CHAPTER 5 REVIEW

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Understanding Concepts

1. (a) In a reagent mix, the one consumed first, causing the reaction to cease, is the limiting reagent. Some of the other reagent will remain, so it is said to be in excess.
   (b) A chemical reaction involves change in the electrons of an entity; a nuclear reaction involves change in the atomic nuclei.
   (c) Alpha decay involves the emission of an alpha particle (helium-4 nucleus) from an atomic nucleus, while beta decay involves the emission of a beta particle (electron) from a nucleus.
   (d) 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.
   (e) An empirical formula shows the simplest integral ratio of component entities. A molecular formula shows the actual numerical ratio of atoms in a molecule of the substance.
2. (a) $2\ SO_{2(g)} + O_{2(g)} \rightarrow 2\ SO_{3(g)}$
   (b) $SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$
   (c) $CaO_{(s)} + SO_{2(g)} \rightarrow O_{2(g)} + CaSO_{4(s)}$
   (d) $CaO_{(s)} + H_2SO_{3(aq)} \rightarrow H_2O_{(l)} + CaSO_{3(s)}$
   (e) $Al_2(SiO_3)_{3(s)} + 3\ H_2SO_{4(aq)} \rightarrow 3\ H_2SiO_{3(aq)} + Al_2(SO_4)_{3(s)}$
3. (a) ${}^{233}_{90}\text{Th} \rightarrow {}^{0}_{-1}\text{e} + {}^{233}_{91}\text{Pa}$
   (b) ${}^{233}_{91}\text{Pa} \rightarrow {}^{0}_{-1}\text{e} + {}^{233}_{92}\text{U}$
4. ${}^{131}_{53}\text{I} \rightarrow {}^{0}_{-1}\text{e} + {}^{131}_{54}\text{Xe}$
5. (a) ${}^{122}_{53}\text{I} \rightarrow {}^{122}_{54}\text{Xe} + {}^{0}_{-1}\text{e}$
   (b) ${}^{59}_{26}\text{Fe} \rightarrow {}^{59}_{27}\text{Co} + {}^{0}_{-1}\text{e}$
   (c) ${}^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$
   (d) ${}^{252}_{98}\text{Cf} + {}^{10}_{5}\text{B} \rightarrow {}^{259}_{103}\text{Lr} + 3\ {}^{1}_{0}\text{n}$
   (e) ${}^{239}_{94}\text{Pu} + {}^{4}_{2}\text{He} \rightarrow {}^{242}_{96}\text{Cm} + {}^{1}_{0}\text{n}$
6. The mass number drops by 28, which means 28/4 = 7 alpha decays. The atomic number only drops by 10, which means 14 − 10 = 4 beta decays.
7. ${}^{190}_{75}\text{Re} \rightarrow {}^{190}_{76}\text{Os} + {}^{0}_{-1}\text{e}$
   ${}^{9}_{3}\text{Li} \rightarrow {}^{8}_{3}\text{Li} + {}^{1}_{0}\text{n}$
   ${}^{214}_{83}\text{Bi} \rightarrow {}^{210}_{79}\text{Au} + {}^{4}_{2}\text{He}$
   ${}^{162}_{69}\text{Tm} \rightarrow {}^{162}_{70}\text{Yb} + {}^{0}_{-1}\text{e}$
   ${}^{120}_{49}\text{In} \rightarrow {}^{120}_{50}\text{Sn} + {}^{0}_{-1}\text{e}$
8.

