are 6.86×10^{20} molecules of ammonium phosphate in a 0.170-g sample.

(b) $m_{H_2SO_4} = 250\ g\ H_2SO_4$

$M_{H_2SO_4} = 98.08\ g/mol\ H_2SO_4$

1 mol H_2SO_4 = 98.08 g H_2SO_4

1 mol H_2SO_4 = 6.02×10^{23} molecules H_2SO_4

$$N_{H_2SO_4} = 250\ \cancel{g\ H_2SO_4} \times \frac{1\ \cancel{mol\ H_2SO_4}}{98.08\ \cancel{g\ H_2SO_4}} \times \frac{6.02 \times 10^{23}\ molecules\ H_2SO_4}{1\ \cancel{mol\ H_2SO_4}}$$

$$N_{H_2SO_4} = 1.5 \times 10^{24}\ molecules\ H_2SO_4$$

There are 1.5×10^{24} molecules of hydrogen sulfate in a 250-g sample.

9. (a) $m_{P_4} = 9.9\ g\ P_4$

$M_{P_4} = 123.88\ g/mol\ P_4$

1 mol P_4 = 123.88 g P_4

1 mol P_4 = 6.02×10^{23} molecules P_4

1 molecule P_4 = 4 atoms P

$$N_P = 9.9\ \cancel{g\ P_4} \times \frac{1\ \cancel{mol\ P_4}}{123.88\ \cancel{g\ P_4}} \times \frac{6.02\times10^{23}\ \cancel{molecules\ P_4}}{1\ \cancel{mol\ P_4}} \times \frac{4\ atoms\ P}{1\ \cancel{molecule\ P_4}}$$

$$N_P = 1.9\times10^{23}\ atoms\ P$$

There are 1.9×10^{23} atoms of phosphorus in a 9.9-g sample.

(b) $m_{Br_2} = 2.12\ g\ Br_2$

$M_{Br_2} = 159.80\ g/mol\ Br_2$

1 mol Br_2 = 159.80 g Br_2
1 mol Br_2 = 6.02×10^{23} molecules Br_2
1 molecule Br_2 = 2 atoms Br

$$N_{Br} = 2.12\ \cancel{g\ Br_2} \times \frac{1\ \cancel{mol\ Br_2}}{159.80\ \cancel{g\ Br_2}} \times \frac{6.02\times10^{23}\ \cancel{molecules\ Br_2}}{1\ \cancel{mol\ Br_2}} \times \frac{2\ atoms\ Br}{1\ \cancel{molecule\ Br_2}}$$

$$N_{Br} = 1.60\times10^{22}\ atoms\ Br$$

There are 1.60×10^{22} atoms of bromine in 2.12 g of bromine molecules.

(c) $m_{KOH} = 34.4\ g\ KOH$
$M_{KOH} = 56.11\ g/mol\ KOH$
1 mol KOH = 56.11 g KOH
1 mol KOH = 6.02×10^{23} molecules KOH
1 molecule KOH = 1 atom K

$$N_{KOH} = 34.4\ \cancel{g\ KOH} \times \frac{1\ \cancel{mol\ KOH}}{56.11\ \cancel{g\ KOH}} \times \frac{6.02\times10^{23}\ \cancel{molecules\ KOH}}{1\ \cancel{mol\ KOH}} \times \frac{1\ atom\ K}{1\ \cancel{molecule\ KOH}}$$

$$N_{KOH} = 3.69\times10^{23}\ atoms\ K$$

There are 3.69×10^{23} atoms of potassium in 34.4 g of potassium hydroxide.

(d) $m_{Al(C_2H_3O_2)_3} = 43.5\ g\ Al(C_2H_3O_2)_3$

$M_{Al(C_2H_3O_2)_3} = 204.13\ g/mol\ Al(C_2H_3O_2)_3$

1 mol $Al(C_2H_3O_2)_3$ = 204.13 g $Al(C_2H_3O_2)_3$
1 mol $Al(C_2H_3O_2)_3$ = 6.02×10^{23} molecules $Al(C_2H_3O_2)_3$
1 molecule $Al(C_2H_3O_2)_3$ = 1 atom Al

$$N_{Al(C_2H_3O_2)_3} = 43.5\ \cancel{g\ Al(C_2H_3O_2)_3} \times \frac{1\ \cancel{mol\ Al(C_2H_3O_2)_3}}{204.13\ \cancel{g\ Al(C_2H_3O_2)_3}} \times \frac{6.02\times10^{23}\ \cancel{molecules\ Al(C_2H_3O_2)_3}}{1\ \cancel{mol\ Al(C_2H_3O_2)_3}} \times \frac{1\ atom\ Al}{1\ \cancel{molecule\ Al(C_2H_3O_2)_3}}$$

$$N_{Al(C_2H_3O_2)_3} = 1.28\times10^{23}\ atoms\ Al$$

There are 1.28×10^{23} atoms of aluminum in 43.5 g of aluminum acetate.

10. **Table 2** Relationships among Mass, Amount, and Number of Entities

Mass	Amount	Number of entities
45 g $H_2O_{(l)}$	2.5 mol $H_2O_{(l)}$	1.5 x 10^{24} molecules $H_2O_{(l)}$
23 g $Na_{(s)}$	1.0 mol $Na_{(s)}$	6.02 x 10^{23} atoms $Na_{(s)}$
9.5 x 10^3 g $NH_{3(l)}$	5.6 x 10^2 mol $NH_{3(l)}$	3.4 x 10^{26} molecules $NH_{3(l)}$

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DETERMINING CHEMICAL FORMULAS—ADDITIONAL PRACTICE

1. (a) NF_3
   (b) NF_2
   (c) HO
   (d) C_4H_4S
2. (a) Ba = 89.56%
   O = 10.44%

$$m_{Ba} = \frac{89.56}{100} \times 100 \text{ g}$$

$$m_{Ba} = 89.56 \text{ g}$$

$$m_{O} = \frac{10.44}{100} \times 100 \text{ g}$$

$$m_{O} = 10.44 \text{ g}$$

$$n_{Ba} = 89.56 \ \cancel{\text{g Ba}} \times \frac{1 \text{ mol Ba}}{137.33 \ \cancel{\text{g Ba}}}$$

$$n_{Ba} = 0.6522 \text{ mol Ba}$$

$$n_{O} = 10.44 \ \cancel{\text{g O}} \times \frac{1 \text{ mol O}}{16.00 \ \cancel{\text{g O}}}$$

$$n_{O} = 0.6525 \text{ mol O}$$

$$n_{Ba} : n_{O} = 0.6522 : 0.6525$$

$$n_{Ba} : n_{O} = \frac{0.6522}{0.6522} : \frac{0.6525}{0.6522}$$

$$n_{Ba} : n_{O} = 1 : 1$$

The empirical formula of the compound is BaO.

   (b) C = 42.88%
   O = 57.12%

$$m_{C} = \frac{42.88}{100} \times 100 \text{ g}$$

$$m_{C} = 42.88 \text{ g}$$

$$m_{O} = \frac{57.12}{100} \times 100 \text{ g}$$

$$m_{O} = 57.12 \text{ g}$$

$$n_{C} = 42.88 \ \cancel{\text{g C}} \times \frac{1 \text{ mol C}}{12.01 \ \cancel{\text{g C}}}$$

$$n_{C} = 3.570 \text{ mol C}$$

$$n_{O} = 57.12 \ \cancel{\text{g O}} \times \frac{1 \text{ mol O}}{16.00 \ \cancel{\text{g O}}}$$

$$n_{O} = 3.570 \text{ mol O}$$

$$n_{C} : n_{O} = 3.570 : 3.570$$

$$n_{C} : n_{O} = 1 : 1$$

The empirical formula of the compound is CO.

(c) N = 26.19%
H = 7.550%
Cl = 66.26%

$$m_{\text{N}} = \frac{26.19}{100} \times 100 \text{ g}$$
$$m_{\text{N}} = 26.19 \text{ g}$$

$$m_{\text{H}} = \frac{7.550}{100} \times 100 \text{ g}$$
$$m_{\text{H}} = 7.550 \text{ g}$$

$$m_{\text{Cl}} = \frac{66.26}{100} \times 100 \text{ g}$$
$$m_{\text{Cl}} = 66.26 \text{ g}$$

$$n_{\text{N}} = 26.19 \ \cancel{\text{g N}} \times \frac{1 \text{ mol N}}{14.01 \ \cancel{\text{g N}}}$$
$$n_{\text{N}} = 1.869 \text{ mol N}$$

$$n_{\text{H}} = 7.550 \ \cancel{\text{g H}} \times \frac{1 \text{ mol H}}{1.01 \ \cancel{\text{g H}}}$$
$$n_{\text{H}} = 7.475 \text{ mol H}$$

$$n_{\text{Cl}} = 66.26 \ \cancel{\text{g Cl}} \times \frac{1 \text{ mol Cl}}{35.45 \ \cancel{\text{g Cl}}}$$
$$n_{\text{Cl}} = 1.869 \text{ mol Cl}$$

$n_{\text{N}} : n_{\text{H}} : \text{n}_{\text{Cl}} = 1.869 : 7.475 : 1.869$

$$n_{\text{N}} : n_{\text{H}} : n_{\text{Cl}} = \frac{1.869}{1.869} : \frac{7.475}{1.869} : \frac{1.869}{1.869}$$
$$n_{\text{N}} : n_{\text{H}} : n_{\text{Cl}} = 1 : 4 : 1$$

The empirical formula of this compound is NH_4Cl.

(d) C = 39.99%
H = 6.730%
O = 53.28%

$$m_{\text{C}} = \frac{39.99}{100} \times 100 \text{ g}$$
$$m_{\text{C}} = 39.99 \text{ g}$$

$$m_{\text{H}} = \frac{6.730}{100} \times 100 \text{ g}$$
$$m_{\text{H}} = 6.730 \text{ g}$$

$$m_{\text{O}} = \frac{53.28}{100} \times 100 \text{ g}$$
$$m_{\text{O}} = 53.28 \text{ g}$$

$$n_{\text{C}} = 39.99 \ \cancel{\text{g C}} \times \frac{1 \text{ mol C}}{12.01 \ \cancel{\text{g C}}}$$
$$n_{\text{C}} = 3.330 \text{ mol C}$$

$$n_H = 6.730\ \cancel{\text{g H}} \times \frac{1\ \text{mol H}}{1.01\ \cancel{\text{g H}}}$$

$$n_H = 6.663\ \text{mol H}$$

$$n_O = 53.28\ \cancel{\text{g O}} \times \frac{1\ \text{mol O}}{16.00\ \cancel{\text{g O}}}$$

$$n_O = 3.330\ \text{mol O}$$

$n_C : n_H : n_O$ = 3.330 : 6.663 : 3.330

$$n_C : n_H : n_O = \frac{3.330}{3.330} : \frac{6.663}{3.330} : \frac{3.330}{3.330}$$

$$n_C : n_H : n_O = 1 : 2 : 1$$

The empirical formula of the compound is CH_2O.

