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Understanding Concepts

1. (a) $n_{NaHCO_3} = 34.2$ mol

   $M_{NaHCO_3} = 84.01$ g/mol

   $m_{NaHCO_3} = 34.2 \text{ mol} \times \dfrac{84.01 \text{ g}}{1 \text{ mol}}$

   $m_{NaHCO_3} = 2.87 \times 10^3 \text{ g} = 2.87 \text{ kg}$

   The mass of baking soda is 2.87 kg.

   (b) $n_{H_2O_2} = 2.17$ mol

   $M_{H_2O_2} = 34.02$ g/mol

   $m_{H_2O_2} = 2.17 \text{ mol} \times \dfrac{34.02 \text{ g}}{1 \text{ mol}}$

   $m_{H_2O_2} = 73.8 \text{ g}$

   The mass of hydrogen peroxide is 73.8 g.

   (c) $n_{Mg(OH)_2} = 6.13 \times 10^{-2}$ mol

   $M_{Mg(OH)_2} = 58.33$ g/mol

   $m_{Mg(OH)_2} = 6.13 \times 10^{-2} \text{ mol} \times \dfrac{58.33 \text{ g}}{1 \text{ mol}}$

   $m_{Mg(OH)_2} = 3.58 \text{ g}$

   The mass of magnesium hydroxide is 3.58 g.

   (d) $n_{CO} = 4.10 \times 10^{-3}$ mol

   $M_{CO} = 28.01$ g/mol

   $m_{CO} = 4.10 \times 10^{-3} \text{ mol} \times \dfrac{28.01 \text{ g}}{1 \text{ mol}}$

   $m_{CO} = 0.115 \text{ g} \text{ (or 115 mg)}$

   The mass of carbon monoxide is 115 mg.

   (e) $n_{Fe} = 1.19 \times 10^3$ mol

   $M_{Fe} = 55.85$ g/mol

   $m_{Fe} = 1.19 \times 10^3 \text{ mol} \times \dfrac{55.85 \text{ g}}{1 \text{ mol}}$

   $m_{Fe} = 6.65 \times 10^4 \text{ g} = 66.5 \text{ kg}$

   The mass of iron is 66.5 kg.

   (f) $n_{C_{56}H_{88}O_2} = 5.99$ mol

   $M_{C_{56}H_{88}O_2} = 793.44$ g/mol

   $m_{C_{56}H_{88}O_2} = 5.99 \text{ mol} \times \dfrac{793.44 \text{ g}}{1 \text{ mol}}$

   $m_{C_{56}H_{88}O_2} = 4.75 \times 10^3 \text{ g} = 4.75 \text{ kg}$

   The mass of vitamin D is 4.75 kg.

2. (a) $m_{Ag} = 10.5$ g

   $M_{Ag} = 107.87$ g/mol

$$n_{Ag} = 10.5 \text{ g} \times \frac{1 \text{ mol}}{107.87 \text{ g}}$$

$n_{Ag} = 0.0973 \text{ mol} = 97.3 \text{ mmol}$

The amount of silver is 97.3 mmol.

(b) $m_{C_2H_5OH} = 8.55 \text{ g}$

$M_{C_2H_5OH} = 46.08 \text{ g/mol}$

$$n_{C_2H_5OH} = 8.55 \text{ g} \times \frac{1 \text{ mol}}{46.08 \text{ g}}$$

$n_{C_2H_5OH} = 0.186 \text{ mol (or 186 mmol)}$

The amount of ethanol is 186 mmol.

(c) $m_{NH_4NO_3} = 6.74 \times 10^3 \text{ g}$

$M_{NH_4NO_3} = 80.06 \text{ g/mol}$

$$n_{NH_4NO_3} = 6.74 \times 10^3 \text{ g} \times \frac{1 \text{ mol}}{80.06 \text{ g}}$$

$n_{NH_4NO_3} = 84.2 \text{ mol}$

The amount of ammonium nitrate is 84.2 mol.

(d) $m_{HC_2H_3O_2} = 50.0 \text{ g}$

$M_{HC_2H_3O_2} = 60.06 \text{ g/mol}$

$$n_{HC_2H_3O_2} = 50.0 \text{ g} \times \frac{1 \text{ mol}}{60.06 \text{ g}}$$

$n_{HC_2H_3O_2} = 0.832 \text{ mol (or 832 mmol)}$

The amount of acetic acid is 832 mmol.

(e) $m_{C_{27}H_{46}O} = 38.9 \text{ g}$

$M_{C_{27}H_{46}O} = 386.73 \text{ g/mol}$

$$n_{C_{27}H_{46}O} = 38.9 \text{ g} \times \frac{1 \text{ mol}}{386.73 \text{ g}}$$

$n_{C_{27}H_{46}O} = 0.101 \text{ mol (or 101 mmol)}$

The amount of cholesterol is 101 mmol.

(f) $m_{NaF} = 1.25 \times 10^{-2} \text{ g}$

$M_{NaF} = 41.99 \text{ g/mol}$

$$n_{NaF} = 1.25 \times 10^{-2} \text{ g} \times \frac{1 \text{ mol}}{41.99 \text{ g}}$$

$n_{NaF} = 2.98 \times 10^{-4} \text{ mol} = 0.298 \text{ mmol (or 298 µmol)}$

The amount of sodium fluoride is 298 µmol.

3. (a) $m_{Au} = 5.00 \text{ g}$

$M_{Au} = 196.97 \text{ g/mol}$

$N_A = 6.02 \times 10^{23} \text{ atoms/mol}$

$$n_{Au} = 5.00 \text{ g} \times \frac{1 \text{ mol}}{196.97 \text{ g}}$$

$n_{Au} = 0.0254 \text{ mol}$

$$N_{Au} = 0.0254 \text{ mol} \times \frac{6.02 \times 10^{23} \text{ atoms}}{\text{mol}}$$

$N_{Au} = 1.53 \times 10^{22} \text{ atoms}$

(b) $n_{Au} = 5.0 \times 10^{-2}$ mol

$N_A = 6.02 \times 10^{23}$ atoms/mol

$N_{Au} = 5.0 \times 10^{-2}$ mol $\times \dfrac{6.02 \times 10^{23} \text{ atoms}}{\text{mol}}$

$N_{Au} = 3.01 \times 10^{22}$ atoms

(c) $m_{O_2} = 5.00$ g

$M_{O_2} = 32.00$ g/mol

$N_A = 6.02 \times 10^{23}$ molecules /mol

$n_{O_2} = 5.00$ g $\times \dfrac{1 \text{ mol}}{32.00 \text{ g}}$

$n_{O_2} = 0.156$ mol

$N_{O_2} = 0.156$ mol $\times \dfrac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mol}} \times \dfrac{2 \text{ atoms}}{1 \text{ molecule}}$

$N_{O_2} = 1.88 \times 10^{23}$ atoms

(d) $n_{O_2} = 5.0 \times 10^{-2}$ mol

$N_A = 6.02 \times 10^{23}$ molecules/mol

$N_{O_2} = 5.0 \times 10^{-2}$ mol $\times \dfrac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mol}} \times \dfrac{2 \text{ atoms}}{1 \text{ molecule}}$

$N_{O_2} = 6.02 \times 10^{22}$ atoms

The sample with the most atoms is (c): 5.00 g of oxygen gas.