$2\ C_8H_{18(l)}$	+	$25\ O_{2(g)}$	$\rightarrow$	$16\ CO_{2(g)}$	+	$18\ H_2O_{(g)}$
692 g				m		
114.26 g/mol				44.01 g/mol		

$$n_{C_8H_{18}} = 692\ \cancel{g} \times \frac{1\ \text{mol}}{114.26\ \cancel{g}}$$

$$n_{C_8H_{18}} = 6.06\ \text{mol}$$

$$n_{CO_2} = 6.06\ \text{mol} \times \frac{16}{2}$$

$n_{CO_2} = 48.5\ \text{mol}$

$m_{CO_2} = 48.5\ \cancel{\text{mol}} \times \frac{44.01\ \text{g}}{1\ \cancel{\text{mol}}}$

$m_{CO_2} = 2.13 \times 10^3\ \text{g} = 2.13\ \text{kg}$

or

$m_{CO_2} = 692\ \cancel{\text{g}}\ \cancel{C_8H_{18}} \times \frac{1\ \cancel{\text{mol}}\ \cancel{C_8H_{18}}}{114.26\ \cancel{\text{g}}\ \cancel{C_8H_{18}}} \times \frac{16\ \cancel{\text{mol}}\ \cancel{CO_2}}{2\ \cancel{\text{mol}}\ \cancel{C_8H_{18}}} \times \frac{44.01\ \text{g}\ CO_2}{1\ \cancel{\text{mol}}\ \cancel{CO_2}}$

$m_{CO_2} = 2.13 \times 10^3\ \text{g} = 2.13\ \text{kg}$

The mass of carbon dioxide formed is 2.13 kg.

9. (a)

$WO_{3(s)}$	+	$3\ H_{2(g)}$	→	$W_{(s)}$	+	$3\ H_2O_{(g)}$
m				5.00 g		
231.85 g/mol				183.85 g/mol		

$n_W = 5.00\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{183.85\ \cancel{\text{g}}}$

$n_W = 0.0272\ \text{mol}$

$n_{WO_3} = 0.0272\ \text{mol} \times \frac{1}{1}$

$n_{WO_3} = 0.0272\ \text{mol}$

$m_{WO_3} = 0.0272\ \cancel{\text{mol}} \times \frac{231.85\ \text{g}}{1\ \cancel{\text{mol}}}$

$m_{WO_3} = 6.31\ \text{g}$

or

$m_{WO_3} = 5.00\ \cancel{\text{g}}\ \cancel{W} \times \frac{1\ \cancel{\text{mol}}\ \cancel{W}}{183.85\ \cancel{\text{g}}\ \cancel{W}} \times \frac{1\ \cancel{\text{mol}}\ \cancel{WO_3}}{1\ \cancel{\text{mol}}\ \cancel{W}} \times \frac{231.85\ \text{g}\ WO_3}{1\ \cancel{\text{mol}}\ \cancel{WO_3}}$

$m_{WO_3} = 6.31\ \text{g}$

The mass of tungsten(VI) oxide needed is 6.31 g.

(b)

$WO_{3(s)}$	+	$3\ H_{2(g)}$	→	$W_{(s)}$	+	$3\ H_2O_{(g)}$
				5.00 g		m
				183.85 g/mol		18.02 g/mol

$n_W = 5.00\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{183.85\ \cancel{\text{g}}}$

$n_W = 0.0272\ \text{mol}$

$n_{H_2O} = 0.0272\ \text{mol} \times \frac{3}{1}$

$n_{H_2O} = 0.0816\ \text{mol}$

$m_{H_2O} = 0.0816\ \cancel{\text{mol}} \times \frac{18.02\ \text{g}}{1\ \cancel{\text{mol}}}$

$m_{H_2O} = 1.47\ \text{g}$

or

$m_{H_2O} = 5.00\ \cancel{\text{g}}\ \cancel{W} \times \frac{1\ \cancel{\text{mol}}\ \cancel{W}}{183.85\ \cancel{\text{g}}\ \cancel{W}} \times \frac{3\ \cancel{\text{mol}}\ \cancel{H_2O}}{1\ \cancel{\text{mol}}\ \cancel{W}} \times \frac{18.02\ \text{g}\ H_2O}{1\ \cancel{\text{mol}}\ \cancel{H_2O}}$

$m_{H_2O} = 1.47\ \text{g}$

The mass of water vapour produced is 1.47 g.