(e) C = 19.67%
H = 4.960%
N = 22.95%
O = 52.42%

$$m_C = \frac{19.67}{100} \times 100\ \text{g}$$

$$m_C = 19.67\ \text{g}$$

$$m_H = \frac{4.960}{100} \times 100\ \text{g}$$

$$m_H = 4.960\ \text{g}$$

$$m_N = \frac{22.95}{100} \times 100\ \text{g}$$

$$m_N = 22.95\ \text{g}$$

$$m_O = \frac{52.42}{100} \times 100\ \text{g}$$

$$m_O = 52.42\ \text{g}$$

$$n_C = 19.67\ \cancel{\text{g C}} \times \frac{1\ \text{mol C}}{12.01\ \cancel{\text{g C}}}$$

$$n_C = 1.683\ \text{mol C}$$

$$n_H = 4.960\ \cancel{\text{g H}} \times \frac{1\ \text{mol H}}{1.01\ \cancel{\text{g H}}}$$

$$n_H = 4.911\ \text{mol H}$$

$$n_N = 22.95\ \cancel{\text{g N}} \times \frac{1\ \text{mol N}}{14.01\ \cancel{\text{g N}}}$$

$$n_N = 1.638\ \text{mol N}$$

$$n_O = 52.42\ \cancel{\text{g O}} \times \frac{1\ \text{mol O}}{16.00\ \cancel{\text{g O}}}$$

$$n_O = 3.276\ \text{mol O}$$

$n_C : n_H : n_N : n_O$ = 1.683 : 4.911 : 1.638 : 3.276

$$n_C : n_H : n_N : n_O = \frac{1.683}{1.683} : \frac{4.911}{1.683} : \frac{1.638}{1.683} : \frac{3.276}{1.683}$$
$$n_C : n_H : n_N : n_O = 1 : 3 : 1 : 2$$

The empirical formula of the compound is CH_3NO_2.

(f) Ni = 78.58%
O = 21.42%

$$m_{Ni} = \frac{78.58}{100} \times 100 \text{ g}$$
$$m_{Ni} = 78.58 \text{ g}$$

$$m_O = \frac{21.42}{100} \times 100 \text{ g}$$
$$m_O = 21.42 \text{ g}$$

$$n_{Ni} = 78.58 \ \cancel{\text{g Ni}} \times \frac{1 \text{ mol Ni}}{58.69 \ \cancel{\text{g Ni}}}$$
$$n_{Ni} = 1.339 \text{ mol Ni}$$

$$n_O = 21.42 \ \cancel{\text{g O}} \times \frac{1 \text{ mol O}}{16.00 \ \cancel{\text{g O}}}$$
$$n_O = 1.339 \text{ mol O}$$

$n_{Ni} : n_O = 1.339 : 1.339$

$n_{Ni} : n_O = 1 : 1$

The empirical formula is NiO.

(g) C = 83.60%
H = 16.40%

$$m_C = \frac{83.60}{100} \times 100 \text{ g}$$
$$m_C = 83.60 \text{ g}$$

$$m_H = \frac{16.40}{100} \times 100 \text{ g}$$
$$m_H = 16.40 \text{ g}$$

$$n_C = 83.60 \ \cancel{\text{g C}} \times \frac{1 \text{ mol C}}{12.01 \ \cancel{\text{g C}}}$$
$$n_C = 6.961 \text{ mol C}$$

$$n_H = 16.40 \ \cancel{\text{g H}} \times \frac{1 \text{ mol H}}{1.01 \ \cancel{\text{g H}}}$$
$$n_H = 16.24 \text{ mol H}$$

$n_C : n_H = 6.961 : 16.24$

$$n_C : n_H = \frac{6.961}{6.961} : \frac{16.24}{6.961}$$
$$n_C : n_H = 1 : 2.333$$

$$n_C : n_H = 3(1) : 3(2.333)$$
$$n_C : n_H = 3 : 7$$

The empirical formula of the compound is C_3H_7.

(h) Na = 57.47%
O = 40.00%
H = 2.53%

$$m_{Na} = \frac{57.47}{100} \times 100 \text{ g}$$
$$m_{Na} = 57.47 \text{ g}$$

$$m_O = \frac{40.00}{100} \times 100 \text{ g}$$
$$m_O = 40.00 \text{ g}$$

$$m_H = \frac{2.53}{100} \times 100 \text{ g}$$
$$m_H = 2.53 \text{ g}$$

$$n_{Na} = 57.47 \ \cancel{\text{g Na}} \times \frac{1 \text{ mol Na}}{22.99 \ \cancel{\text{g Na}}}$$
$$n_{Na} = 2.500 \text{ mol Na}$$

$$n_O = 40.00 \ \cancel{\text{g O}} \times \frac{1 \text{ mol O}}{16.00 \ \cancel{\text{g O}}}$$
$$n_O = 2.500 \text{ mol O}$$

$$n_H = 2.53 \ \cancel{\text{g H}} \times \frac{1 \text{ mol H}}{1.01 \ \cancel{\text{g H}}}$$
$$n_H = 2.50 \text{ mol H}$$

$$n_{Na} : n_O : n_H = 2.500 : 2.500 : 2.50$$

$$n_{Na} : n_O : n_H = \frac{2.500}{2.500} : \frac{2.500}{2.500} : \frac{2.50}{2.500}$$
$$n_{Na} : n_O : n_H = 1 : 1 : 1$$

The empirical formula of the compound is NaOH.

(i) S = 40.05%
O = 59.95%

$$m_S = \frac{40.05}{100} \times 100 \text{ g}$$
$$m_S = 40.05 \text{ g}$$

$$m_O = \frac{59.95}{100} \times 100 \text{ g}$$
$$m_O = 59.95 \text{ g}$$

$$n_S = 40.05 \ \cancel{\text{g S}} \times \frac{1 \text{ mol S}}{32.06 \ \cancel{\text{g S}}}$$
$$n_S = 1.249 \text{ mol S}$$

$$n_{\mathrm{O}} = 59.95\ \cancel{\mathrm{g\ O}} \times \frac{1\ \mathrm{mol\ O}}{16.00\ \cancel{\mathrm{g\ O}}}$$

$$n_{\mathrm{O}} = 3.747\ \mathrm{mol\ O}$$

$n_{\mathrm{S}} : n_{\mathrm{O}} = 1.249 : 3.747$

$$n_{\mathrm{S}} : n_{\mathrm{O}} = \frac{1.249}{1.249} : \frac{3.747}{1.249}$$

$$n_{\mathrm{S}} : n_{\mathrm{O}} = 1 : 3$$

The empirical formula of the compound is SO_3.

(j) Sn = 78.76%
O = 21.24%

$$m_{\mathrm{Sn}} = \frac{78.76}{100} \times 100\ \mathrm{g}$$

$$m_{\mathrm{Sn}} = 78.76\ \mathrm{g}$$

$$m_{\mathrm{O}} = \frac{21.24}{100} \times 100\ \mathrm{g}$$

$$m_{\mathrm{O}} = 21.24\ \mathrm{g}$$

$$n_{\mathrm{Sn}} = 78.76\ \cancel{\mathrm{g\ Sn}} \times \frac{1\ \mathrm{mol\ Sn}}{118.71\ \cancel{\mathrm{g\ Sn}}}$$

$$n_{\mathrm{Sn}} = 0.6635\ \mathrm{mol\ Sn}$$

$$n_{\mathrm{O}} = 21.24\ \cancel{\mathrm{g\ O}} \times \frac{1\ \mathrm{mol\ O}}{16.00\ \cancel{\mathrm{g\ O}}}$$

$$n_{\mathrm{O}} = 1.328\ \mathrm{mol\ O}$$

$n_{\mathrm{Sn}} : n_{\mathrm{O}} = 0.6635 : 1.328$

$$n_{\mathrm{Sn}} : n_{\mathrm{O}} = \frac{0.6635}{0.6635} : \frac{1.328}{0.6635}$$

$$n_{\mathrm{Sn}} : n_{\mathrm{O}} = 1 : 2$$

The empirical formula of the compound is SnO_2.

3. (a) Mg = 2.3 g
Cl = 6.75 g

$$n_{\mathrm{Mg}} = 2.3\ \cancel{\mathrm{g\ Mg}} \times \frac{1\ \mathrm{mol\ Mg}}{24.31\ \cancel{\mathrm{g\ Mg}}}$$

$$n_{\mathrm{Mg}} = 0.095\ \mathrm{mol\ Mg}$$

$$n_{\mathrm{Cl}} = 6.75\ \cancel{\mathrm{g\ Cl}} \times \frac{1\ \mathrm{mol\ Cl}}{35.45\ \cancel{\mathrm{g\ Cl}}}$$

$$n_{\mathrm{Cl}} = 0.190\ \mathrm{mol\ Cl}$$

$n_{\mathrm{Mg}} : n_{\mathrm{Cl}} = 0.095 : 0.190$

$$n_{\mathrm{Mg}} : n_{\mathrm{Cl}} = \frac{0.095}{0.095} : \frac{0.190}{0.095}$$

$$n_{\mathrm{Mg}} : n_{\mathrm{Cl}} = 1 : 2$$

The empirical formula of the compound is $MgCl_2$.

(b) Al = 36.0 g
S = 64.2 g

$$n_{\text{Al}} = 36.0\ \cancel{\text{g Al}} \times \frac{1\ \text{mol Al}}{26.98\ \cancel{\text{g Al}}}$$

$$n_{\text{Al}} = 1.33\ \text{mol Al}$$

$$n_{\text{S}} = 64.2\ \cancel{\text{g S}} \times \frac{1\ \text{mol S}}{32.06\ \cancel{\text{g S}}}$$

$$n_{\text{S}} = 2.00\ \text{mol S}$$

$n_{\text{Al}} : n_{\text{S}} = 1.33 : 2.00$

$$n_{\text{Al}} : n_{\text{S}} = \frac{1.33}{1.33} : \frac{2.00}{1.33}$$

$$n_{\text{Al}} : n_{\text{S}} = 1 : 1.5$$

$$n_{\text{Al}} : n_{\text{S}} = 2(1) : 2(1.5)$$

$$n_{\text{Al}} : n_{\text{S}} = 2 : 3$$

The empirical formula of the resulting compound is Al_2S_3.

