10.4 GAS STOICHIOMETRY

PRACTICE

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Understanding Concepts

1. $2\ CH_3OH_{(l)}$ + $3\ O_{2(g)}$ $\rightarrow$ $2\ CO_{2(g)}$ + $4\ H_2O_{(g)}$

15 g v

32.05 g/mol   22.4 L/mol (STP)

$$n_{CH_3OH} = 15\ \cancel{g} \times \frac{1\ mol}{32.05\ \cancel{g}}$$
$$n_{CH_3OH} = 0.47\ mol$$
$$n_{O_2} = 0.47\ mol \times \frac{3}{2}$$
$$n_{O_2} = 0.70\ mol$$
$$v_{O_2} = 0.70\ \cancel{mol} \times \frac{22.4\ L}{1\ \cancel{mol}}$$
$$v_{O_2} = 16\ L$$

or

$$v_{O_2} = 15\ \cancel{g\ CH_3OH} \times \frac{1\ \cancel{mol\ CH_3OH}}{32.05\ \cancel{g CH_3OH}} \times \frac{3\ \cancel{mol\ O_2}}{2\ \cancel{mol\ CH_3OH}} \times \frac{22.4\ L\ O_2}{1\ \cancel{mol\ O_2}}$$
$$v_{O_2} = 16\ L$$

The volume of oxygen needed is 16 L

2. $2\ NaCl_{(l}$ $\rightarrow$ $2\ Na_{(s)}$ + $Cl_{2(g)}$

105 kg v

22.99 g/mol   24.8 L/mol (SATP)

$$n_{Na} = 105\ k\cancel{g} \times \frac{1\ mol}{22.99\ \cancel{g}}$$
$$n_{Na} = 4.57\ kmol$$
$$n_{Cl_2} = 4.57\ kmol \times \frac{1}{2}$$
$$n_{Cl_2} = 2.28\ kmol$$
$$v_{Cl_2} = 2.28\ k\cancel{mol} \times \frac{24.8\ L}{1\ \cancel{mol}}$$
$$v_{Cl_2} = 56.6\ kL$$

or

$$v_{Cl_2} = 105\ k\cancel{g\ Na} \times \frac{1\ \cancel{mol\ Na}}{22.99\ \cancel{g\ Na}} \times \frac{1\ \cancel{mol\ Cl_2}}{2\ \cancel{mol\ Na}} \times \frac{24.8\ L\ Cl_2}{1\ \cancel{mol\ Cl_2}}$$

$$v_{Cl_2} = 56.6\ kL$$

The volume of chlorine produced is 56.6 kL, or 56.6 m^3.

3. $C_3H_{8(g)}$ + $5\ O_{2(g)}$ $\rightarrow$ $3\ CO_{2(g)}$ + $8\ H_2O_{(g)}$

m v

44.11 g/mol   24.8 L/mol (SATP)

$$v_{O_2} = 125\ L \times 20\% = 25\ L$$
$$n_{O_2} = 25\ \cancel{L} \times \frac{1\ mol}{24.8\ \cancel{L}}$$

$$n_{O_2} = 1.0 \text{ mol}$$
$$n_{C_3H_8} = 1.0 \text{ mol} \times \frac{1}{5}$$
$$n_{C_3H_8} = 0.20 \text{ mol}$$
$$m_{C_3H_8} = 0.20 \cancel{\text{mol}} \times \frac{44.11 \text{ g}}{1 \cancel{\text{mol}}}$$
$$m_{C_3H_8} = 8.9 \text{ g}$$

or

$$m_{C_3H_8} = 25 \cancel{\text{L}} \cancel{O_2} \times \frac{1 \cancel{\text{mol}} \cancel{O_2}}{24.8 \cancel{\text{L}} \cancel{O_2}} \times \frac{1 \cancel{\text{mol}} \cancel{C_3H_8}}{5 \cancel{\text{mol}} \cancel{O_2}} \times \frac{44.11 \text{ g } C_3H_8}{1 \cancel{\text{mol}} \cancel{C_3H_8}}$$
$$m_{C_3H_8} = 8.9 \text{ g}$$

The mass of propane that can be burned is 8.9 g.