10. (a)

$HC_4H_7O_{2(l)}$	+	$C_2H_5OH_{(l)}$	→	$C_4H_7O_2C_2H_{5(l)}$	+	$H_2O_{(l)}$
30.0 g		18.0 g				
88.12 g/mol		46.08 g/mol				

$n_{HC_4H_7O_2} = 30.0\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{88.12\ \cancel{\text{g}}}$

$n_{HC_4H_7O_2} = 0.340\ \text{mol}$

$$n_{C_2H_5OH} = 18.0\ \cancel{g} \times \frac{1\ \text{mol}}{46.08\ \cancel{g}}$$
$$n_{C_2H_5OH} = 0.391\ \text{mol}$$

Since the reactant mole ratio is 1:1, the $HC_4H_7O_{2(l)}$ is obviously the limiting reagent for this reaction.

(b) $HC_4H_7O_{2(l)} \quad + \quad C_2H_5OH_{(l)} \quad \rightarrow \quad C_4H_7O_2C_2H_{5(l)} \quad + \quad H_2O_{(l)}$

30.0 g		m		
88.12 g/mol		116.18 g/mol		

$$n_{HC_4H_7O_2} = 30.0\ \cancel{g} \times \frac{1\ \text{mol}}{88.12\ \cancel{g}}$$
$$n_{HC_4H_7O_2} = 0.340\ \text{mol}$$
$$n_{C_4H_7O_2C_2H_5} = 0.340\ \text{mol} \times \frac{1}{1}$$
$$n_{C_4H_7O_2C_2H_5} = 0.340\ \text{mol}$$
$$m_{C_4H_7O_2C_2H_5} = 0.340\ \cancel{\text{mol}} \times \frac{116.18\ \text{g}}{1\ \cancel{\text{mol}}}$$
$$m_{C_4H_7O_2C_2H_5} = 39.6\ \text{g}$$

or

$$m_{C_4H_7O_2C_2H_5} = 30.0\ \cancel{g}\ \cancel{HC_4H_7O_2} \times \frac{1\ \cancel{\text{mol}}\ \cancel{HC_4H_7O_2}}{} \times \frac{1\ \cancel{\text{mol}}\ \cancel{C_4H_7O_2C_2H_5}}{} \times \frac{116.18\ \text{g}\ C_4H_7O_2C_2H_5}{}$$
$$m_{C_4H_7O_2C_2H_5} = 39.6\ \text{g}$$

The mass of ethylbutanoate produced is 39.6 g.

11. Use the equation mole ratios in sequence: 1 mol $NH_{3(g)}$ reacts to form 1 mol $NO_{(g)}$; and 1 mol $NO_{(g)}$ reacts to form 1 mol $NO_{2(g)}$; and 1 mol $NO_{2(g)}$ reacts to form 2/3 mol $HNO_{3(aq)}$. This simplifies to: 1 mol $NH_{3(g)}$ reacts to form 2/3 mol $HNO_{3(aq)}$, or integrally, 3 mol $NH_{3(g)}$ react to form 2 mol $HNO_{3(aq)}$.

since	3 $NH_{3(g)}$	react to form	2 $HNO_{3(aq)}$
	4.00 mol		m
			63.02 g/mol

$$n_{HNO_3} = 4.00\ \text{mol} \times \frac{2}{3}$$
$$n_{HNO_3} = 2.67\ \text{mol}$$
$$m_{HNO_3} = 2.67\ \cancel{\text{mol}} \times \frac{63.02\ \text{g}}{1\ \cancel{\text{mol}}}$$
$$m_{HNO_3} = 168\ \text{g}$$

or

$$m_{HNO_3} = 4.00\ \cancel{\text{mol}}\ \cancel{NH_3} \times \frac{2\ \cancel{\text{mol}}\ \cancel{HNO_3}}{3\ \cancel{\text{mol}}\ \cancel{NH_3}} \times \frac{63.02\ \text{g}\ HNO_3}{1\ \cancel{\text{mol}}\ \cancel{HNO_3}}$$
$$m_{HNO_3} = 168\ \text{g}$$

The mass of nitric acid produced is 168 g.