4. $m_{CaCO_3} = 335$ mg

$M_{CaCO_3} = 100.09$ g/mol

$n_{CaCO_3} = 335$ mg $\times \dfrac{1 \text{ mol}}{100.09 \text{ g}}$

$n_{CaCO_3} = 3.35$ mmol

The amount of calcium carbonate is 3.35 mmol.

5. Assume a 100 g sample, for convenience.

$m_{Pb^{2+}} = 68.3$ g $\qquad M_{Pb^{2+}} = 207.20$ g/mol

$m_S = 10.6$ g $\qquad\quad M_S = 32.06$ g/mol

$m_O = 21.1$ g $\qquad\quad M_O = 16.00$ g/mol

$n_{Pb^{2+}} = 68.3$ g $\times \dfrac{1 \text{ mol}}{207.20 \text{ g}}$

$n_{Pb^{2+}} = 0.330$ mol

$n_S = 10.6$ g $\times \dfrac{1 \text{ mol}}{32.06 \text{ g}}$

$n_S = 0.331$ mol

$n_O = 21.1$ g $\times \dfrac{1 \text{ mol}}{16.00 \text{ g}}$

$n_O = 1.32$ mol

The mole ratio, Pb^{2+} : S : O is 0.330 : 0.331 : 1.32.

Simplifying (dividing each value by the lowest), we obtain 1.00 : 1.00 : 4.00, or almost exactly 1 : 1 : 4, making the empirical formula $PbSO_{4(s)}$.

6. (a) m_{Ba} $= 137.33 \text{ u} \times 1$ $= 137.33 \text{ u}$

   m_{Cr} $= 52.00 \text{ u} \times 1$ $= 52.00 \text{ u}$

   m_{O} $= 16.00 \text{ u} \times 4$ $= 64.00 \text{ u}$

   m_{BaCrO_4} $= 253.33 \text{ u}$

   $$\% \text{ Ba} = \frac{137.33 \text{ u}}{253.33 \text{ u}} \times 100\%$$

   $\% \text{ Ba} = 54.210\%$

   $$\% \text{ Cr} = \frac{52.00 \text{ u}}{253.33 \text{ u}} \times 100\%$$

   $\% \text{ Cr} = 20.53\%$

   $$\% \text{ O} = \frac{64.00 \text{ u}}{253.33 \text{ u}} \times 100\%$$

   $\% \text{ O} = 25.26\%$

   The percentage composition of $BaCrO_4$ is 54.210% barium, 20.53% chromium, and 25.26% oxygen, by mass.

(b) m_{Co} $= 58.93 \text{ u} \times 1$ $= 58.93 \text{ u}$

   m_{C} $= 12.01 \text{ u} \times 1$ $= 12.01 \text{ u}$

   m_{O} $= 16.00 \text{ u} \times 3$ $= 48.00 \text{ u}$

   m_{CoCO_3} $= 118.94 \text{ u}$

   $$\% \text{ Co} = \frac{58.93 \text{ u}}{118.94 \text{ u}} \times 100\%$$

   $\% \text{ Co} = 49.55\%$

   $$\% \text{ C} = \frac{12.01 \text{ u}}{118.94 \text{ u}} \times 100\%$$

   $\% \text{ C} = 10.10\%$

   $$\% \text{ O} = \frac{48.00 \text{ u}}{118.94 \text{ u}} \times 100\%$$

   $\% \text{ O} = 40.36\%$

   The percentage composition of $CoCO_{3(s)}$ is 49.55% cobalt, 10.10% carbon, and 40.36% oxygen, by mass.

(c) m_{Fe} $= 55.85 \text{ u} \times 1$ $= 55.85 \text{ u}$

   m_{Cl} $= 35.45 \text{ u} \times 3$ $= 106.35 \text{ u}$

   m_{H} $= 1.01 \text{ u} \times 12$ $= 12.12 \text{ u}$

   m_{O} $= 16.00 \text{ u} \times 6$ $= 96.00 \text{ u}$

   $m_{FeCl_3 \cdot 6H_2O}$ $= 270.32 \text{ u}$

   $$\% \text{ Fe} = \frac{55.85 \text{ u}}{270.32 \text{ u}} \times 100\%$$

   $\% \text{ Fe} = 20.66\%$

   $$\% \text{ Cl} = \frac{106.35 \text{ u}}{270.32 \text{ u}} \times 100\%$$

$$\% \text{ Cl} = 39.342\%$$

$$\% \text{ H} = \frac{12.12 \text{ u}}{270.32 \text{ u}} \times 100\%$$

$$\% \text{ H} = 4.484\%$$

$$\% \text{ O} = \frac{96.00 \text{ u}}{270.32 \text{ u}} \times 100\%$$

$$\% \text{ O} = 35.51\%$$

The percentage composition of $FeCl_3 \cdot 6H_2O_{(g)}$ is 20.66% iron, 39.342% chlorine, 4.484% hydrogen, and 35.51% oxygen, by mass.

7. (a) Two moles of solid nickel(II) sulfide react with three moles of oxygen gas to form two moles of solid nickel(II) oxide and two moles of sulfur dioxide gas.
   The mole ratio is 2:3:2:2 for the reaction as written.
   (b) Two moles of solid aluminum react with three moles of aqueous copper(II) chloride to form two moles of aqueous aluminum chloride and three moles of solid copper.
   The mole ratio is 2:3:2:3 for the reaction as written.
   (c) Two moles of liquid hydrogen peroxide decompose to form two moles of liquid water and one mole of oxygen gas.
   The mole ratio is 2:2:1 for the reaction as written.