Applying Inquiry Skills

4. (a) **Prediction**

$$2\,H_2O_{2(aq)} \rightarrow 2\,H_2O_{(l)} + O_{2(g)}$$

50.0 mL $\qquad$ v (lab p & T conditions)

0.88 mol/L

$$n_{H_2O_2} = 50.0 \text{ m}\cancel{\text{L}} \times \frac{0.88 \text{ mol}}{1 \cancel{\text{L}}}$$
$$n_{H_2O_2} = 44 \text{ mmol}$$
$$n_{O_2} = 44 \text{ mmol} \times \frac{1}{2}$$
$$n_{O_2} = 22 \text{ mmol}$$

p = (94.6 – 2.49) kPa = 92.1 kPa (corrected for water vapour pressure)

T = 21°C = 294 K

v_{O_2} = ?

R = 8.31 kPa · L/(mol · K)

$$pv = nRT$$
$$v_{O_2} = \frac{nRT}{p}$$
$$= \frac{22 \text{ m}\cancel{\text{mol}} \times \frac{8.31 \cancel{\text{kPa}} \cdot \text{L}}{\cancel{\text{mol}} \cdot \cancel{\text{K}}} \times 294 \cancel{\text{K}}}{92.1 \cancel{\text{kPa}}}$$
$$v_{O_2} = 5.8 \times 10^3 \text{ mL} = 0.58 \text{ L}$$

or

$$v_{O_2} = 50.0 \text{ m}\cancel{\text{L}} \cancel{H_2O_2} \times \frac{0.88 \cancel{\text{mol}} \cancel{H_2O_2}}{1 \cancel{\text{L}} \cancel{H_2O_2}} \times \frac{1 \cancel{\text{mol}} \cancel{O_2}}{2 \cancel{\text{mol}} \cancel{H_2O_2}} \times \frac{8.31 \cancel{\text{kPa}} \cdot \text{L } O_2}{1 \cancel{\text{mol}} \cancel{O_2} \cdot \cancel{\text{K}}} \times \frac{294 \cancel{\text{K}}}{92.1 \cancel{\text{kPa}}}$$
$$v_{O_2} = 5.8 \times 10^3 \text{ mL} = 0.58 \text{ L}$$

According to the ideal gas law, the volume of oxygen at room pressure and temperature is predicted to be 0.58 L.

(b) **Analysis**

According to the evidence, the volume of oxygen gas produced at room conditions is 556 mL = 0.556 L.

(c) **Evaluation**

difference $= |0.556 - 0.58|\text{ L} = 0.02 \text{ L}$

$$\% \text{ difference} = \frac{0.02 \cancel{L}}{0.58 \cancel{L}} \times 100\% = 4\%$$

The evidence agrees well with the predicted value, within 4%.

(d) **Evaluation**

The ideal gas law is judged to be verified by this investigation, since the evidence agrees well with the prediction.

Making Connections

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

300 L

All gases measured at 40°C and 1.50 atm.

$$v_{O_2} = 300 \text{ L} \times \frac{1}{2}$$

$$v_{O_2} = 150 \text{ L}$$

or

$$v_{O_2} = 300 \cancel{\text{L}}\ \cancel{H_2} \times \frac{1 \text{ L } O_2}{2 \cancel{\text{L}}\ \cancel{H_2}}$$

$$v_{O_2} = 150 \text{ L}$$

The volume of oxygen required is 150 L.

(b) A vehicle burning hydrogen fuel by using oxygen from the air (which contains nitrogen) could still produce NO_x pollutants if the combustion temperature were high enough.

SECTION 10.4 QUESTIONS

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Understanding Concepts

1. $2\ Fe_{(s)} \quad + \quad 3\ H_2SO_{4(aq)} \quad \rightarrow \quad Fe_2(SO_4)_{3(aq)} \quad + \quad 3\ H_{2(g)}$