4. empirical formula = C_2H_5O
$M_{\text{compound}} = 135.18$ g/mol

$$M_{C_2H_5O} = 2(12.01\ \text{g/mol}) + 5(1.01\ \text{g/mol}) + 1(16.00\ \text{g/mol})$$

$$M_{C_2H_5O} = 45.07\ \text{g/mol}$$

$$\frac{M_{\text{compound}}}{M_{C_2H_5O}} = \frac{135.18\ \text{g/mol}}{45.07\ \text{g/mol}}$$

$$\frac{M_{\text{compound}}}{M_{C_2H_5O}} = 3$$

$$\begin{aligned}\text{molecular formula} &= 3(\text{empirical formula}) \\ &= 3(C_2H_5O) \\ \text{molecular formula} &= C_6H_{15}O_3\end{aligned}$$

The molecular formula of the compound is $C_6H_{15}O_3$.

5. empirical formula = CH_2O
$M_{\text{compound}} = 1.50 \times 10^2$ g/mol

$$M_{CH_2O} = 1(12.01\ \text{g/mol}) + 2(1.01\ \text{g/mol}) + 1(16.00\ \text{g/mol})$$

$$M_{CH_2O} = 30.03\ \text{g/mol}$$

$$\frac{M_{\text{compound}}}{M_{CH_2O}} = \frac{1.50 \times 10^2\ \text{g/mol}}{30.03\ \text{g/mol}}$$

$$\frac{M_{\text{compound}}}{M_{CH_2O}} = 5$$

$$\begin{aligned}\text{molecular formula} &= 5(\text{empirical formula}) \\ &= 5(CH_2O) \\ \text{molecular formula} &= C_5H_{10}O_5\end{aligned}$$

The molecular formula of the compound is $C_5H_{10}O_5$.

6. (a) C = 49.5%
H = 5.20%
N = 28.8%
O = 16.5%

$$m_C = \frac{49.5}{100} \times 100 \text{ g}$$
$$m_C = 49.5 \text{ g}$$

$$m_H = \frac{5.20}{100} \times 100 \text{ g}$$
$$m_H = 5.20 \text{ g}$$

$$m_N = \frac{28.8}{100} \times 100 \text{ g}$$
$$m_N = 28.8 \text{ g}$$

$$m_O = \frac{16.5}{100} \times 100 \text{ g}$$
$$m_O = 16.5 \text{ g}$$

$$n_C = 49.5 \ \cancel{\text{g C}} \times \frac{1 \text{ mol C}}{12.01 \ \cancel{\text{g C}}}$$
$$n_C = 4.12 \text{ mol C}$$

$$n_H = 5.20 \ \cancel{\text{g H}} \times \frac{1 \text{ mol H}}{1.01 \ \cancel{\text{g H}}}$$
$$n_H = 5.15 \text{ mol H}$$

$$n_N = 28.8 \ \cancel{\text{g N}} \times \frac{1 \text{ mol N}}{14.01 \ \cancel{\text{g N}}}$$
$$n_N = 2.06 \text{ mol N}$$

$$n_O = 16.5 \ \cancel{\text{g O}} \times \frac{1 \text{ mol O}}{16.00 \ \cancel{\text{g O}}}$$
$$n_O = 1.03 \text{ mol O}$$

$n_C : n_H : n_N : n_O = 4.12 : 5.15 : 2.06 : 1.03$

$$n_C : n_H : n_N : n_O = \frac{4.12}{1.03} : \frac{5.15}{1.03} : \frac{2.06}{1.03} : \frac{1.03}{1.03}$$
$$n_C : n_H : n_N : n_O = 4 : 5 : 2 : 1$$

The empirical formula of the compound is $C_4H_5N_2O$.

(b) empirical formula = $C_4H_5N_2O$
M_{compound} = 194.2 g/mol

$$M_{C_4H_5N_2O} = 4(12.01 \text{ g/mol}) + 5(1.01 \text{ g/mol}) + 2(14.01 \text{ g/mol}) + 1(16.00 \text{ g/mol})$$
$$M_{C_4H_5N_2O} = 97.11 \text{ g/mol}$$

$$\frac{M_{\text{compound}}}{M_{C_4H_5N_2O}} = \frac{194.2 \text{ g/mol}}{97.11 \text{ g/mol}}$$
$$\frac{M_{\text{compound}}}{M_{C_4H_5N_2O}} = 2$$

$$\text{molecular formula} = 2(\text{empirical formula})$$
$$= 2(C_4H_5N_2O)$$
$$\text{molecular formula} = C_8H_{10}N_4O_2$$

The molecular formula of the compound is $C_8H_{10}N_4O_2$.

7. empirical formula = CH_4
   M_{compound} = 64 g/mol

   M_{CH_4} = 1(12.01 g/mol) + 4(1.01 g/mol)

   M_{CH_4} = 16.05 g/mol

$$\frac{M_{\text{compound}}}{M_{CH_4}} = \frac{64 \text{ g/mol}}{16.05 \text{ g/mol}}$$
$$\frac{M_{\text{compound}}}{M_{CH_4}} = 4$$

$$\text{molecular formula} = 4(\text{empirical formula})$$
$$= 4(CH_4)$$
$$\text{molecular formula} = C_4H_{16}$$

The molecular formula of the compound is C_4H_{16}.

8. (a) C = 48.38%
   H = 8.120%
   O = 100% – (48.38% + 8.120%)
   O = 43.50%

$$m_C = \frac{48.38}{100} \times 100 \text{ g}$$
$$m_C = 48.38 \text{ g}$$

$$m_H = \frac{8.120}{100} \times 100 \text{ g}$$
$$m_H = 8.120 \text{ g}$$

$$m_O = \frac{43.50}{100} \times 100 \text{ g}$$
$$m_O = 43.50 \text{ g}$$

$$n_C = 48.38 \cancel{\text{ g C}} \times \frac{1 \text{ mol C}}{12.01 \cancel{\text{ g C}}}$$
$$n_C = 4.028 \text{ mol C}$$

$$n_H = 8.120 \cancel{\text{ g H}} \times \frac{1 \text{ mol H}}{1.01 \cancel{\text{ g H}}}$$
$$n_H = 8.040 \text{ mol H}$$

$$n_O = 43.50 \cancel{\text{ g O}} \times \frac{1 \text{ mol O}}{16.00 \cancel{\text{ g O}}}$$
$$n_O = 2.719 \text{ mol O}$$

$$n_C : n_H : n_O = 4.028 : 8.040 : 2.719$$

$$n_C : n_H : n_O = \frac{4.028}{2.719} : \frac{8.040}{2.719} : \frac{2.719}{2.719}$$
$$n_C : n_H : n_O = 1.5 : 3 : 1$$
$$n_C : n_H : n_O = 2(1.5) : 2(3) : 2(1)$$
$$n_C : n_H : n_O = 3 : 6 : 2$$

The empirical formula of the compound is $C_3H_6O_2$.

(b) empirical formula = $C_3H_6O_2$
$M_{compound}$ = 182.2 g/mol

$$M_{C_3H_6O_2} = 3(12.01\text{ g/mol}) + 6(1.01\text{ g/mol}) + 2(16.00\text{ g/mol})$$
$$M_{C_3H_6O_2} = 74.09\text{ g/mol}$$

$$\frac{M_{compound}}{M_{C_3H_6O_2}} = \frac{148.2\text{ g/mol}}{74.09\text{ g/mol}}$$
$$\frac{M_{compound}}{M_{C_3H_6O_2}} = 2$$

$$\begin{aligned}\text{molecular formula} &= 2(\text{empirical formula})\\ &= 2(C_3H_6O_2)\\ \text{molecular formula} &= C_6H_{12}O_4\end{aligned}$$

The molecular formula of the compound is $C_6H_{12}O_4$.

2.4 ALTERNATIVE EXERCISE

(Pages 75–76)

ACTIVITY: PERCENTAGE COMPOSITION OF A COPPER COMPOUND

Observations

(a) *Qualitative Observations*
As the copper compound dissolves in the water, it changes from a green solution to a blue-green-coloured solution. When the copper salt solution reacts with the aluminum, the blue-green colour disappears, and a brown solid coats the outer surface of the aluminum strip.

Quantitative Observations

Table 1

Item(s) measured	Mass (g)
empty beaker	168.95
beaker + copper salt	169.95
filter paper + watch glass	38.88
filter paper + watch glass + dry copper	39.27

Analysis

(b) A chemical reaction took place because a brown solid formed on the outer surface of the aluminum strip, and the blue-green colour of the copper salt solution disappeared.

(c) $m_{\text{copper salt}} = 169.95\text{ g} - 168.95\text{ g}$

$m_{\text{copper salt}} = 1.00\text{ g}$

$m_{\text{Cu}} = 39.27\text{ g} - 38.88\text{ g}$

$m_{\text{Cu}} = 0.39\text{ g}$

$\%\text{ Cu} = \dfrac{0.39\text{ g}}{1.00\text{ g}} \times 100\%$

$\%\text{ Cu} = 39\%$

(d) $\text{percentage Cu in CuCl}_2 \bullet 2\text{H}_2\text{O} = \dfrac{63.55}{170.49} \times 100\%$

$\text{percentage Cu in CuCl}_2 \bullet 2\text{H}_2\text{O} = 37.27\%$

$\text{percentage Cu in CuCl} \bullet 2\text{H}_2\text{O} = \dfrac{63.55}{135.04} \times 100\%$

$\text{percentage Cu in CuCl} \bullet 2\text{H}_2\text{O} = 47.06\%$

$\text{percentage Cu in CuCl}_2 \bullet \text{H}_2\text{O} = \dfrac{63.55}{152.47} \times 100\%$

$\text{percentage Cu in CuCl}_2 \bullet \text{H}_2\text{O} = 41.68\%$

(e) The formula for the copper-containing compound used is $CuCl_2 \bullet 2H_2O$.

Evaluation

(f) The percentage of copper would have been larger because the excess water would have been assumed to be copper.

(g) Blue colour on the filter paper indicates the presence of unreacted copper ion, which would result in a lower value for the percentage of copper in the copper salt.

(h) $\text{percent error} = \dfrac{(39\% - 37.27\%)}{37.27\%} \times 100\%$

$\text{percent error} = 4.6\%$

The percent error is 4.6%.