8. (a) $2 \text{ NaCl}_{(s)} \rightarrow 2 \text{ Na}_{(s)} + Cl_{2(g)}$

   decomposition

   (b) $4 \text{ Na}_{(s)} + O_{2(g)} \rightarrow 2 \text{ Na}_2O_{(s)}$

   synthesis

   (c) $2 \text{ Na}_{(s)} + 2 \text{ H}_2O_{(l)} \rightarrow H_{2(g)} + 2 \text{ NaOH}_{(aq)}$

   single displacement

   (d) $AlCl_{3(aq)} + 3 \text{ NaOH}_{(aq)} \rightarrow Al(OH)_{3(s)} + 3 \text{ NaCl}_{(aq)}$

   double displacement

   (e) $2 \text{ Al}_{(s)} + 3 \text{ H}_2SO_{4(aq)} \rightarrow 3 \text{ H}_{2(g)} + Al_2(SO_4)_{3(aq)}$

   single displacement

   (f) $2 \text{ C}_8H_{18(l)} + 25 \text{ O}_{2(g)} \rightarrow 16 \text{ CO}_{2(g)} + 18 \text{ H}_2O_{(g)}$

   combustion

9. (a) $8 \text{ Ni}_{(s)} + S_{8(s)} \rightarrow 8 \text{ NiS}_{(s)}$

   synthesis   The mole ratio is 8:1:8 as written here.

   (b) $2 \text{ C}_6H_{6(l)} + 15 \text{ O}_{2(g)} \rightarrow 12 \text{ CO}_{2(g)} + 6 \text{ H}_2O_{(g)}$

   combustion   The mole ratio is 2:15:12:6 as written here.

   (c) $2 \text{ K}_{(s)} + 2 \text{ H}_2O_{(l)} \rightarrow 2 \text{ KOH}_{(aq)} + H_{2(g)}$

   single displacement   The mole ratio is 2:2:2:1 as written here.

10. $Cl_{2(g)} + 2 \text{ KI}_{(aq)} \rightarrow I_{2(s)} + 2 \text{ KCl}_{(aq)}$

    A diagnostic test for iodine is adding trichlorotrifluoroethylene and shaking in a closed container. A purple colour in the TTFE layer indicates iodine. Another test would be to do a "reverse" starch test, i.e., add the mixture to starch to test for iodine.
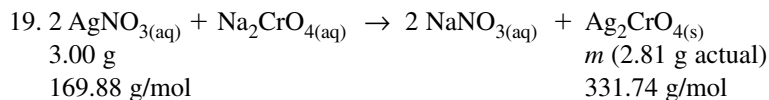   *Note:* In low concentrations, this reaction produces no precipitate. $I_{2(aq)}$ is acceptable as a product on this basis.

11. (a) $2\ C_2H_{2(g)} + 5\ O_{2(g)} \rightarrow 4\ CO_{2(g)} + 2\ H_2O_{(g)}$

    technological perspective

   (b) $MgCl_{2(s)} \rightarrow Mg_{(s)} + Cl_{2(g)}$

    scientific perspective

   (c) $2\ Fe_{(s)} + 3\ CuSO_{4(aq)} \rightarrow 3\ Cu_{(s)} + Fe_2(SO_4)_{3(aq)}$

    economic perspective

   (d) $2\ ZnS_{(s)} + 3\ O_{2(g)} \rightarrow 2\ ZnO_{(s)} + 2\ SO_{2(g)}$

    political perspective

   (e) $2\ Pb(C_2H_5)_{4(l)} + 27\ O_{2(g)} \rightarrow 2\ PbO_{(s)} + 16\ CO_{2(g)} + 20\ H_2O_{(g)}$

    ecological perspective

12. (a) $^{230}_{90}Th \rightarrow {}^{4}_{2}He + {}^{226}_{88}Ra$

   (b) $^{214}_{82}Pb \rightarrow {}^{0}_{-1}e + {}^{214}_{83}Bi$

   (c) $^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{1}_{1}p + {}^{17}_{8}O$

13. Assume one mole of compound, 162.24 g.

   mass % C = 74.0% M_C = 12.01 g/mol

   mass % H = 8.7% M_H = 1.01 g/mol

   mass % N = 17.3% M_N = 14.01 g/mol

   $$n_C = \frac{74.0}{100} \times 162.24\ g \times \frac{1\ mol}{12.01\ g}$$
   $$n_C = 10.0\ mol$$
   $$n_H = \frac{8.7}{100} \times 162.24\ g \times \frac{1\ mol}{1.01\ g}$$
   $$n_H = 14\ mol$$
   $$n_N = \frac{17.3}{100} \times 162.24\ g \times \frac{1\ mol}{14.01\ g}$$
   $$n_N = 2.00\ mol$$

   The integral mole ratio is 10 : 14 : 2, so the molecular formula of nicotine is $C_{10}H_{14}N_2$.

14. (a) In a reagent mix the reagent consumed first, causing the reaction to cease, is the limiting reagent. Some of the other reagent will remain unreacted, so it is said to be in excess.

   (b) One reagent is present in excess to ensure that all of the other reagent is able to react, and that stoichiometric calculations made from that quantity will be accurate.

15. (a) A graph may be used in quantitative analysis to predict the quantity of one substance involved in the reaction from the known quantity of another substance.

   (b) Use of graphs for prediction is very quick and easy, since no calculation is required.

16. The reaction equation coefficients always show the ratio of substances in numerical amount (moles), so any quantity measurements must be changed to amounts before the ratio can be applied.

17. (a) The quantity of product predicted by stoichiometric calculation is the theoretical yield. When the reaction is carried out, the measured quantity of product obtained is the actual yield. The percentage yield is the ratio of actual/theoretical yields, expressed as a percentage.

   (b) Yield less than predicted in a reaction may be due to experimental error inherent in the procedure; to impurities in the reagents; to unwanted side reactions; and to reactions that are not quantitative — that do not "go to completion."