12. (a) $C_3H_5(OH)_{3(l)} + 3\ HNO_{3(aq)} \rightarrow \quad C_3H_5(NO_3)_{3(s)} + H_2O_{(l)}$

(b) $C_3H_5(OH)_{3(l)} + \ 3\ HNO_{3(aq)} \rightarrow \quad C_3H_5(NO_3)_{3(s)} + H_2O_{(l)}$

10.4 g	19.2 g		
92.11 g/mol	63.02 g/mol		

$$n_{C_3H_5(OH)_3} = 10.4\ \cancel{g} \times \frac{1\ \text{mol}}{92.11\ \cancel{g}}$$
$$n_{C_3H_5(OH)_3} = 0.113\ \text{mol}$$
$$n_{HNO_3} = 19.2\ \cancel{g} \times \frac{1\ \text{mol}}{63.02\ \cancel{g}}$$
$$n_{HNO_3} = 0.305\ \text{mol}$$

Since the reactant mole ratio is 1:3, 0.305 mol of $HNO_{3(aq)}$ would require 0.305 mol × 1/3 = 0.102 mol of $C_3H_5(OH)_{3(l)}$ to react completely. The amount of $C_3H_5(OH)_{3(l)}$ is in excess, so the $HNO_{3(aq)}$ is the limiting reagent for this reaction.

(c)
$$\begin{array}{llll} C_3H_5(OH)_{3(l)} \; + & 3\ HNO_{3(aq)} \; \rightarrow & C_3H_5(NO_3)_{3(s)} \; + & H_2O_{(l)} \\ & 19.2\text{ g} & m\text{ (22.6 g actual)} & \\ & 63.02\text{ g/mol} & 227.11\text{ g/mol} & \end{array}$$

$$\begin{aligned} n_{HNO_3} &= 19.2\ \cancel{\text{g}} \times \frac{1\text{ mol}}{63.02\ \cancel{\text{g}}} \\ n_{HNO_3} &= 0.305\text{ mol} \\ n_{C_3H_5(NO_3)_3} &= 0.305\text{ mol} \times \frac{1}{3} \\ n_{C_3H_5(NO_3)_3} &= 0.102\text{ mol} \\ m_{C_3H_5(NO_3)_3} &= 0.102\ \cancel{\text{mol}} \times \frac{227.11\text{ g}}{1\ \cancel{\text{mol}}} \\ m_{C_3H_5(NO_3)_3} &= 23.1\text{ g} \end{aligned}$$

or

$$\begin{aligned} m_{C_3H_5(NO_3)_3} &= 19.2\ \cancel{\text{g}\ HNO_3} \times \frac{1\ \cancel{\text{mol}\ HNO_3}}{63.02\ \cancel{\text{g}\ HNO_3}} \times \frac{1\ \cancel{\text{mol}\ C_3H_5(NO_3)_3}}{3\ \cancel{\text{mol}\ HNO_3}} \times \frac{227.11\text{ g } C_3H_5(NO_3)_3}{\cancel{\qquad\qquad}} \\ m_{C_3H_5(NO_3)_3} &= 23.1\text{ g} \end{aligned}$$

The theoretical yield of nitroglycerin should be 23.1 g.

(d) $\%\text{ yield} = \dfrac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$

$$\%\text{ yield} = \frac{22.6\ \cancel{\text{g}}}{23.1\ \cancel{\text{g}}} \times 100\% = 97.8\%$$

The percentage yield of nitroglycerin in this reaction is 97.8%

13. 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.”