(i), (j) Some sources of error include not transferring all the copper to the filter paper (causing percentage of copper to be too small), not allowing all the copper ions to react (causing percentage of copper to be too small), and not removing all the aluminum chloride during filtration (causing percentage of copper to be too large).

(k) Increase the reaction time to allow all of the copper ions to react with aluminum. Increase the drying time of copper to remove as much water as possible.

2.1–2.4 SELF QUIZ

(Pages 77–78)

Modified True or False

1. True
2. True
3. True
4. False; The atomic mass unit is equal to one-twelfth the mass of a carbon-12 atom.
5. False; Isotopes differ in the number of neutrons in the nucleus.
6. True
7. True
8. True

9. False; A combustion analyzer measures the percentage of carbon, oxygen, hydrogen and nitrogen.
10. True
11. True

Multiple Choice

12. (c)
13. (d)
14. (b)
15. (c)
16. (a)
17. (a)
18. (a)
19. (d)
20. (d)
21. (b)
22. (d)
23. (c)
24. (b)
25. (b)
26. (b)
27. (c)
28. (d)
29. (a)

Completion

30. Avogadro's
31. amount
32. observed, measured
33. atomic
34. mole
35. mass
36. lowest

2.5 EXTENSION EXERCISE

(Pages 79–80)

CONCENTRATION OF SOLUTIONS—ADDITIONAL PRACTICE

1. $v_{\text{ethanol}} = 6.25\text{ mL}$
   $v_{\text{solution}} = 250\text{ mL}$
   $c_{\text{solution}} = ?$

$$\begin{aligned} c_{\text{solution}} &= \frac{v_{\text{ethanol}}}{v_{\text{solution}}} \times 100\% \\ &= \frac{6.25\text{ mL}}{250\text{ mL}} \times 100\% \\ c_{\text{solution}} &= 2.5\%\text{ V/V} \end{aligned}$$

   The concentration of the ethanol solution is 2.5% V/V.

2. $v_{\text{milk}} = 26\text{ mL}$
   $v_{\text{mixture}} = 310\text{ mL}$
   $c_{\text{mixture}} = ?$

$$c_{\text{mixture}} = \frac{v_{\text{milk}}}{v_{\text{mixture}}} \times 100\%$$
$$= \frac{26 \text{ mL}}{310 \text{ mL}} \times 100\%$$
$$c_{\text{mixture}} = 8.4\% \text{ V/V}$$

The concentration of milk in the new mixture is 8.4% V/V.

3. $m_{\text{NaClO}} = 0.60$ g
$v_{\text{solution}} = 5.0$ L = 5000 mL
$c_{\text{solution}} = ?$

$$c_{\text{solution}} = \frac{m_{\text{NaClO}}}{v_{\text{solution}}} \times 100\%$$
$$= \frac{0.60 \text{ g}}{5000 \text{ mL}} \times 100\%$$
$$c_{\text{solution}} = 0.012\% \text{ W/V}$$

The concentration of sodium hypochlorite in the bleach is 0.012% W/V.

4. $c_{\text{solution}} = 2.5\%$ W/V
$v_{\text{solution}} = 192$ mL
$m_{C_7H_6O_3} = ?$

$$c_{\text{solution}} = \frac{m_{C_7H_6O_3}}{v_{\text{solution}}}$$
$$\frac{2.5 \text{ g}}{100} = \frac{m_{C_7H_6O_3}}{192 \text{ mL}}$$
$$m_{C_7H_6O_3} = \frac{(2.5)(192)}{100}$$
$$m_{C_7H_6O_3} = 4.8 \text{ g}$$

The mass of salicylic acid is 4.8 g.

5. $c_{\text{solution}} = 95\%$ W/V
$v_{\text{solution}} = 550$ mL
$m_{\text{ethylene glycol}} = ?$

$$c_{\text{solution}} = \frac{m_{\text{ethylene glycol}}}{v_{\text{solution}}}$$
$$\frac{95 \text{ g}}{100} = \frac{m_{\text{ethylene glycol}}}{550 \text{ mL}}$$
$$m_{\text{ethylene glycol}} = \frac{(95)(550)}{100}$$
$$m_{\text{ethylene glycol}} = 520 \text{ g}$$

The mass of the ethylene glycol is 520 g.

6. **Table 1** Concentrations of Solutions

Concentration	Amount of solute	Volume of solution
4.56 mol/L	11 mol	2.5 L
2.18 mol/L	1.06 mol	0.486 L
0.081 mol/L	0.42 mol	5.2 L
12 mol/L	2.4 mol $NaCl_{(s)}$	0.20 L
0.10 mol/L	0.025 mol	250 mL
0.25 mol/L	0.11 mol KOH	0.450 L

7. $m_{H_2SO_4} = 490.0\text{ g}$

$v_{H_2SO_4} = 5.5\text{ L}$

$c_{H_2SO_4} = ?$

$M_{H_2SO_4} = 2.02\text{ g/mol} + 32.06\text{ g/mol} + 64.00\text{ g/mol}$

$M_{H_2SO_4} = 98.08\text{ g/mol}$

$$n_{H_2SO_4} = 490.0\ \cancel{\text{g H}_2\text{SO}_4} \times \frac{1\text{ mol H}_2\text{SO}_4}{98.08\ \cancel{\text{g H}_2\text{SO}_4}}$$

$$n_{H_2SO_4} = 4.996\text{ mol H}_2\text{SO}_4$$

$$c_{H_2SO_4} = \frac{n_{H_2SO_4}}{v_{H_2SO_4}}$$

$$= \frac{4.996\text{ mol H}_2\text{SO}_4}{5.5\text{ L}}$$

$$c_{H_2SO_4} = 0.91\text{ mol/L}$$

The concentration of sulfuric acid in the battery acid is 0.91 mol/L.

8. $v_{ZnCl_2} = 200\text{ mL or }0.200\text{ L}$

$c_{ZnCl_2} = 0.15\text{ mol/L}$

$n_{ZnCl_2} = ?$

$$c_{ZnCl_2} = \frac{n_{ZnCl_2}}{v_{ZnCl_2}}$$

$$n_{ZnCl_2} = c_{ZnCl_2} v_{ZnCl_2}$$

$$= 0.200\ \cancel{\text{L}} \times \frac{0.15\text{ mol}}{\cancel{\text{L}}}$$

$$n_{ZnCl_2} = 0.030\text{ mol}$$

$$m_{ZnCl_2} = 0.030\ \cancel{\text{mol ZnCl}_2} \times \frac{136.28\text{ g ZnCl}_2}{1\ \cancel{\text{mol ZnCl}_2}}$$

$$m_{ZnCl_2} = 4.1\text{ g ZnCl}_2$$

Place 4.1 g of zinc chloride in a 200-mL volumetric flask. Add a small amount of water to the flask and swirl the flask to dissolve the zinc chloride. Add water to the 200-mL mark on the flask and invert several times to mix the contents.

9. $m_{Hg} = 23.0$ mg

$v_{H_2O} = 3.00 \times 10^4$ L

(a) $c_{Hg} = ?$

$$c_{Hg} = \frac{m_{Hg}}{v_{H_2O}}$$
$$= \frac{23.0 \text{ mg}}{3.00 \times 10^4 \text{ L}}$$
$$= 7.7 \times 10^{-4} \text{ mg/L}$$
$$c_{Hg} = 7.7 \times 10^{-4} \text{ ppm}$$

The concentration of mercury is 7.7×10^{-4} ppm.

(b) The water in part (a) is safe to drink since the concentration is less than 2 ppm.

10. (a) $v_{solution} = 65$ L

$c_{S_8} = 550$ ppm

$m_{S_8} = ?$

$$c_{S_8} = \frac{m_{S_8}}{v_{solution}}$$
$$m_{S_8} = c_{S_8} v_{solution}$$
$$= \left(\frac{550 \text{ mg}}{1 \cancel{\text{L}}}\right)(65 \cancel{\text{L}})$$
$$m_{S_8} = 3.6 \times 10^4 \text{ mg}$$

The mass of sulfur currently present in 65 L of diesel fuel is 3.6×10^4 mg, or 36 g.

(b) $m_{S_8} = ?$

$$c_{S_8} = \frac{m_{S_8}}{v_{solution}}$$
$$m_{S_8} = c_{S_8} v_{solution}$$
$$= \left(\frac{15 \text{ mg}}{1 \cancel{\text{L}}}\right)(65 \cancel{\text{L}})$$
$$m_{S_8} = 980 \text{ mg}$$

The maximum mass of sulfur that will be allowed by June 2006 is 980 mg.

11. $c_i = 18$ mol/L
$c_f = 0.25$ mol/L
$v_f = 250$ mL
$v_i = ?$

$$c_i v_i = c_f v_f$$
$$v_i = \frac{c_f v_f}{c_i}$$
$$= \frac{(0.25 \cancel{\text{mol/L}})(250 \text{ mL})}{18 \cancel{\text{mol/L}}}$$
$$v_i = 3.5 \text{ mL}$$

The volume of 18-mol/L hydrogen sulfate required is 3.5 mL.

2.5 ALTERNATIVE EXERCISE

(Pages 81–82)

EXPLORE AN ISSUE: HOUSEHOLD PRODUCT SAFETY TESTING

TAKE A STAND: SHOULD ANIMAL TESTS BE USED?

Students' answers will vary. The following graphic organizer is a sample of what students may find during their research.

(a), (c)

Statement: Animal tests, such as the Draize test and the LD_{50}, should continue to be used in household product safety testing.	
For	**Against**
• humans need to know whether consumer products are safe to use • animals used for product testing are usually bred for this purpose, or are obtained from animal shelters where they would otherwise be euthanized • Health Canada uses non-animal tests whenever possible, but animal tests are sometimes the only option • Health Canada uses the services of veterinarians to ensure that animals used in product testing are treated humanely, and do not suffer unnecessarily • although cell culture-based and computer modelling-based tests provide cruelty-free alternatives to animal testing, these methods cannot take into account the complex interactions that occur in a living organism, and thus provide poor results	• results of animal-based product safety testing do not necessarily extend to humans • large numbers of animals suffer unnecessarily because of toxicity tests such as the Draize test • cell and tissue culture-based toxicity tests and computer modelling provide a cruelty-free alternative to animal testing

(b) Groups that have addressed the issue of animal testing include the US Environmental Protection Agency, which has announced that it no longer supports the use of the LD_{50} test. Animal rights groups, such as People for the Ethical Treatment of Animals (PETA), are continually advocating for animal rights, and do not support the use of animals for any type of testing. Some cosmetic companies, such as M.A.C. and The Body Shop, market their products as free of animal testing, as well as campaign for animal rights. Many companies that continue to use animal testing have managed to reduce the number of animals they test on, as well as use alternative tests that do not involve animals.