18. Science emphasizes explanation and is international in scope. Technology emphasizes efficient operation (or problem solving) and is usually more local in scope.
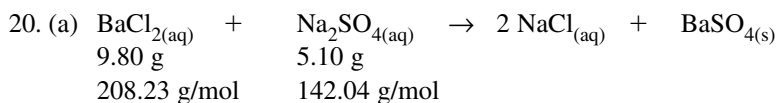
19. $2 AgNO_{3(aq)} + Na_2CrO_{4(aq)} \rightarrow 2 NaNO_{3(aq)} + Ag_2CrO_{4(s)}$
   3.00 g m (2.81 g actual)
   169.88 g/mol   331.74 g/mol

$$n_{AgNO_3} = 3.00 \text{ g} \times \frac{1 \text{ mol}}{169.88 \text{ g}}$$

$$n_{AgNO_3} = 0.0177 \text{ mol}$$

$$n_{Ag_2CrO_4} = 0.0177 \text{ mol} \times \frac{1}{2}$$

$$n_{Ag_2CrO_4} = 0.00883 \text{ mol}$$

$$m_{Ag_2CrO_4} = 0.00883 \text{ mol} \times \frac{331.74 \text{ g}}{1 \text{ mol}}$$

$$m_{Ag_2CrO_4} = 2.93 \text{ g}$$

or

$$m_{Ag_2CrO_4} = 3.00 \text{ g } AgNO_3 \times \frac{1 \text{ mol } AgNO_3}{} \times \frac{1 \text{ mol } Ag_2CrO_4}{} \times \frac{331.74 \text{ g } Ag_2CrO_4}{1 \text{ mol } Ag_2CrO_4}$$

$$m_{Ag_2CrO_4} = 2.93 \text{ g}$$

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

$$\% \text{ yield} = \frac{2.81 \text{ g}}{2.93 \text{ g}} \times 100\% = 95.9\%$$

The percentage yield of silver chromate in this reaction is 95.9%.

20. (a) $BaCl_{2(aq)} + Na_2SO_{4(aq)} \rightarrow 2 NaCl_{(aq)} + BaSO_{4(s)}$
       9.80 g   5.10 g
       208.23 g/mol   142.04 g/mol

$$n_{BaCl_2} = 9.80 \text{ g} \times \frac{1 \text{ mol}}{208.23 \text{ g}}$$

$$n_{BaCl_2} = 0.0471 \text{ mol}$$

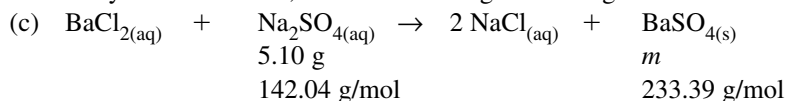$$n_{Na_2SO_4} = 5.10 \text{ g} \times \frac{1 \text{ mol}}{142.04 \text{ g}}$$

$$n_{Na_2SO_4} = 0.0359 \text{ mol}$$

Since the reactant mole ratio is 1:1, the $Na_2SO_{4(aq)}$ is obviously the limiting reagent for this reaction, and the $BaCl_{2(aq)}$ is in excess.

(b) The $BaCl_{2(aq)}$ is in excess by $(0.0471 - 0.0359) \text{ mol} = 0.0112 \text{ mol}$.

$$m_{BaCl_2} = 0.0112 \text{ mol} \times \frac{208.23 \text{ g}}{1 \text{ mol}} = 2.33 \text{ g}$$

The $BaCl_{2(aq)}$ is in excess by 2.33 g.

Note: The excess of barium chloride may also be found by calculating the stoichiometric mass required to react with 5.10 g of sodium sulfate, and then subtracting that from 9.80 g. This method will produce an answer of 2.32 g, essentially the same value, since the third significant digit is uncertain anyway.

(c) $BaCl_{2(aq)} + Na_2SO_{4(aq)} \rightarrow 2 NaCl_{(aq)} + BaSO_{4(s)}$
                        5.10 g m
                        142.04 g/mol   233.39 g/mol

$$n_{Na_2SO_4} = 5.10 \text{ g} \times \frac{1 \text{ mol}}{142.04 \text{ g}}$$

$$n_{Na_2SO_4} = 0.0359 \text{ mol}$$

$$n_{BaSO_4} = 0.0359 \text{ mol} \times \frac{1}{1}$$

$$n_{BaSO_4} = 0.0359 \text{ mol}$$

$$m_{BaSO_4} = 0.0359 \text{ mol} \times \frac{233.39 \text{ g}}{1 \text{ mol}}$$

$$m_{BaSO_4} = 8.38 \text{ g}$$

or

$$m_{BaSO_4} = 5.10 \text{ g Na}_2SO_4 \times \frac{1 \text{ mol Na}_2SO_4}{} \times \frac{1 \text{ mol BaSO}_4}{} \times \frac{233.39 \text{ g BaSO}_4}{1 \text{ mol BaSO}_4}$$

$$m_{BaSO_4} = 8.38 \text{ g}$$
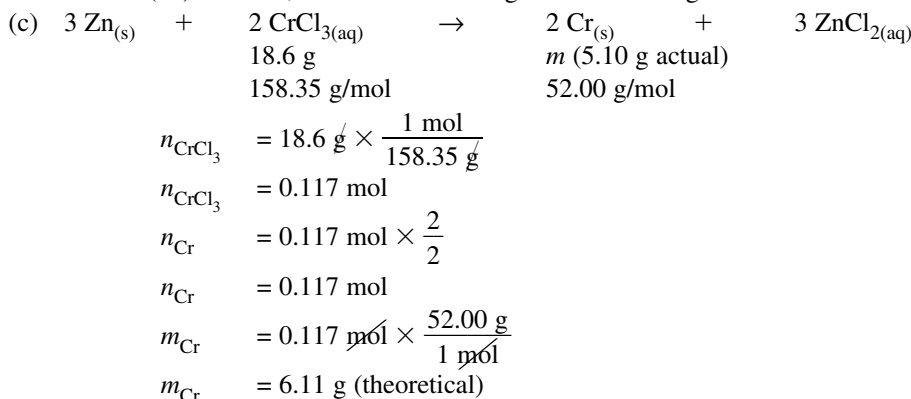
The mass of barium sulfate produced would be 8.38 g.