14. (a)
$$\begin{array}{llll} SiO_{2(s)} \; + & 4\ HF_{(aq)} \; \rightarrow & SiF_{4(g)} \; + & 2\ H_2O_{(l)} \\ 6.80\text{ g} & & m & \\ 60.09\text{ g/mol} & & 104.09\text{ g/mol} & \end{array}$$

$$\begin{aligned} n_{SiO_2} &= 6.80\ \cancel{\text{g}} \times \frac{1\text{ mol}}{60.09\ \cancel{\text{g}}} \\ n_{SiO_2} &= 0.113\text{ mol} \\ n_{SiF_4} &= 0.113\text{ mol} \times \frac{1}{1} \\ n_{SiF_4} &= 0.113\text{ mol} \\ m_{SiF_4} &= 0.113\ \cancel{\text{mol}} \times \frac{104.09\text{ g}}{1\ \cancel{\text{mol}}} \\ m_{SiF_4} &= 11.8\text{ g} \end{aligned}$$

or

$$\begin{aligned} m_{SiF_4} &= 6.80\ \cancel{\text{g}\ SiO_2} \times \frac{1\ \cancel{\text{mol}\ SiO_2}}{60.09\ \cancel{\text{g}\ SiO_2}} \times \frac{1\ \cancel{\text{mol}\ SiF_4}}{1\ \cancel{\text{mol}\ SiO_2}} \times \frac{104.09\text{ g } SiF_4}{1\ \cancel{\text{mol}\ SiF_4}} \\ m_{SiF_4} &= 11.8\text{ g} \end{aligned}$$

The mass of silicon tetrafluoride produced is 11.8 g.

(b)
$$\begin{array}{llll} SiO_{2(s)} \; + & 4\ HF_{(aq)} \; \rightarrow & SiF_{4(g)} \; + & 2\ H_2O_{(l)} \\ 53.2\text{ g} & m & & \\ 60.09\text{ g/mol} & 20.01\text{ g/mol} & & \end{array}$$

$$\begin{aligned} n_{SiO_2} &= 53.2\ \cancel{\text{g}} \times \frac{1\text{ mol}}{60.09\ \cancel{\text{g}}} \\ n_{SiO_2} &= 0.885\text{ mol} \end{aligned}$$

$$\begin{aligned}
n_{HF} &= 0.885\text{ mol } \times \frac{4}{1}\\
n_{HF} &= 3.54\text{ mol}\\
m_{HF} &= 3.54\text{ }\cancel{\text{mol}} \times \frac{20.01\text{ g}}{1\text{ }\cancel{\text{mol}}}\\
m_{HF} &= 70.9\text{ g}
\end{aligned}$$

or

$$\begin{aligned}
m_{HF} &= 53.2\text{ }\cancel{\text{g}}\text{ }\cancel{SiO_2} \times \frac{1\text{ }\cancel{\text{mol}}\text{ }\cancel{SiO_2}}{60.09\text{ }\cancel{\text{g}}\text{ }\cancel{SiO_2}} \times \frac{4\text{ }\cancel{\text{mol}}\text{ }\cancel{HF}}{1\text{ }\cancel{\text{mol}}\text{ }\cancel{SiO_2}} \times \frac{20.01\text{ g HF}}{1\text{ }\cancel{\text{mol}}\text{ }\cancel{HF}}\\
m_{HF} &= 70.9\text{ g}
\end{aligned}$$

The mass of hydrofluoric acid required is 70.9 g.