2.6 ALTERNATIVE EXERCISE

(Pages 83–84)

TECH CONNECT: THE BREATHALYZER

Questions

1. (a) A police officer may ask a suspected drunk driver to perform a number of simple sobriety tests such as touching one's nose or walking a straight line.
   (b) A person with a high blood alcohol content may be able to touch his/her nose or walk a reasonably straight line, but may not have the fine motor skills and judgment needed to drive a car safely.
2. (a) The concentration of alcohol in the breath is proportional to the alcohol's concentration in the bloodstream. As blood moves through the lungs, some of the alcohol passes into the lungs by diffusion. A driver's breath can therefore be analyzed to determine blood alcohol concentration.

(b) The concentration of alcohol in the breath may be used as an indication of intoxication because the alcohol that a person drinks appears in the breath at a concentration that is proportional to the BAC.

3. The legal standard for drunkenness in Canada is a BAC of 0.08% W/V.

4. (a) The three main parts of a Breathalyzer are (1) a breath tube used to blow exhaled air into the machine; (2) two vials containing a mixture of chemicals (one vial changes colour when the chemicals in it react with alcohol in the breath) and (3) an instrument that measures the change in colour associated with the reaction, and displays the measurement as a BAC value.

   (b) When the ethanol in exhaled breath reacts with a solution containing reddish-orange dichromate ions, green chromate ions are formed. In a Breathalyzer, the colour of a solution of unreacted dichromate is compared to a vial containing a dichromate solution that has reacted with ethanol in a person's breath. A system of colour-sensitive photocells detects the difference in colour, and displays the difference as a BAC.

5. (a) The first device for measuring BAC was invented by Robert Borkenstein in 1953.

   (b) Unlike the Breathalyzer, the Intoxilizer works on the theory of infrared absorption. The machine has a light bulb positioned at one end of a breath capture cylinder. There are filter wheels at the other end of the cylinder and on the other side of the filter wheels is a light receiver. A person suspected of driving under the influence blows into a breath tube, which leads to a breath chamber cylinder. The machine shines a light through this cylinder and the filter wheels spin on the other end of the breath tube chamber. The infrared light causes the alcohol molecules to absorb light at a particular frequency. The difference in light emitted and received is calculated by a computer program in the machine and determines the BAC value.

   (c) A fuel cell detector is another instrument used to measure BAC.

2.6 ALTERNATIVE EXERCISE

(Pages 85–86)

EXPLORE AN ISSUE: LOWERING THE CANADIAN BAC LIMIT

TAKE A STAND: SHOULD THE CANADIAN BAC BE LOWERED

(a)

Statement: The level of BAC in the *Criminal Code of Canada* should be lowered from 0.08% W/V to 0.05% W/V.	
For	**Against**
• 4.5 Canadians are killed every day as a result of alcohol-related traffic accidents • studies show that alcohol-related impairment begins at blood alcohol concentrations far less than 0.08% • countries such as Austria, Belgium, France, and Australia have already lowered their BAC limits to 0.05% • reducing the BAC limit to 0.05% will decrease the number of alcohol-related accidents	• countries with a BAC of 0.05% are lenient when deciding to press charges for impaired driving • Canada is already one of the strictest countries when dealing with impaired driving • all provinces in Canada, except Quebec, already give short-term roadside suspensions to individuals with a BAC of 0.05% or higher; it only becomes a criminal offence when BAC is equal to or greater than 0.08%

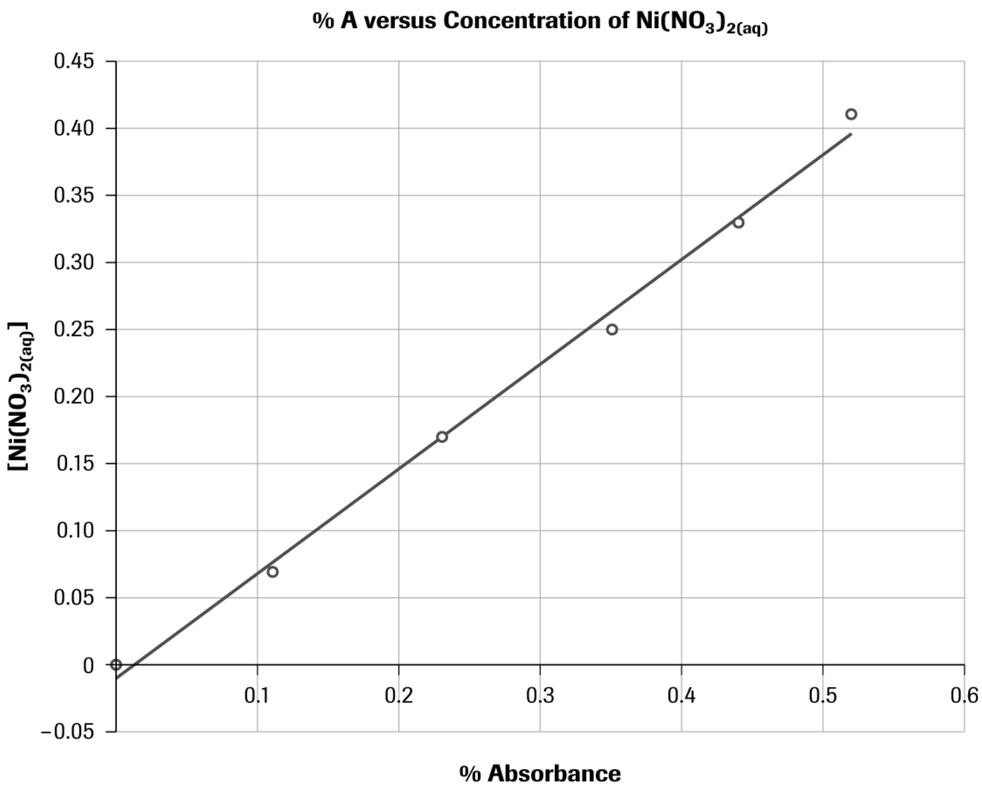
2.7 ALTERNATIVE EXERCISE

(Pages 89–90)

ACTIVITY: DETERMINING CONCENTRATION USING A SPECTROPHOTOMETER

Analysis

(a)



(b) Percent absorbance is directly proportional to concentration.
(c) $[Ni(NO_3)_{2(aq)}] \approx 0.11$ mol/L

Evaluation

(d), (e) The spectrophotometer is set to 0% A initially because distilled water is used as a "blank" that does not absorb light. The blank is then used to compare the light-absorbing properties of other (coloured) solutions.
(f) Smudges, such as fingerprints on the walls of the cuvettes, may have absorbed some of the light in the spectrophotometer, resulting in a higher %A reading than should have been obtained.
(g) Using rubber gloves may help to prevent the possible error mentioned in (f).

2.8 ALTERNATIVE EXERCISE

(Pages 91–93)

CASE STUDY: BIOMAGNIFICATION

Questions

1. (a) Dr. Dewailly discovered that Inuit women living in Arctic regions of Quebec had PCB concentrations that were five times greater than those found in non-Inuit women living in southern Quebec.

(b) Dr. Dewailly was startled by the discovery because the Arctic was considered to be a pristine environment. It was thought to be free of the high levels of pollutants associated with more industrialized areas of North America.

2. Three health risks associated with PCB toxicitiy are impaired reproduction, an impaired nervous system, and cancer.
3. (a) Seals and fish may have contributed to the high concentration of PCBs.
   (b) Fat-soluble compounds, such as PCBs, accumulate in the fat tissue of animals. Larger animals eat large numbers of smaller animals. If the smaller animals are contaminated, the large animals are consuming greater amounts of PCBs.
4. (a) Biomagnification is the increase in the concentration of fat soluble toxins at each level of a food chain.
   (b) DDT and heavy metals such as mercury are substances that biomagnify.
   (c) A toxin must have the following properties to biomagnify: (1) It must be long-lived; (2) It must be mobile (easily spread); (3) It must be fat-soluble; and (4) It must be biologically active.
5. Developing nations use some biomagnifying toxins such as DDT to help control the populations of insects that destroy crops and spread diseases like malaria. Asking them to stop using these substances may be unfair since developed nations used the same substances in the past for similar purposes.
6. (a) Mercury enters the food chain when plants and small organisms, such as plankton, take up mercury through passive surface absorption.
   (b) Mercury poisoning may cause kidney problems, and may impair reproduction, growth, neurological development, and learning ability.
   (c) Mercury can be converted to a highly toxic organic compound called methylmercury through biogeochemical interactions. Methylmercury is absorbed into the body about six times more easily than inorganic mercury, and can migrate through cells that normally form a barrier to toxins.
   (d) Health Canada uses 0.5 ppm of total mercury as a guideline to determine whether commercial marine and freshwater fish are suitable for sale and consumption. The Canadian guideline is lower than the American guideline of 1.0 ppm.
   (e) Certain fish such as shark, swordfish, and fresh and frozen tuna, contain mercury at levels that are known to exceed the 0.5 ppm legal limit. Pregnant women, women of child-bearing age and young children are advised to limit their consumption of shark, swordfish, and fresh and frozen tuna to no more than one meal per month.
   (f) The use of smaller, younger tuna in the canning process makes it possible for mercury levels in canned tuna to fall within the 0.5 ppm guideline. Thus, canned tuna is exempt from the consumption restrictions described in (e).

2.9 EXTENSION EXERCISE

(Pages 94–95)

THE MOLE AND CHEMICAL EQUATIONS—ADDITIONAL PRACTICE

1. (a) 1 mol $CH_{4(g)}$: 2 mol $O_{2(g)}$: 1 mol $CO_{2(g)}$: 2 mol $H_2O_{(g)}$
   (b) 2 mol $KClO_{3(aq)}$: 2 mol $KCl_{(aq)}$: 3 mol $O_{2(g)}$
   (c) 2 mol $Al_{(s)}$: 6 mol $HCl_{(aq)}$: 2 mol $AlCl_{3(aq)}$: 3 mol $H_{2(g)}$
2. $m_{H_2} = 3.18 \text{ g } H_2$

   $M_{H_2} = 2.02 \text{ g/mol } H_2$

   $M_{Cl_2} = 70.90 \text{ g } Cl_2$

   1 mol H_2 = 2.02 g H_2
   1 mol Cl_2 = 70.90 g Cl_2
   1 mol Cl_2 = 1 mol H_2

   $$m_{Cl_2} = 3.18 \cancel{\text{ g } H_2} \times \frac{1 \cancel{\text{ mol } H_2}}{2.02 \cancel{\text{ g } H_2}} \times \frac{1 \cancel{\text{ mol } Cl_2}}{1 \cancel{\text{ mol } H_2}} \times \frac{70.90 \text{ g } Cl_2}{1 \cancel{\text{ mol } Cl_2}}$$

   $$m_{Cl_2} = 112 \text{ g } Cl_2$$

   Therefore, 112 g of chlorine combines with 3.18 g of hydrogen to form hydrogen chloride.