21. (a) $\quad$ 3 Zn$_{(s)}$ $\quad$ + $\quad$ 2 CrCl$_{3(aq)}$ $\quad$ → $\quad$ 2 Cr$_{(s)}$ $\quad$ + $\quad$ 3 ZnCl$_{2(aq)}$
$\qquad$ 15.0 g $\qquad\qquad$ 18.6 g
$\qquad$ 65.38 g/mol $\qquad$ 158.35 g/mol

$$n_{Zn} = 15.0 \text{ g} \times \frac{1 \text{ mol}}{65.38 \text{ g}}$$

$$n_{Zn} = 0.229 \text{ mol}$$

$$n_{CrCl_3} = 18.6 \text{ g} \times \frac{1 \text{ mol}}{}$$

$$n_{CrCl_3} = 0.117 \text{ mol}$$
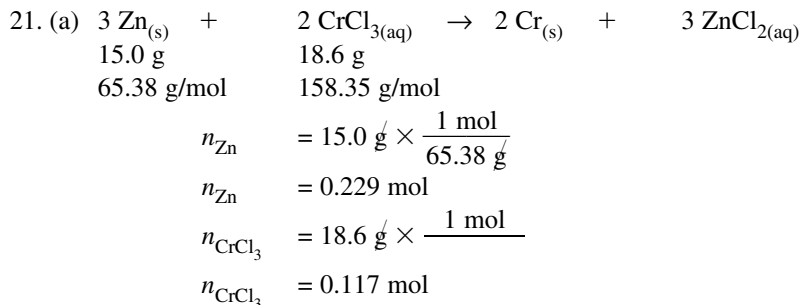
Since the reactant mole ratio is 3:2, 0.229 mol Zn$_{(s)}$ would require an amount of 0.229 mol × 2/3 = 0.153 mol CrCl$_{3(aq)}$ for complete reaction — more than is present. The CrCl$_{3(aq)}$ is obviously the limiting reagent for this reaction, so the Zn$_{(s)}$ is in excess.

(b) The 0.117 mol of CrCl$_{3(aq)}$ present would require an amount of 0.117 mol × 3/2 = 0.176 mol Zn$_{(s)}$ for complete reaction. The Zn$_{(s)}$ is in excess by (0.229 − 0.176) mol = 0.053 mol.

$$m_{Zn} = 0.053 \text{ mol} \times \frac{65.38 \text{ g}}{1 \text{ mol}} = 3.5 \text{ g}$$

The Zn$_{(s)}$ is in excess by 3.5 g.

Note: The excess of zinc may also be found by calculating the stoichiometric mass required to react with 18.6 g of chromium(III) chloride, and then subtracting that from 15.0 g. The same answer is obtained.

(c) $\quad$ 3 Zn$_{(s)}$ $\quad$ + $\quad$ 2 CrCl$_{3(aq)}$ $\quad$ → $\quad$ 2 Cr$_{(s)}$ $\quad$ + $\quad$ 3 ZnCl$_{2(aq)}$
$\qquad\qquad\qquad$ 18.6 g $\qquad\qquad$ m (5.10 g actual)
$\qquad\qquad\qquad$ 158.35 g/mol $\qquad$ 52.00 g/mol

$$n_{CrCl_3} = 18.6 \text{ g} \times \frac{1 \text{ mol}}{158.35 \text{ g}}$$

$$n_{CrCl_3} = 0.117 \text{ mol}$$

$$n_{Cr} = 0.117 \text{ mol} \times \frac{2}{2}$$

$$n_{Cr} = 0.117 \text{ mol}$$

$$m_{Cr} = 0.117 \text{ mol} \times \frac{52.00 \text{ g}}{1 \text{ mol}}$$

$$m_{Cr} = 6.11 \text{ g (theoretical)}$$

or

$$m_{Cr} = 18.6 \text{ g CrCl}_3 \times \frac{1 \text{ mol CrCl}_3}{158.35 \text{ g CrCl}_3} \times \frac{2 \text{ mol Cr}}{2 \text{ mol CrCl}_3} \times \frac{52.00 \text{ g Cr}}{1 \text{ mol Cr}}$$

$$m_{Cr} = 6.11 \text{ g (theoretical)}$$

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

$$\% \text{ yield} = \frac{5.10 \text{ g}}{6.11 \text{ g}} \times 100\% = 83.5\%$$

The percentage yield of chromium in this reaction is 83.5%.

22. The hydrated compound must be FePO$_4$·XH$_2$O$_{(s)}$, where X represents some number of water molecules. The anhydrous compound is FePO$_{4(s)}$.
The mass of hydrated compound is (29.93 − 24.80)g = 5.13 g
The mass of anhydrous compound is (28.27 − 24.80)g = 3.47 g

The mass of water of hydration is $(5.13 - 3.47)\text{g} = 1.66$ g
The molar mass of water, H_2O, is 18.02 g/mol.
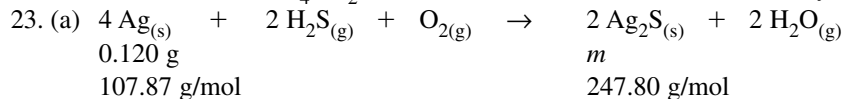The molar mass of iron(III) phosphate, $FePO_4$, is 150.82 g/mol.

$$n_{H_2O} = 1.66 \text{ g} \times \frac{1 \text{ mol}}{18.02 \text{ g}}$$

$$n_{H_2O} = 0.0921 \text{ mol}$$

$$n_{FePO_4} = 3.47 \text{ g} \times \frac{1 \text{ mol}}{150.82 \text{ g}}$$

$$n_{FePO_4} = 0.0230 \text{ mol}$$

The mole ratio of $FePO_4 : H_2O$ is $0.0230 : 0.0921$ or $1.00 : 4.00$, so the hydrated compound formula is $FePO_4 \cdot 4H_2O_{(s)}$.

23. (a) $4 \text{ Ag}_{(s)} + 2 \text{ H}_2\text{S}_{(g)} + \text{O}_{2(g)} \rightarrow 2 \text{ Ag}_2\text{S}_{(s)} + 2 \text{ H}_2\text{O}_{(g)}$
   0.120 g $\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ m
   107.87 g/mol $\qquad\qquad\qquad\qquad\qquad$ 247.80 g/mol

$$n_{Ag} = 0.120 \text{ g} \times \frac{1 \text{ mol}}{107.87 \text{ g}}$$

$$n_{Ag} = 0.00111 \text{ mol}$$

$$n_{Ag_2S} = 0.00111 \text{ mol} \times \frac{2}{4}$$

$$n_{Ag_2S} = 0.000556 \text{ mol}$$

$$m_{Ag_2S} = 0.000556 \text{ mol} \times \frac{247.80 \text{ g}}{1 \text{ mol}}$$
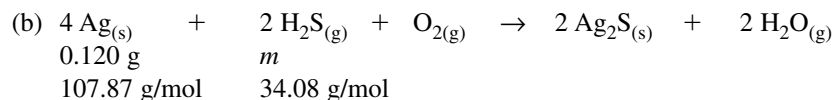
$$m_{Ag_2S} = 0.138 \text{ g (or 138 mg)}$$

or

$$m_{Ag_2S} = 0.120 \text{ g Ag} \times \frac{1 \text{ mol Ag}}{107.87 \text{ g Ag}} \times \frac{2 \text{ mol Ag}_2\text{S}}{4 \text{ mol Ag}} \times \frac{247.80 \text{ g Ag}_2\text{S}}{1 \text{ mol Ag}_2\text{S}}$$

$$m_{Ag_2S} = 0.138 \text{ g (or 138 mg)}$$

The mass of silver sulfide produced would be 138 mg.