(c)
$$\begin{array}{lllllllll}
SiO_{2(s)} & + & 4\ HF_{(aq)} & \rightarrow & SiF_{4(g)} & + & 2\ H_2O_{(l)}\\
10.6\text{ g} & & & & & & m\\
60.09\text{ g/mol} & & & & & & 18.02\text{ g/mol}
\end{array}$$

$$\begin{aligned}
n_{SiO_2} &= 10.6\text{ }\cancel{\text{g}} \times \frac{1\text{ mol}}{60.09\text{ }\cancel{\text{g}}}\\
n_{SiO_2} &= 0.176\text{ mol}\\
n_{H_2O} &= 0.176\text{ mol } \times \frac{2}{1}\\
n_{H_2O} &= 0.353\text{ mol}\\
m_{H_2O} &= 0.353\text{ }\cancel{\text{mol}} \times \frac{18.02\text{ g}}{1\text{ }\cancel{\text{mol}}}\\
m_{H_2O} &= 6.36\text{ g}
\end{aligned}$$

or

$$\begin{aligned}
m_{H_2O} &= 10.6\text{ }\cancel{\text{g}}\text{ }\cancel{SiO_2} \times \frac{1\text{ }\cancel{\text{mol}}\text{ }\cancel{SiO_2}}{60.09\text{ }\cancel{\text{g}}\text{ }\cancel{SiO_2}} \times \frac{2\text{ }\cancel{\text{mol}}\text{ }\cancel{H_2O}}{1\text{ }\cancel{\text{mol}}\text{ }\cancel{SiO_2}} \times \frac{18.02\text{ g }H_2O}{1\text{ }\cancel{\text{mol}}\text{ }\cancel{H_2O}}\\
m_{H_2O} &= 6.36\text{ g}
\end{aligned}$$

The mass of water produced is 6.36 g.

15. (a)
$$\begin{array}{lllllll}
C_2H_5OH_{(l)} & + & 3\ O_{2(g)} & \rightarrow & 2\ CO_{2(g)} & + & 3\ H_2O_{(g)}
\end{array}$$

(b)
$$\begin{array}{lllllll}
C_2H_5OH_{(l)} & + & 3\ O_{2(g)} & \rightarrow & 2\ CO_{2(g)} & + & 3\ H_2O_{(g)}\\
450.0\text{ g} & & & & m & & \\
46.08\text{ g/mol} & & & & 44.01\text{ g/mol} & &
\end{array}$$

$$\begin{aligned}
n_{C_2H_5OH} &= 450.0\text{ }\cancel{\text{g}} \times \frac{1\text{ mol}}{46.08\text{ }\cancel{\text{g}}}\\
n_{C_2H_5OH} &= 9.766\text{ mol}\\
n_{CO_2} &= 9.766\text{ mol } \times \frac{2}{1}\\
n_{CO_2} &= 19.53\text{ mol}\\
m_{CO_2} &= 19.53\text{ }\cancel{\text{mol}} \times \frac{44.01\text{ g}}{1\text{ }\cancel{\text{mol}}}\\
m_{CO_2} &= 859.6\text{ g}
\end{aligned}$$

or

$$\begin{aligned}
m_{CO_2} &= 450.0\text{ }\cancel{\text{g}}\text{ }\cancel{C_2H_5OH} \times \frac{1\text{ }\cancel{\text{mol}}\text{ }\cancel{C_2H_5OH}}{} \times \frac{2\text{ }\cancel{\text{mol}}\text{ }\cancel{CO_2}}{1\text{ }\cancel{\text{mol}}\text{ }\cancel{C_2H_5OH}} \times \frac{44.01\text{ g }CO_2}{1\text{ }\cancel{\text{mol}}\text{ }\cancel{CO_2}}\\
m_{CO_2} &= 859.6\text{ g}
\end{aligned}$$

The mass of carbon dioxide produced is 859.6 g.