3. m_{CaCl_2} = 1.50 g $CaCl_2$
M_{CaCl_2} = 110.98 g/mol $CaCl_2$
M_{AgCl} = 143.32 g/mol AgCl
1 mol $CaCl_2$ = 110.98 g $CaCl_2$
1 mol AgCl = 143.32 g AgCl
2 mol AgCl = 1 mol $CaCl_2$

$$m_{AgCl} = 1.50\ \cancel{g\ CaCl_2} \times \frac{1\ \cancel{mol\ CaCl_2}}{110.98\ \cancel{g\ CaCl_2}} \times \frac{2\ \cancel{mol\ AgCl}}{1\ \cancel{mol\ CaCl_2}} \times \frac{143.32\ g\ AgCl}{1\ \cancel{mol\ AgCl}}$$

$$m_{AgCl} = 3.87\ g\ AgCl$$

Therefore, 3.87 g of silver chloride will precipitate from the solution.

4. m_{H_2O} = 7.5 g H_2O
M_{H_2O} = 18.02 g/mol H_2O
$M_{Fe_3O_4}$ = 231.55 g/mol Fe_3O_4
1 mol H_2O = 18.02 g H_2O
1 mol Fe_3O_4 = 231.55 g Fe_3O_4
1 mol Fe_3O_4 = 4 mol H_2O

$$m_{Fe_3O_4} = 7.5\ \cancel{g\ H_2O} \times \frac{1\ \cancel{mol\ H_2O}}{18.02\ \cancel{g\ H_2O}} \times \frac{1\ \cancel{mol\ Fe_3O_4}}{4\ \cancel{mol\ H_2O}} \times \frac{231.55\ g\ Fe_3O_4}{1\ \cancel{mol\ Fe_3O_4}}$$

$$m_{Fe_3O_4} = 24\ g\ Fe_4O_3$$

Therefore, 24 g of magnetic iron oxide is formed.

5. m_{Zn} = 2.0 g Zn
M_{Zn} = 65.38 g/mol Zn
M_{Cu} = 63.55 g/mol Cu
1 mol Zn = 65.38 g Zn
1 mol Cu = 63.55 g Cu
1 mol Cu = 1 mol Zn

$$m_{Cu} = 2.0\ \cancel{g\ Zn} \times \frac{1\ \cancel{mol\ Zn}}{65.38\ \cancel{g\ Zn}} \times \frac{1\ \cancel{mol\ Cu}}{1\ \cancel{mol\ Zn}} \times \frac{63.55\ g\ Cu}{1\ \cancel{mol\ Cu}}$$

$$m_{Cu} = 1.9\ g\ Cu$$

Therefore, 1.9 g of copper is produced.

6. m_{S_8} = 10 mg S_8, or 1.0×10^{-2} g S_8
M_{S_8} = 256.48 g/mol S_8
1 mol S_8 = 256.48 g S_8
8 mol SO_2 = 1 mol S_8
1 mol SO_2 = 6.02×10^{23} molecules SO_2

$$N_{SO_2} = 1.0 \times 10^{-2}\ \cancel{g\ S_8} \times \frac{1\ \cancel{mol\ S_8}}{256.48\ \cancel{g\ S_8}} \times \frac{8\ \cancel{mol\ SO_2}}{1\ \cancel{mol\ S_8}} \times \frac{6.02 \times 10^{23}\ molecules\ SO_2}{1\ \cancel{mol\ SO_2}}$$

$$N_{SO_2} = 1.9 \times 10^{20}\ molecules\ SO_2$$

Therefore, 1.9×10^{20} molecules of sulfur dioxide are formed.

7. m_{CaO} = 48 kg CaO, or 4.8×10^4 g CaO
M_{CaO} = 56.08 g/mol CaO
M_{HCl} = 36.46 g/mol HCl
1 mol CaO = 56.08 g CaO
1 mol HCl = 36.46 g HCl

2 mol HCl = 1 mol CaO

$$m_{HCl} = 4.8 \times 10^4 \ \cancel{\text{g CaO}} \times \frac{1 \ \cancel{\text{mol CaO}}}{56.08 \ \cancel{\text{g CaO}}} \times \frac{2 \ \cancel{\text{mol HCl}}}{1 \ \cancel{\text{mol CaO}}} \times \frac{36.46 \text{ g HCl}}{1 \ \cancel{\text{mol HCl}}}$$

$$m_{HCl} = 6.2 \times 10^4 \text{ g HCl}$$

Therefore, 6.2×10^4 g of hydrochloric acid, or 62 kg, is required.

8. $m_{Al_2O_3}$ = 78.6 g Al_2O_3

$M_{Al_2O_3}$ = 101.96 g/mol Al_2O_3

3 mol H_2SO_4 = 1 mol Al_2O_3
1 mol H_2SO_4 = 6.02×10^{23} molecules H_2SO_4

$$N_{H_2SO_4} = 78.6 \ \cancel{\text{g Al}_2\text{O}_3} \times \frac{1 \ \cancel{\text{mol Al}_2\text{O}_3}}{101.96 \ \cancel{\text{g Al}_2\text{O}_3}} \times \frac{3 \ \cancel{\text{mol H}_2\text{SO}_4}}{1 \ \cancel{\text{mol Al}_2\text{O}_3}} \times \frac{6.02 \times 10^{23} \text{ molecules H}_2\text{SO}_4}{1 \ \cancel{\text{mol H}_2\text{SO}_4}}$$

$$N_{H_2SO_4} = 1.39 \times 10^{24} \text{molecules H}_2\text{SO}_4$$

Therefore, 1.39×10^{24} molecules of sulfuric acid are required.

9. $m_{CH_3NO_2}$ = 63 kg CH_3NO_2, or 6.3×10^4 g CH_3NO_2

$M_{CH_3NO_2}$ = 61.05 g/mol CH_3NO_2

M_{H_2O} = 18.02 g/mol H_2O

1 mol CH_3NO_2 = 61.05 g CH_3NO_2
1 mol H_2O = 18.02 g H_2O
6 mol H_2O = 4 mol CH_3NO_2

$$m_{H_2O} = 6.3 \times 10^4 \ \cancel{\text{g CH}_3\text{NO}_2} \times \frac{1 \ \cancel{\text{mol CH}_3\text{NO}_2}}{61.05 \ \cancel{\text{g CH}_3\text{NO}_2}} \times \frac{6 \ \cancel{\text{mol H}_2\text{O}}}{4 \ \cancel{\text{mol CH}_3\text{NO}_2}} \times \frac{18.02 \text{ g H}_2\text{O}}{1 \ \cancel{\text{mol H}_2\text{O}}}$$

$$m_{H_2O} = 2.8 \times 10^4 \text{ g H}_2\text{O}$$

Therefore, 2.8×10^4 g of water, or 28 kg, is produced.

10. The answer to this problem is (c) since this equation has the highest nitric acid-to-water ratio, 10 : 3 (or 3.3 : 1), compared with 2 : 1 in (a) and (b).

2.9 ALTERNATIVE EXERCISE

(Pages 96–98)

CASE STUDY: COMBUSTION AND CARBON MONOXIDE POISONING

Questions

1. (a) Combustion is a chemical reaction in which oxygen reacts rapidly with a fuel to produce energy in the form of heat and light.
   (b) Complete combustion produces carbon dioxide and water vapour. Incomplete combustion produces carbon particles (soot), carbon monoxide, and water vapour.
2. (a) Complete combustion of methane:
   $CH_{4(g)} + 2\ O_{2(g)} \rightarrow CO_{2(g)} + 2\ H_2O_{(g)}$

$$m_{O_2} = 1.0 \ \cancel{\text{g CH}_4} \times \frac{1 \ \cancel{\text{mol CH}_4}}{16.05 \ \cancel{\text{g CH}_4}} \times \frac{2 \ \cancel{\text{mol O}_2}}{1 \ \cancel{\text{mol CH}_4}} \times \frac{32.00 \text{ g O}_2}{1 \ \cancel{\text{mol O}_2}}$$

$$m_{O_2} = 4.0 \text{ g O}_2$$

The complete combustion of 1.0 g of methane requires 4.0 g of oxygen.

(b) Incomplete combustion of methane:
$CH_{4(g)} + O_{2(g)} \rightarrow C_{(s)} + 2\ H_2O_{(g)}$

$$m_{O_2} = 1.0\ \cancel{g\ CH_4} \times \frac{1\ \cancel{mol\ CH_4}}{16.05\ \cancel{g\ CH_4}} \times \frac{1\ \cancel{mol\ O_2}}{1\ \cancel{mol\ CH_4}} \times \frac{32.00\ g\ O_2}{1\ \cancel{mol\ O_2}}$$

$$m_{O_2} = 2.0\ g\ O_2$$

The incomplete combustion of 1.0 g of methane requires 2.0 g of oxygen.

(c) Twice as much oxygen is required to completely combust 1.0 g of methane than is required to incompletely combust 1.0 g of methane.

3. (a) Sulfur oxides are produced by the combustion of sulfur impurities in fuel, and nitrogen oxides are produced by the combustion of nitrogen in air.
   (b) Sulfur oxides and nitrogen oxides are the main contributors to environmental acid precipitation.
4. The fuel : oxygen ratio decreases between complete and incomplete combustion.
5. (a) In stoichiometric combustion, fuel reacts with the exact amount of oxygen required to combust all of the hydrocarbon molecules in the fuel to carbon dioxide and water vapour.
   (b) Stoichiometric combustion is rare because it is very difficult to mix fuel and air according to precise stoichiometric ratios.
6. Three conditions that support incomplete combustion are incomplete air–fuel mixing, insufficient air supply to the flame, and insufficient time for reactants to react.
7. Carbon monoxide attaches itself to hemoglobin in red blood cells and hinders the blood's ability to transport oxygen throughout the body.
8. It is better to prevent carbon monoxide poisoning because carbon monoxide bonds very strongly to hemoglobin and is very difficult to remove.
9. (a) Most of the carbon monoxide produced in homes comes from the combustion of fuel for heating and cooking. Carbon monoxide gas may accumulate in a home when a blocked chimney or damaged furnace heat exchanger allows gases to enter a home. Carbon monoxide can also enter a home from the garage when an automobile, lawn mower, or other engine is in operation. Gas stoves and ranges can also produce carbon monoxide gas, which can present problems if the appliances are used for long periods of time, or if they are not operated properly. Some other common sources of carbon monoxide include space heaters and indoor use of charcoal for heating or cooking.
   (b) Carbon monoxide detectors trigger an alarm before carbon monoxide levels reach 100 ppm over 90 min, 200 ppm over 35 min or 400 ppm over 15 min. Carbon monoxide detectors require a continuous power supply.