10 g						v
55.85 g/mol						22.4 L/mol (STP)

$$n_{Fe} = 10 \cancel{\text{g}} \times \frac{1 \text{ mol}}{55.85 \cancel{\text{g}}}$$

$$n_{Fe} = 0.18 \text{ mol}$$

$$n_{H_2} = 0.18 \text{ mol} \times \frac{3}{2}$$

$$n_{H_2} = 0.27 \text{ mol}$$

$$n_{H_2} = 0.27 \cancel{\text{mol}} \times \frac{22.4 \text{ L}}{1 \cancel{\text{mol}}}$$

$$n_{H_2} = 6.0 \text{ L}$$

or

$$n_{H_2} = 10 \cancel{\text{g}}\ \cancel{Fe} \times \frac{1 \cancel{\text{mol}}\ \cancel{Fe}}{55.85 \cancel{\text{g}}\ \cancel{Fe}} \times \frac{3 \cancel{\text{mol}}\ \cancel{H_2}}{2 \cancel{\text{mol}}\ \cancel{Fe}} \times \frac{22.4 \text{ L } H_2}{1 \cancel{\text{mol}}\ \cancel{H_2}}$$

$$n_{H_2} = 6.0 \text{ L}$$

The volume of hydrogen produced will be 6.0 L.

2. $CH_{4(g)}$ + $2\ O_{2(g)}$ → $CO_{2(g)}$ + $2\ H_2O_{(g)}$

2.00 ML, 0°C, 120 kPa v (SATP)

$$v_{O_2} = 2.00\ \text{ML} \times \frac{2}{1}$$

$$v_{O_2} = 4.00\ \text{ML} \quad \text{(at 0°C = 273 K, 120 kPa)}$$

$$p_1 = 120\ \text{kPa}$$
$$T_1 = 0°C = 273\ \text{K}$$
$$v_1 = 2.00\ \text{ML}$$
$$p_2 = 100\ \text{kPa}$$
$$T_2 = 25°C = 298\ \text{K}$$
$$v_{O_2} = ?$$

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$

$$v_{O_2} = \frac{T_2 p_1 v_1}{T_1 p_2}$$

$$= \frac{298\ \cancel{\text{K}} \times 120\ \cancel{\text{kPa}} \times 2.00\ \text{ML}}{273\ \cancel{\text{K}} \times 100\ \cancel{\text{kPa}}}$$

$$v_{O_2} = 2.62\ \text{ML}$$

or

$$v_{O_2} = 2.00\ \text{M}\cancel{\text{L}}\ \cancel{CH_4} \times \frac{2\ \text{L}\ O_2}{1\ \cancel{\text{L}}\ \cancel{CH_4}} \times \frac{120\ \cancel{\text{kPa}}}{100\ \cancel{\text{kPa}}} \times \frac{298\ \cancel{\text{K}}}{273\ \cancel{\text{K}}}$$

$$v_{O_2} = 2.62\ \text{ML}$$

The SATP volume of oxygen required is 2.62 ML, or $2.62 \times 10^3\ \text{m}^3$.

3. $2\ NH_{3(g)}$ + $H_2SO_{4(aq)}$ → $(NH_4)_2SO_{4(s)}$

75.0 kL, 10°C = 283 K, 110 kPa m

$R = 8.31\ \text{kPa} \cdot \text{L/(mol} \cdot \text{K)}$ 132.16 g/mol

$$pv = nRT$$

$$n_{NH_3} = \frac{pv}{RT}$$

$$= \frac{110\ \cancel{\text{kPa}} \times 75.0\ \text{k}\cancel{\text{L}}}{\frac{8.31\ \cancel{\text{kPa}} \cdot \cancel{\text{L}}}{1\ \text{mol} \cdot \cancel{\text{K}}} \times 283\ \cancel{\text{K}}}$$

$$n_{NH_3} = 3.51\ \text{kmol}$$

$$n_{(NH_4)_2SO_4} = 3.51\ \text{kmol} \times \frac{1}{2}$$

$$n_{(NH_4)_2SO_4} = 1.75\ \text{kmol}$$

$$m_{(NH_4)_2SO_4} = 1.75\ \text{k}\cancel{\text{mol}} \times \frac{132.16\ \text{g}}{1\ \cancel{\text{mol}}}$$

$$m_{(NH_4)_2SO_4} = 232\ \text{kg}$$

or

$$m_{(NH_4)_2SO_4} = 75.0\ \text{k}\cancel{\text{L}}\ \cancel{NH_3} \times \frac{1\ \cancel{\text{mol}}\ \cancel{NH_3} \cdot \cancel{\text{K}}}{8.31\ \cancel{\text{kPa}} \cdot 1\ \cancel{\text{L}}\ \cancel{NH_3}} \times \frac{100\ \cancel{\text{kPa}}}{283\ \cancel{\text{K}}}$$

(continued) $\times \dfrac{1\ \cancel{\text{mol}}\ \cancel{(NH_4)_2SO_4}}{} \times \dfrac{132.16\text{ g }(NH_4)_2SO_4}{}$

$m_{(NH_4)_2SO_4} = 232\text{ kg}$

The mass of ammonium sulfate that can be produced is 232 kg.