(c)
$$\begin{array}{lllllll}
C_2H_5OH_{(l)} & + & 3\ O_{2(g)} & \rightarrow & 2\ CO_{2(g)} & + & 3\ H_2O_{(g)}\\
450.0\text{ g} & & & & & & m
\end{array}$$

46.08 g/mol 18.02 g/mol

$$\begin{aligned}
n_{C_2H_5OH} &= 450.0\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{46.08\ \cancel{\text{g}}}\\
n_{C_2H_5OH} &= 9.766\ \text{mol}\\
n_{H_2O} &= 9.766\ \text{mol} \times \frac{3}{1}\\
n_{H_2O} &= 29.30\ \text{mol}\\
m_{H_2O} &= 29.30\ \cancel{\text{mol}} \times \frac{18.02\ \text{g}}{1\ \cancel{\text{mol}}}\\
m_{H_2O} &= 527.9\ \text{g}
\end{aligned}$$

or

$$\begin{aligned}
m_{H_2O} &= 450.0\ \cancel{\text{g}}\ \text{C}_2\cancel{\text{H}_5\text{O}}\text{H} \times \frac{1\ \cancel{\text{mol}}\ \text{C}_2\cancel{\text{H}_5\text{O}}\text{H}}{46.08\ \cancel{\text{g}}\ \text{C}_2\cancel{\text{H}_5\text{O}}\text{H}} \times \frac{3\ \cancel{\text{mol}}\ \cancel{\text{H}_2\text{O}}}{1\ \cancel{\text{mol}}\ \text{C}_2\cancel{\text{H}_5\text{O}}\text{H}} \times \frac{18.02\ \text{g H}_2\text{O}}{1\ \cancel{\text{mol}}\ \cancel{\text{H}_2\text{O}}}\\
m_{H_2O} &= 527.9\ \text{g}
\end{aligned}$$

The mass of water produced is 527.9 g.

(d) $C_2H_5OH_{(l)} + 3\ O_{2(g)} \rightarrow 2\ CO_{2(g)} + 3\ H_2O_{(g)}$

450.0 g *m*

46.08 g/mol 32.00 g/mol

$$\begin{aligned}
n_{C_2H_5OH} &= 450.0\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{46.08\ \cancel{\text{g}}}\\
n_{C_2H_5OH} &= 9.766\ \text{mol}\\
n_{O_2} &= 9.766\ \text{mol} \times \frac{3}{1}\\
n_{O_2} &= 29.30\ \text{mol}\\
m_{O_2} &= 29.30\ \cancel{\text{mol}} \times \frac{32.00\ \text{g}}{1\ \cancel{\text{mol}}}\\
m_{O_2} &= 937.5\ \text{g}
\end{aligned}$$

or

$$\begin{aligned}
m_{O_2} &= 450.0\ \cancel{\text{g}}\ \text{C}_2\cancel{\text{H}_5\text{O}}\text{H} \times \frac{1\ \cancel{\text{mol}}\ \text{C}_2\cancel{\text{H}_5\text{O}}\text{H}}{46.08\ \cancel{\text{g}}\ \text{C}_2\cancel{\text{H}_5\text{O}}\text{H}} \times \frac{3\ \cancel{\text{mol}}\ \cancel{\text{O}_2}}{1\ \cancel{\text{mol}}\ \text{C}_2\cancel{\text{H}_5\text{O}}\text{H}} \times \frac{32.00\ \text{g O}_2}{1\ \cancel{\text{mol}}\ \cancel{\text{O}_2}}\\
m_{O_2} &= 937.5\ \text{g}
\end{aligned}$$

The mass of oxygen required is 937.5 g.

(e) $C_2H_5OH_{(l)} + 3\ O_{2(g)} \rightarrow 2\ CO_{2(g)} + 3\ H_2O_{(g)}$

The masses involved, respectively, in this reaction are:

450.0 g 937.5 g 859.6 g 527.9 g

Addition shows that (450.0 + 937.5) = (859.6 + 527.9) = 1387.5, so the result agrees with the law of conservation of mass.