2.5–2.9 SELF QUIZ

(Pages 99–100)

Modified True of False

1. True
2. False; A solution is concentrated if it has a relatively large quantity of solute per unit volume of solution.
3. False; The concentration of a solution may be expressed as a V/V percentage if it is composed of a solid solute and a liquid solvent.
4. False; Adding more solvent to a solution does not change the amount of solute in the solution.
5. True

Multiple Choice

6. (a)
7. (b)
8. (a)
9. (d)
10. (c)
11. (c)
12. (c)
13. (d)
14. (c)

Completion

15. concentration, solution
16. liquids
17. mol/L
18. 1
19. solvent
20. stoichiometry
21. balanced
22. amounts

2.10 EXTENSION EXERCISE

(Page 101)

LIMITING AND EXCESSREAGENTS—ADDITIONAL PRACTICE

1. (a) $AgNO_{3(aq)} + KCl_{(aq)} \rightarrow AgCl_{(s)} + KNO_{3(aq)}$

$$n_{AgNO_3} = 5.10\ \cancel{\text{g AgNO}_3} \times \frac{1\text{ mol AgNO}_3}{169.88\ \cancel{\text{g AgNO}_3}}$$

$$n_{AgNO_3} = 0.0300\text{ mol}$$

$$n_{KCl} = 4.48\ \cancel{\text{g KCl}} \times \frac{1\text{ mol KCl}}{74.55\ \cancel{\text{g KCl}}}$$

$$n_{KCl} = 0.0601\text{ mol}$$

Therefore, $AgNO_{3(aq)}$ is the limiting reagent.

(b) $$m_{AgCl} = 0.0300\ \cancel{\text{mol AgNO}_3} \times \frac{1\ \cancel{\text{mol AgCl}}}{1\ \cancel{\text{mol AgNO}_3}} \times \frac{143.32\text{ g AgCl}}{1\ \cancel{\text{mol AgCl}}}$$

$$m_{AgCl} = 4.3\text{ g AgCl}$$

The mass of silver chloride formed is 4.3 g.

Before the reaction, there is 0.0601 mol potassium chloride. During the reaction, 0.0300 mol potassium chloride is consumed. The mole ratio is 1:1. Therefore, 0.0301 mol potassium chloride remain after the reaction.

$$m_{KCl} = 0.0301\ \cancel{\text{mol KCl}} \times \frac{74.55\text{ g KCl}}{1\ \cancel{\text{mol KCl}}}$$

$$m_{KCl} = 2.24\text{ g KCl}$$

Therefore, 2.24 g of potassium chloride remains unreacted.

2. (a) $4\ NH_{3(g)} + 5\ O_{2(g)} \rightarrow 4\ NO_{(g)} + 6\ H_2O_{(l)}$

(b)

Balanced equation	$4\ NH_{3(g)}$	+	$5\ O_{2(g)}$	$\rightarrow$	$4\ NO_{(g)}$	+	$6\ H_2O_{(l)}$
Before reaction	4.00 mol		7.00 mol				
Reaction according to balanced equation	4.00 mol		5.00 mol				
After reaction	0 mol		2.00 mol				

Ammonia is the limiting reagent.

$n_{NH_3} = 4.00 \text{ mol } NH_3$

$M_{NO} = 30.01 \text{ g/mol NO}$

1 mol NO = 30.01 g NO
4 mol NO = 4 mol NH_3

$$m_{NO} = 4.00\ \cancel{\text{mol } NH_3} \times \frac{4\ \cancel{\text{mol NO}}}{4\ \cancel{\text{mol } NH_3}} \times \frac{30.01 \text{ g NO}}{1\ \cancel{\text{mol NO}}}$$

$$m_{NO} = 120 \text{ g NO}$$

The mass of nitrogen monoxide formed is 120 g.

(c) According to the reaction chart, 2.00 mol oxygen remains after the reaction.

$$m_{O_2} = 2.00\ \cancel{\text{mol } O_2} \times \frac{32.00 \text{ g } O_2}{1\ \cancel{\text{mol } O_2}}$$

$$m_{O_2} = 64.0 \text{ g } O_2$$

Therefore, 64.0 g of oxygen remains unreacted.

3. According to the balanced equation, 3 mol iodine is required to react with 2 mol aluminum. Before the reaction, there is 2.00 mol aluminum, but only 0.500 mol iodine. Therefore, iodine is the limiting reagent.

$$m_{AlI_3} = 0.500\ \cancel{\text{mol } I_2} \times \frac{2\ \cancel{\text{mol } AlI_3}}{3\ \cancel{\text{mol } I_2}} \times \frac{407.68 \text{ g } AlI_3}{1\ \cancel{\text{mol } AlI_3}}$$

$$m_{AlI_3} = 136 \text{ g } AlI_3$$

The theoretical yield of aluminum iodide is 136 g.

4. (a) $N_{2(g)} + 2\ O_{2(g)} + 2\ NO_{2(g)}$

(b) According to the balanced equation, 1 mol nitrogen is required to react with 2 mol oxygen. Before the reaction, there is 0.200 mol nitrogen and 0.200 mol oxygen. Therefore, oxygen is the limiting reagent.

$$m_{NO_2} = 0.200\ \cancel{\text{mol } O_2} \times \frac{2\ \cancel{\text{mol } NO_2}}{2\ \cancel{\text{mol } O_2}} \times \frac{46.01 \text{ g } NO_2}{1\ \cancel{\text{mol } NO_2}}$$

$$m_{NO_2} = 9.20 \text{ g } NO_2$$

The theoretical yield of nitrogen dioxide is 9.20 g.

(c) Nitrogen is the limiting reagent.

$$n_{NO_2} = 2.00\ \cancel{\text{mol } N_2} \times \frac{2 \text{ mol } NO_2}{1\ \cancel{\text{mol } N_2}}$$

$$n_{NO_2} = 4.00 \text{ mol } NO_2$$

The amount of nitrogen dioxide produced is 4.00 mol.

5. (a) $2\ SO_{2(g)} + O_{2(g)} + 2\ H_2O_{(l)} \rightarrow 2\ H_2SO_{4(l)}$

(b) According to the balanced equation, 2 mol sulfur dioxide reacts with 1 mol oxygen and 2 mol water. Before the reaction, there is 1.50 mol sulfur dioxide, 1.00 mol oxygen, and 2.00 mol water. Therefore, sulfur dioxide is the limiting reagent.

$$m_{H_2SO_4} = 1.50\ \cancel{\text{mol } SO_2} \times \frac{2\ \cancel{\text{mol } H_2SO_4}}{2\ \cancel{\text{mol } SO_2}} \times \frac{98.08 \text{ g } H_2SO_4}{1\ \cancel{\text{mol } H_2SO_4}}$$

$$m_{H_2SO_4} = 147 \text{ g } H_2SO_4$$

The theoretical yield of hydrogen sulfate is 147 g.

6. (a) $C_3H_{8(g)} + 5\ O_{2(g)} \rightarrow 3\ CO_{2(g)} + 4\ H_2O_{(g)}$
(b) According to the balanced equation, 1 mol propane reacts with 5 mol oxygen. Before the reaction, there is 10.0 mol propane and 2.00 mol oxygen. Therefore, oxygen is the limiting reagent.

(c)
$$m_{H_2O} = 2.00\ \cancel{\text{mol } O_2} \times \frac{4\ \cancel{\text{mol } H_2O}}{5\ \cancel{\text{mol } O_2}} \times \frac{18.02\ \text{g } H_2O}{1\ \cancel{\text{mol } H_2O}}$$
$$m_{H_2O} = 28.8\ \text{g } H_2O$$

Therefore, 28.8 g of water vapour is formed.

7. (a) $2\ Ag_{(s)} + Cu(NO_3)_{2(aq)} \rightarrow Cu_{(s)} + 2\ AgNO_{3(aq)}$
(b) According to the balanced equation, 2 mol silver reacts with 1 mol copper(II) nitrate. Before the reaction, there is 2.000 mol silver and 2.000 mol copper(II) nitrate. Therefore, silver is the limiting reagent.

(c)
$$m_{Cu} = 2.000\ \cancel{\text{mol Ag}} \times \frac{1\ \cancel{\text{mol Cu}}}{2\ \cancel{\text{mol Ag}}} \times \frac{63.55\ \text{g Cu}}{1\ \cancel{\text{mol Cu}}}$$
$$m_{Cu} = 63.55\ \text{g Cu}$$

Therefore, 63.55 g of copper is formed.

2.11 ALTERNATIVE EXERCISE

(Pages 104–105)

ACTIVITY: THE LIMITING REAGENT AND PERCENTAGE COMPOSITION OF A MIXTURE

Observations

Part A

	Precipitate forms with $Ba(NO_3)_{2(aq)}$ (Yes/No)	Precipitate forms with $CuSO_{4(aq)}$ (Yes/No)
Test 1	yes	—
Test 2	—	no

Part B

Mass of filter paper + precipitate (step 12)	2.35 g
Mass of filter paper (step 5)	1.38 g
(a) Mass of precipitate	0.97 g

Analysis

(b) Since a precipitate formed when barium nitrate was added to the filtrate in test tube 1, but not when copper sulfate was added to the filtrate in test tube 2, barium nitrate is the limiting reagent.
(c) Since barium nitrate is the limiting reagent in this reaction, its amount (and mass) in the $Ba(NO_3)_{2(s)}/CuSO_{4(s)}$ mixture may be calculated using the mass of the barium sulfate precipitate formed in the reaction.

$$m_{Ba(NO_3)_2} = 0.97\ \cancel{\text{g } BaSO_4} \times \frac{1\ \cancel{\text{mol } BaSO_4}}{233.39\ \cancel{\text{g } BaSO_4}} \times \frac{1\ \cancel{\text{mol } Ba(NO_3)_2}}{1\ \cancel{\text{mol } BaSO_4}} \times \frac{261.35\ \text{g } Ba(NO_3)_2}{1\ \cancel{\text{mol } Ba(NO_3)_2}}$$
$$m_{Ba(NO_3)_2} = 1.1\ \text{g } Ba(NO_3)_2$$

$$\%\ Ba(NO_3)_2 \text{ in } Ba(NO_3)_2/CuSO_4 \text{ mixture} = \frac{1.1\ \text{g}}{2.01\ \text{g}} \times 100\%$$
$$\%\ Ba(NO_3)_2 \text{ in } Ba(NO_3)_2/CuSO_4 \text{ mixture} = 55\%$$

$$\% \ CuSO_4 \text{ in } Ba(NO_3)_2/CuSO_4 \text{ mixture} = 100\% - 55\%$$
$$\% \ CuSO_4 \text{ in } Ba(NO_3)_2/CuSO_4 \text{ mixture} = 45\%$$

In a mixture of solid barium nitrate and solid copper(II) sulfate, 55% is barium nitrate and 45% is copper(II) sulfate.