(b) $4 \text{ Ag}_{(s)} + 2 \text{ H}_2\text{S}_{(g)} + \text{O}_{2(g)} \rightarrow 2 \text{ Ag}_2\text{S}_{(s)} + 2 \text{ H}_2\text{O}_{(g)}$
   0.120 g $\qquad$ m
   107.87 g/mol $\quad$ 34.08 g/mol

$$n_{Ag} = 0.120 \text{ g} \times \frac{1 \text{ mol}}{107.87 \text{ g}}$$

$$n_{Ag} = 0.00111 \text{ mol}$$

$$n_{H_2S} = 0.00111 \text{ mol} \times \frac{2}{4}$$

$$n_{H_2S} = 0.000556 \text{ mol}$$

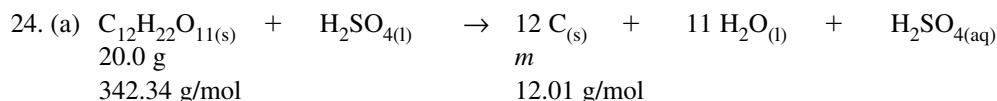$$m_{H_2S} = 0.000556 \text{ mol} \times \frac{34.08 \text{ g}}{1 \text{ mol}}$$

$$m_{H_2S} = 0.0190 \text{ g (or 19.0 mg)}$$

or

$$m_{H_2S} = 0.120 \text{ g Ag} \times \frac{1 \text{ mol Ag}}{107.87 \text{ g Ag}} \times \frac{2 \text{ mol H}_2\text{S}}{4 \text{ mol Ag}} \times \frac{34.08 \text{ g H}_2\text{S}}{1 \text{ mol H}_2\text{S}}$$

$$m_{H_2S} = 0.0190 \text{ g (or 19.0 mg)}$$
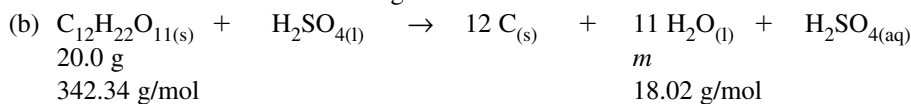
The mass of hydrogen sulfide needed would be 19.0 mg.

24. (a) $C_{12}H_{22}O_{11(s)} + H_2SO_{4(l)} \rightarrow 12 \text{ C}_{(s)} + 11 \text{ H}_2\text{O}_{(l)} + H_2SO_{4(aq)}$
   20.0 g $\qquad\qquad\qquad\qquad\qquad\qquad$ m
   342.34 g/mol $\qquad\qquad\qquad\qquad\quad$ 12.01 g/mol

$$n_{C_{12}H_{22}O_{11}} = 20.0 \text{ g} \times \frac{1 \text{ mol}}{342.34 \text{ g}}$$

$$n_{C_{12}H_{22}O_{11}} = 0.0584 \text{ mol}$$

$$n_C = 0.0584 \text{ mol} \times \frac{12}{1}$$

$$n_C = 0.701 \text{ mol}$$

$$m_C = 0.701 \text{ mol} \times \frac{12.01 \text{ g}}{1 \text{ mol}}$$

$$m_C = 8.42 \text{ g}$$

or

$$m_C = 20.0 \text{ g } C_{12}H_{22}O_{11} \times \frac{1 \text{ mol } C_{12}H_{22}O_{11}}{} \times \frac{12 \text{ mol C}}{1 \text{ mol } C_{12}H_{22}O_{11}} \times \frac{12.01 \text{ g C}}{1 \text{ mol C}}$$

$$m_C = 8.42 \text{ g}$$

The mass of carbon formed is 8.42 g.

(b) $C_{12}H_{22}O_{11(s)}$ + $H_2SO_{4(l)}$ → 12 $C_{(s)}$ + 11 $H_2O_{(l)}$ + $H_2SO_{4(aq)}$
20.0 g m
342.34 g/mol   18.02 g/mol

$$n_{C_{12}H_{22}O_{11}} = 20.0 \text{ g} \times \frac{1 \text{ mol}}{342.34 \text{ g}}$$

$$n_{C_{12}H_{22}O_{11}} = 0.0584 \text{ mol}$$

$$n_{H_2O} = 0.0584 \text{ mol} \times \frac{11}{1}$$

$$n_{H_2O} = 0.643 \text{ mol}$$

$$m_{H_2O} = 0.643 \text{ mol} \times \frac{18.02 \text{ g}}{1 \text{ mol}}$$

$$m_{H_2O} = 11.6 \text{ g}$$

or

$$m_{H_2O} = 20.0 \text{ g } C_{12}H_{22}O_{11} \times \frac{1 \text{ mol } C_{12}H_{22}O_{11}}{} \times \frac{11 \text{ mol } H_2O}{1 \text{ mol } C_{12}H_{22}O_{11}} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O}$$

$$m_{H_2O} = 11.6 \text{ g}$$

The mass of water formed is 11.6 g.