16. $2\ CuO_{(s)} + C_{(s)} \rightarrow 2\ Cu_{(s)} + CO_{2(g)}$

50.0 kg *m*

79.55 g/mol 1 2.01 g/mol

$$\begin{aligned}
n_{CuO} &= 50.0\ \text{k}\cancel{\text{g}} \times \frac{1\ \text{mol}}{79.55\ \cancel{\text{g}}}\\
n_{CuO} &= 0.629\ \text{kmol}\\
n_{C} &= 0.629\ \text{kmol} \times \frac{1}{2}\\
n_{C} &= 0.314\ \text{kmol}\\
m_{C} &= 0.314\ \text{k}\cancel{\text{mol}} \times \frac{12.01\ \text{g}}{1\ \cancel{\text{mol}}}
\end{aligned}$$

$$m_C = 3.77\text{ kg}$$

or

$$m_C = 50.0\text{ k}\cancel{\text{g}}\ \cancel{\text{CuO}} \times \frac{1\ \cancel{\text{mol}}\ \cancel{\text{CuO}}}{79.55\ \cancel{\text{g}}\ \cancel{\text{CuO}}} \times \frac{1\ \cancel{\text{mol}}\ \cancel{\text{C}}}{2\ \cancel{\text{mol}}\ \cancel{\text{CuO}}} \times \frac{12.01\text{ g C}}{1\ \cancel{\text{mol}}\ \cancel{\text{C}}}$$

$$m_C = 3.77\text{ kg}$$

The mass of carbon required is 3.77 kg.

Applying Inquiry Skills

17. A solid reaction product can be removed (by filtration, for instance) from the reaction system. If some more of the (presumed) excess reagent is added, and no reaction occurs, then the limiting reagent is completely reacted and the other reagent is present in excess.

18. (a) **Prediction**

$$\begin{array}{lllllll} Na_2SO_{4(aq)} & + & BaCl_{2(aq)} & \rightarrow & 2\ NaCl_{(aq)} & + & BaSO_{4(s)} \\ 142.04\text{ g/mol} & & & & & & 233.39\text{ g/mol} \end{array}$$

Since the substances are in a 1 : 1 mole ratio, the mass ratio of $BaSO_{4(s)}$: $Na_2SO_{4(aq)}$ will be 233.39 : 142.04 or 1.6431 : 1.0000. This means that for each 1.0000 g of sodium sulfate reacted, 1.6431 g of barium sulfate should be produced.

(b) **Experimental Design**

A measured mass of sodium sulfate is dissolved and reacted with excess barium chloride solution. The precipitate is filtered, dried, and weighed.

(c) **Procedure**

1. Use a clean, dry 250-mL beaker to obtain a 2.00 g sample of $Na_2SO_{4(aq)}$.
2. Use a 100-mL graduated cylinder to add approximately 50 mL of $BaCl_{2(aq)}$ to the beaker.
3. Allow the precipitate to settle, and test the clear liquid above the precipitate (the supernatant liquid) with a small amount of the $BaCl_{2(aq)}$ from a medicine dropper to see if further precipitation occurs.
4. If the test in step 3 indicates the reaction is not yet complete, repeat step 3 until no further precipitation occurs.
5. Measure and record the mass of a piece of filter paper to 0.01 g.
6. Filter, wash, and dry the $BaSO_{4(s)}$ precipitate.
7. Measure and record the mass of the filter paper plus dry precipitate to 0.01 g.
8. Dispose of all waste materials according to instructions.

(d) **Analysis**

To determine the purity of the sample, the percentage yield of the $BaSO_{4(s)}$ precipitate is calculated.

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

The $BaSO_{4(s)}$ percentage yield represents the purity of the sodium sulfate reagent as a percentage.

(e) **Evaluation**

This analysis assumes: that the other reagent is pure; that the precipitate is negligibly soluble; and that the experimental error is negligible. If any of these assumptions are incorrect, the actual yield value will be affected.

Making Connections

19. The report for this question should emphasize primarily the social perspective (the advantage of increased food supply) and the environmental perspective (the disadvantage of water pollution) as a typical tradeoff involving technology.