Evaluation

(d) The precipitate may not have been completely dry when its mass was measured. This would result in an incorrect larger mass due to the excess water. Spreading the precipitate into a thin layer (without losing any precipitate) may help it to dry more thoroughly. This could be done by using a larger funnel and a larger piece of filter paper and spreading the precipitate as it is poured.

2.12 EXTENSION EXERCISE

(Pages 106–107)

PERCENTAGE YIELD—ADDITIONAL PRACTICE

1.

Reaction	Actual mass of product	Theoretical mass of product	Percentage yield
(a)	2.62 g	6.20 g	42.2%
(b)	7.33 g	9.21 g	79.6%
(c)	3.2×10^2 kg	6.5×10^2 kg	49.2%

The equation used to calculate the answers is

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

2. $$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$
$$= \frac{5.00 \ \cancel{\text{mol } Cu_2S}}{22.0 \ \cancel{\text{mol } Cu_2S}} \times 100\%$$
$$\text{percentage yield} = 22.7\%$$
The percentage yield of copper(II) sulfate is 22.7%.

3. (a) $4 \ Al_{(s)} + 3 \ O_{2(g)} \rightarrow 2 \ Al_2O_{3(s)}$

(b) $$m_{Al_2O_3} = 160 \ \cancel{\text{g Al}} \times \frac{1 \ \cancel{\text{mol Al}}}{26.98 \ \cancel{\text{g Al}}} \times \frac{2 \ \cancel{\text{mol } Al_2O_3}}{4 \ \cancel{\text{mol Al}}} \times \frac{101.96 \text{ g } Al_2O_3}{1 \ \cancel{\text{mol } Al_2O_3}} \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$
$$m_{Al_2O_3} = 302 \text{ g } Al_2O_3$$
The theoretical yield of aluminum oxide is 302 g.

(c) $$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$
$$= \frac{260 \ \cancel{\text{g } Al_2O_3}}{302 \ \cancel{\text{g } Al_2O_3}} \times 100\%$$
$$\text{percentage yield} = 86.1\%$$

The percentage yield of aluminum oxide is 86.1%.

4. (a) $2\ KClO_{3(s)} \rightarrow 2\ KCl_{(s)} + 3\ O_{2(g)}$

(b)
$$m_{O_2} = 5.45\ \cancel{g\ KClO_3} \times \frac{1\ \cancel{mol\ KClO_3}}{122.55\ \cancel{g\ KClO_3}} \times \frac{3\ \cancel{mol\ O_2}}{2\ \cancel{mol\ KClO_3}} \times \frac{32.00\ g\ O_2}{1\ \cancel{mol\ O_2}}$$
$$m_{O_2} = 2.13\ g\ O_2$$

The theoretical yield of oxygen is 2.13 g.

(c)
$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$
$$= \frac{1.95\ \cancel{g\ O_2}}{2.13\ \cancel{g\ O_2}} \times 100\%$$
$$\text{percentage yield} = 91.5\%$$

The percentage yield of oxygen is 91.5%.

5. $2\ H_{2(g)} + O_{2(g)} \rightarrow 2\ H_2O_{(g)}$

$$m_{H_2O} = 42.0\ \cancel{g\ H_2} \times \frac{1\ \cancel{mol\ H_2}}{2.02\ \cancel{g\ H_2}} \times \frac{2\ \cancel{mol\ H_2O}}{2\ \cancel{mol\ H_2}} \times \frac{18.02\ g\ H_2O}{1\ \cancel{mol\ H_2O}}$$
$$m_{H_2O} = 375\ g\ H_2O$$

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$
$$= \frac{340.2\ \cancel{g\ H_2O}}{375\ \cancel{g\ H_2O}} \times 100\%$$
$$\text{percentage yield} = 90.7\%$$

The percentage yield of water is 90.7%.

6.
$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$
$$= \frac{5.50\ \cancel{g\ NO}}{25.0\ \cancel{g\ NO}} \times 100\%$$
$$\text{percentage yield} = 22.0\%$$

The percentage yield of nitrogen monoxide is 22.0%.

7.
$$m_{K_3PO_4} = 49.0\ \cancel{g\ H_3PO_4} \times \frac{1\ \cancel{mol\ H_3PO_4}}{98.00\ \cancel{g\ H_3PO_4}} \times \frac{1\ \cancel{mol\ K_3PO_4}}{1\ \cancel{mol\ H_3PO_4}} \times \frac{212.27\ g\ K_3PO_4}{1\ \cancel{mol\ K_3PO_4}}$$
$$m_{K_3PO_4} = 106\ g\ K_3PO_4$$

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$
$$= \frac{49.0\ \cancel{g\ K_3PO_4}}{106\ \cancel{g\ K_3PO_4}} \times 100\%$$
$$\text{percentage yield} = 46.2\%$$

The percentage yield of potassium phosphate is 46.2%.

8.
$$m_{Na_2SO_3} = 389.4\ \cancel{g\ Al_2(SO_3)_3} \times \frac{1\ \cancel{mol\ Al_2(SO_3)_3}}{294.14\ \cancel{g\ Al_2(SO_3)_3}} \times \frac{3\ \cancel{mol\ Na_2SO_3}}{1\ \cancel{mol\ Al_2(SO_3)_3}} \times \frac{126.04\ g\ Na_2SO_3}{1\ \cancel{mol\ Na_2SO_3}}$$
$$m_{Na_2SO_3} = 500.6\ g\ Na_2SO_3$$

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$
$$= \frac{212.4 \cancel{\text{ g Na}_2\text{SO}_3}}{500.6 \cancel{\text{ g Na}_2\text{SO}_3}} \times 100\%$$
$$\text{percentage yield} = 42.43\%$$

The percentage yield of sodium sulfite is 42.43%.

2.14 ALTERNATIVE EXERCISE

(Pages 110–113)

CASE STUDY: THE CHEMICAL INDUSTRY

Questions

1. (a) Student answers will vary. Examples include a plastic pen, fabric dye, and paper.
   (b) Plastic pen: petrochemical
   Fabric dye: petrochemical, sulfur, and nitrogen
   Paper: chlorakali
2. Sulfuric acid is the largest-volume industrial chemical produced in the world because it is used in the production of almost all other manufactured goods including fertilizers, petrochemicals, dyestuffs, plastics, and detergents.
3. (a)

Bulk Processing		Continuous Processing	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• different products produced simultaneously • higher purity	• smaller quantities produced	• larger quantities produced	• single product produced • lower purity

   (b) A company would choose one type of process over another based on scale. Continuous processing is usually chosen if larger quantities of product are needed.
4. (a) Coproducts are formed in the same reaction that produces a desired product. Byproducts are produced by side reactions.
   (b) Coproducts can reduce the overall cost of production if they can be sold as useful products. Coproducts can be detrimental to the overall process if they are not useful, and need to be separated and discarded. This step slows down the efficiency of the process and can also be costly.
   (c) Chemical engineers and chemical engineering technologists design and construct processing systems that maximize the yield of a desired product.
5. (a) Student answers will vary. Canned soup is usually prepared by batch processing.
   (b) The batch reactor in soup-making is a large, heated, stainless-steel kettle.
   (c) This apparatus is similar to a pot used to make soup at home, or a beaker in a school chemistry lab.
6. The modern Haber process employs a batch process.
7. (a) Chemical engineering technologists assist chemists and engineers in chemical processes and product research, analysis, production, and quality control.
   (b) Recommended high school courses include English, Mathematics, and Science (Chemistry). Community college programs or private technical training programs in applied chemical, biochemical, or chemical engineering technology are required for certification. Community college technology programs are normally three years long.
   Certification occurs through the Ontario Association of Certified Engineering Technicians and Technologists (OACETT). Applicants need an approved diploma and two years' work experience followed by a successful completion of a certification exam. Although it's still voluntary, many employers ask for certification.

(c) Chemical engineering technologists need to work as members of a professional team. They must be able to manage projects, organize effectively, and solve problems. Computer skills, mathematical skills, design and drawing skills, and written and oral communication skills are also important.
(d) Overall employment of chemical engineering technologists is expected to increase about as fast as the average for all occupations through 2010.

2.10–2.14 SELF QUIZ

(Page 114)

Modified True or False

1. True
2. False; The amount of products formed in a chemical reaction depends on the amount of limiting reagent available.
3. True
4. True
5. False; Increasing the number of steps in the experimental design usually decreases the yield of product in a chemical reaction.
6. False; The actual yield of a chemical reaction is determined by carrying out the reaction in a laboratory and determining the mass of product.

Multiple Choice

7. (c)
8. (d)
9. (b)

Completion

10. theoretical
11. actual
12. actual, theoretical

UNIT 2 SELF QUIZ

(Pages 116–118)

Modified True or False

1. True
2. True
3. True
4. False; The SI symbol is *M*.
5. True
6. True
7. False; The molar mass of ammonia is 17.04 g/mol.
8. True
9. True
10. False; The amount of limiting reagent determines the amount of product formed.
11. False; The theoretical yield will be greater than or equal to the actual yield.
12. True
13. True
14. False; The concentration of potassium chloride will be less than 0.50 mol/L because adding potassium chloride increases the total volume of the solution to more than 1.0 L.
15. False; Adding water to a solution decreases the solution's concentration.

Multiple Choice

16. (c)
17. (c)

18. (b)
19. (b)
20. (a)
21. (d)
22. (c)
23. (a)
24. (b)
25. (a)
26. (c)
27. (b)
28. (a)
29. (b)
30. (a)

Completion

31. atomic
32. molecular/diatomic
33. combustion
34. molar mass
35. aqueous
36. dilution
37. excess
38. low