25. (a) 6 $CO_{2(g)}$ + 6 $H_2O_{(g)}$ → $C_6H_{12}O_{6(aq)}$ + 6 $O_{2(g)}$
       m 100.0 g
       44.01 g/mol   180.18 g/mol
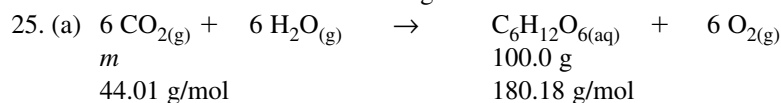
$$n_{C_6H_{12}O_6} = 100.0 \text{ g} \times \frac{1 \text{ mol}}{180.18 \text{ g}}$$

$$n_{C_6H_{12}O_6} = 0.5550 \text{ mol}$$

$$n_{CO_2} = 0.5550 \text{ mol} \times \frac{6}{1}$$

$$n_{CO_2} = 3.330 \text{ mol}$$

$$m_{CO_2} = 3.330 \text{ mol} \times \frac{44.01 \text{ g}}{1 \text{ mol}}$$

$$m_{CO_2} = 146.6 \text{ g}$$

or

$$m_{CO_2} = 100.0 \text{ g } C_6H_{12}O_6 \times \frac{1 \text{ mol } C_6H_{12}O_6}{} \times \frac{6 \text{ mol } CO_2}{} \times \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2}$$

$$m_{CO_2} = 146.6 \text{ g}$$

The mass of carbon dioxide required is 146.6 g.

(b) 6 $CO_{2(g)}$ + 6 $H_2O_{(g)}$ → $C_6H_{12}O_{6(aq)}$ + 6 $O_{2(g)}$
                                          100.0 g m
                                          180.18 g/mol   32.00 g/mol
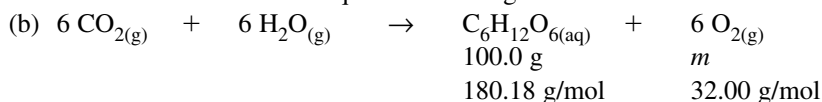
$$n_{C_6H_{12}O_6} = 100.0 \text{ g} \times \frac{1 \text{ mol}}{180.18 \text{ g}}$$

$$n_{C_6H_{12}O_6} = 0.5550 \text{ mol}$$

$$n_{O_2} = 0.5550 \text{ mol} \times \frac{6}{1}$$

$$n_{O_2} = 3.330 \text{ mol}$$

$$m_{O_2} = 3.330 \text{ mol} \times \frac{32.00 \text{ g}}{1 \text{ mol}}$$

$$m_{O_2} = 106.6 \text{ g}$$

or

$$m_{O_2} = 100.0 \text{ g } C_6H_{12}O_6 \times \frac{1 \text{ mol } C_6H_{12}O_6}{180.18 \text{ g } C_6H_{12}O_6} \times \frac{6 \text{ mol } O_2}{1 \text{ mol } C_6H_{12}O_6} \times \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2}$$

$$m_{O_2} = 106.6 \text{ g}$$

The mass of oxygen produced is 106.6 g.

26. $NH_{3(g)}$ + $HCl_{(g)}$ → $NH_4Cl_{(s)}$
    2.00 g   2.00 g m
    17.04 g/mol   36.46 g/mol   53.50 g/mol
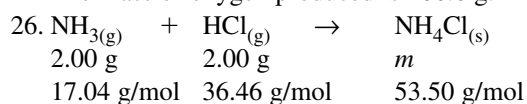
$$n_{NH_3} = 2.00 \text{ g} \times \frac{1 \text{ mol}}{17.04 \text{ g}}$$

$$n_{NH_3} = 0.117 \text{ mol}$$

$$n_{HCl} = 2.00 \text{ g} \times \frac{1 \text{ mol}}{36.46 \text{ g}}$$

$$n_{HCl} = 0.0549 \text{ mol}$$

The reactant mole ratio is 1 : 1, so by inspection $HCl_{(g)}$ is the obvious limiting reagent.

$$n_{NH_4Cl} = 0.0549 \text{ mol} \times \frac{1}{1}$$

$$n_{NH_4Cl} = 0.0549 \text{ mol}$$

$$m_{NH_4Cl} = 0.0549 \text{ mol} \times \frac{53.50 \text{ g}}{1 \text{ mol}}$$

$$m_{NH_4Cl} = 2.93 \text{ g}$$

or

$$m_{NH_4Cl} = 2.00 \text{ g } HCl \times \frac{1 \text{ mol } HCl}{36.46 \text{ g } HCl} \times \frac{1 \text{ mol } NH_4Cl}{1 \text{ mol } HCl} \times \frac{53.50 \text{ g } NH_4Cl}{1 \text{ mol } NH_4Cl}$$

$$m_{NH_4Cl} = 2.93 \text{ g}$$

The mass of solid ammonium chloride produced is 2.93 g.

Applying Inquiry Skills

27. (a) **Prediction**

$$Ba(OH)_{2(aq)} + H_2SO_{4(aq)} \rightarrow BaSO_{4(s)} + 2 H_2O_{(l)}$$
3.43 g m
171.35 g/mol   233.39 g/mol
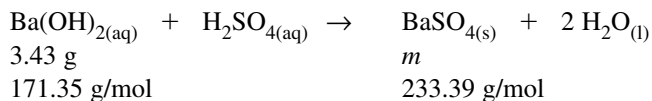
$$n_{Ba(OH)_2} = 3.43 \text{ g} \times \frac{1 \text{ mol}}{171.35 \text{ g}}$$

$$n_{Ba(OH)_2} = 0.0200 \text{ mol}$$

$$n_{BaSO_4} = 0.0200 \text{ mol} \times \frac{1}{1}$$

$$n_{BaSO_4} = 0.0200 \text{ mol}$$

$$m_{BaSO_4} = 0.0200 \text{ mol} \times \frac{233.39 \text{ g}}{1 \text{ mol}}$$

$$m_{BaSO_4} = 4.67 \text{ g}$$
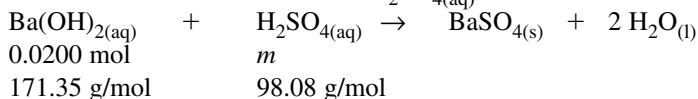
or

$$m_{BaSO_4} = 3.43 \text{ g Ba(OH)}_2 \times \frac{1 \text{ mol Ba(OH)}_2}{} \times \frac{1 \text{ mol BaSO}_4}{} \times \frac{233.39 \text{ g BaSO}_4}{1 \text{ mol BaSO}_4}$$

$$m_{BaSO_4} = 4.67 \text{ g}$$

The theoretical yield of barium sulfate is 4.67 g.