4. $CH_4{\cdot}6H_2O_{(s)} \rightarrow CH_{4(g)} + 6\ H_2O_{(l)}$

1.0 kg $\qquad$ v (20°C = 293 K, 95 kPa)

124.17 g/mol

$R = 8.31\text{ kPa}\cdot\text{L/(mol}\cdot\text{K)}$

$$
\begin{aligned}
n_{CH_4\cdot 6H_2O} &= 1.0\ \text{k}\cancel{\text{g}} \times \frac{1\text{ mol}}{124.17\ \cancel{\text{g}}} \\
n_{CH_4\cdot 6H_2O} &= 0.00805\text{ kmol} \\
n_{CH_4} &= 0.00805\text{ kmol} \times \frac{1}{1} \\
n_{CH_4} &= 0.00805\text{ kmol} \\
pv &= nRT \\
v_{CH_4} &= \frac{nRT}{p} \\
&= \frac{0.00805\ \text{k}\cancel{\text{mol}} \times \dfrac{8.31\ \cancel{\text{kPa}}\cdot\text{L}}{\cancel{\text{mol}}\cdot\cancel{\text{K}}} \times 293\ \cancel{\text{K}}}{95\ \cancel{\text{kPa}}} \\
v_{CH_4} &= 0.21\text{ kL}
\end{aligned}
$$

or

$$v_{CH_4} = 1.0\ \text{k}\cancel{\text{g}}\ \cancel{CH_4{\cdot}6H_2O} \times \frac{1\ \cancel{\text{mol}}\ \cancel{CH_4{\cdot}6H_2O}}{124.17\ \cancel{\text{g}}\ \cancel{CH_4{\cdot}6H_2O}} \times \frac{1\ \cancel{\text{mol}}\ \cancel{CH_4}}{1\ \cancel{\text{mol}}\ \cancel{CH_4{\cdot}6H_2O}}$$

(continued) $\times \dfrac{8.31\ \cancel{\text{kPa}}\cdot\text{L }CH_4}{1\ \cancel{\text{mol}}\ \cancel{CH_4}\cdot\cancel{\text{K}}} \times \dfrac{293\ \cancel{\text{K}}}{95\ \cancel{\text{kPa}}}$

$v_{CH_4} = 0.21\text{ kL}$

The volume of methane gas produced is 0.21 kL, or 0.21 m^3.

Making Connections

5. One consumer reaction that produces and consumes gases is the burning of propane in an outdoor barbeque. The reaction is:

$C_3H_{8(g)} + 5\ O_{2(g)} \rightarrow 3\ CO_{2(g)} + 8\ H_2O_{(g)}$

One industrial reaction that consumes a gas is the production of ammonium sulfate fertilizer. The reaction is:

$2\ NH_{3(g)} + H_2SO_{4(aq)} \rightarrow (NH_4)_2SO_{4(s)}$

One laboratory reaction that produces and consumes gases is the burning of methane (natural gas) in a lab burner. The reaction is:

$CH_{4(g)} + 2\ O_{2(g)} \rightarrow CO_{2(g)} + 2\ H_2O_{(g)}$

Reflecting

6. (a) All stoichiometry involves the numerical ratios of reactants and products, that is, the ratios of amounts in moles.
   (b) In an industry using a chemical reaction, knowledge of stoichiometry is essential to determine how much of reactant to purchase and use. For example, in the reaction
   $2\ NH_{3(g)} + H_2SO_{4(aq)} \rightarrow (NH_4)_2SO_{4(s)}$
   used to make fertilizer, the reacting amounts of ammonia and sulfuric acid would have to be calculate beforehand.
   (c) Adding "just the right amount" of baking powder to a baking mix is an example of consumer use of stoichiometry.