To determine an excess value for $H_2SO_{4(aq)}$:

$$Ba(OH)_{2(aq)} \quad + \quad H_2SO_{4(aq)} \rightarrow \quad BaSO_{4(s)} \quad + \quad 2 H_2O_{(l)}$$

0.0200 mol m

171.35 g/mol   98.08 g/mol

$n_{H_2SO_4}$ $= 0.0200 \text{ mol} \times \dfrac{1}{1}$

$n_{H_2SO_4}$ $= 0.0200 \text{ mol}$

$m_{H_2SO_4}$ $= 0.0200 \text{ mol} \times \dfrac{98.08 \text{ g}}{1 \text{ mol}}$

$m_{H_2SO_4}$ $= 1.96 \text{ g}$

Note: Concentrated sulfuric acid is only about 95% pure, so a larger excess than usual should be used to take this into account. A 20% excess would be:

$1.96 \text{ g} \times 120\% = 2.35 \text{ g}$

(b) **Experimental Design**

A measured mass of barium hydroxide is dissolved, and reacted with excess sulfuric acid solution. The resulting precipitate is filtered and dried and the mass is then measured.

(c) **Procedure**

1. Sulfuric acid and barium hydroxide are corrosive and soluble barium compounds are toxic. Use caution in handling and wash your hands after use.
2. Use a clean, dry 250-mL beaker to obtain a 3.43 g sample of $Ba(OH)_{2(aq)}$.
3. Use a 100-mL beaker to obtain a 2.35 g sample of concentrated $H_2SO_{4(aq)}$, and add it to the 250-mL beaker.
4. Allow the precipitate to settle, and test the clear liquid above the precipitate (the supernatant liquid) with a small amount of the $H_2SO_{4(aq)}$ from a medicine dropper to see if further precipitation occurs.
5. If the test in step 4 indicates the reaction is not yet complete, repeat step 4 until no further precipitation occurs.
6. Measure and record the mass of a piece of filter paper to 0.01 g.
7. Filter, wash, and dry the $BaSO_{4(s)}$ precipitate.
8. Measure and record the mass of the filter paper plus dry precipitate to 0.01 g.
9. Dispose of all waste materials according to instructions.

(d) **Analysis**

The mass of precipitate is $(5.25 - 0.96) \text{ g} = 4.29 \text{ g}$.

(e) **Evaluation**

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

$$\% \text{ yield} = \frac{4.29 \text{ g}}{4.67 \text{ g}} \times 100\% = 91.8\%$$

The percentage yield of barium sulfate in this reaction is 91.8%.

A discrepancy of about 8% is considered rather high, so if we assume the design is adequate, either the technique was poor or the stoichiometric method is suspect.

28. The filtrate could be tested with a small amount of sulfuric acid. If no precipitate forms, the acid was in excess, and no barium hydroxide remains.

29. Actual yield can be higher than theoretical yield if impurities exist in the measured product, increasing its mass. Another cause would be not completely drying a precipitate, which will have the same effect.
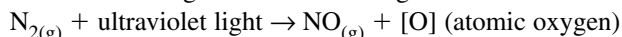
Making Connections

30. Student reports should indicate the postsecondary degrees and courses of study required, and list both industrial and research institutions where analytical chemists might be employed.

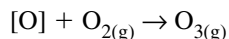31. Student reports should include the basic smog reactions.

    The reaction of nitrogen in internal-combustion engines:

    $$N_{2(g)} + 2\,O_{2(g)} \rightarrow 2\,NO_{2(g)}$$
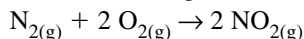
    The reaction of nitrogen dioxide in sunlight:

    $$N_{2(g)} + \text{ultraviolet light} \rightarrow NO_{(g)} + [O] \text{ (atomic oxygen)}$$

    And the reaction of atomic oxygen to produce ozone:

    $$[O] + O_{2(g)} \rightarrow O_{3(g)}$$

    Many further reactions exist as the ozone reacts. The report should also emphasize that there are two basic ways to reduce the effects of car exhaust in cities: by addressing mileage and engines. The amount of smog can be reduced by improving mileage obtained by vehicles, and by reducing mileage, whether by limiting individual trips or by increasing the use of public transport. Smog can also be reduced by lowering nitrogen oxides in exhaust by engine tuning and catalytic conversion.

32. Student reports should explain that sulfuric acid is produced by simply burning sulfur to make sulfur dioxide and then reacting the $SO_{2(g)}$ further with $O_{2(g)}$ to produce $SO_{3(g)}$. The reaction producing sulfur trioxide does not occur readily, so it is accomplished by mixing the reagents in contact with a hot catalytic (platinum or vanadium pentoxide) surface. The $SO_{3(g)}$ is reacted with $H_2SO_{4(l)}$ to form $H_2S_2O_{7(l)}$ (pyrosulfuric acid), which is then diluted with water to reform $H_2SO_{4(l)}$. The $SO_{3(g)}$ is not reacted directly with water because that reaction would release intense heat, and boiling would create a fog or steam of hot sulfuric acid droplets — a very dangerous situation.

    The dangerous property of nearly pure (concentrated) sulfuric acid is its amazingly high affinity for water. Contact with this liquid will immediately remove water from molecules — which means immediate destruction of cells in human tissue, for example.

33. Student reports should explain that aluminum ore is a mixture of hydrates of aluminum oxide, $Al_2O_3 \cdot xH_2O$, and other oxides like iron(III) oxide, $Fe_2O_{3(s)}$. The impurities are removed by adding concentrated $NaOH_{(aq)}$, in which the impurities are not soluble. After filtering out the impurities, pure aluminum oxide (alumina) is precipitated out. Aluminum is extracted from molten aluminum oxide at a very high temperature, using electrical energy.

    $$2\,Al_2O_{3(l)} + \text{electricity} \rightarrow 4\,Al_{(l)} + 3\,O_{2(g)}$$
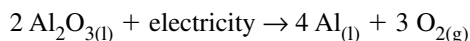
    Aluminum smelters are only built where large amounts of cheap electricity are available, usually from a dedicated hydroelectric dam and generating station. The temperature required to melt pure alumina is prohibitively high, but can be reduced dramatically with the Hall process. This process uses the fact that alumina will dissolve in molten cryolite, Na_3AlF_6, which melts at about 1000°C, a practical level for industrial work.

    ⤷ GO TO www.science.nelson.com, Chemistry 11, Teacher Centre.

Exploring

34. Student reports for this question will necessarily be personal, the only common criteria being that they describe the question requirements listed:
    (a) a company or an industry that does this type of work;
    (b) the type of analytical techniques used;
    (c) the level of education and qualifications needed;
    (d) why this is a career that you may be interested in.

    ⤷ GO TO www.science.nelson.com, Chemistry 11, Teacher Centre.