CHAPTER 10 REVIEW

(Page 492)

Understanding Concepts

1. (a) The total pressure of a mixture of nonreacting gases is equal to the sum of the partial pressures of the individual gases in the mixture.
   (b) $p_{\text{total}} = p_1 + p_2 + p_3 + \ldots$
2. Dalton's law of partial pressures can be explained by these two concepts from the kinetic molecular theory:
   (i) Gas pressure is caused by the collisions of particles (molecules, atoms, ions) with the walls of the container.
   (ii) Gas molecules essentially act independently of each other.
   Therefore, the total pressure (total of the collisions with the walls) is the sum of the individual pressures (collisions of only one kind of particle) of each gas present.
   Note: Point (ii) presupposes, of course, that students know/assume that all particles at the same temperature have the same average kinetic energy.
3. $p_{\text{total}} = (230 + 13 + 7)\ \text{kPa} = 250\ \text{kPa}$
4. $p_{O_2} = \{100\ \text{(exactly)} - 3.17\}\ \text{kPa} = 96.83\ \text{kPa}$
5. (a) When measured at the same temperature and pressure, volumes of gaseous reactants and products of chemical reactions are found to be (to three significant digits) in simple ratios of whole numbers.
   (b) $4\ C_7H_5(NO_2)_{3(s)} + 21\ O_{2(g)} \rightarrow 28\ CO_{2(g)} + 6\ N_{2(g)} + 10\ H_2O_{(g)}$

   5.00 L

   Pressure and temperature conditions equal for all gases measured.

$$v_{CO_2} = 5.00\ \text{L} \times \frac{28}{21}$$
$$v_{CO_2} = 6.67\ \text{L}$$

or

$$v_{CO_2} = 5.00\ \cancel{\text{L}}\ \cancel{O_2} \times \frac{28\ \text{L}\ CO_2}{21\ \cancel{\text{L}}\ \cancel{O_2}}$$
$$v_{CO_2} = 6.67\ \text{L}$$

The volume of carbon dioxide produced is 6.67 L.

$$v_{N_2} = 5.00\ \text{L} \times \frac{6}{21}$$
$$v_{N_2} = 1.43\ \text{L}$$

or

$$v_{N_2} = 5.00\ \cancel{\text{L}}\ \cancel{O_2} \times \frac{6\ \text{L}\ N_2}{21\ \cancel{\text{L}}\ \cancel{O_2}}$$
$$v_{N_2} = 1.43\ \text{L}$$

The volume of nitrogen produced is 1.43 L.

$$v_{H_2O} = 5.00\ \text{L} \times \frac{10}{21}$$
$$v_{H_2O} = 2.38\ \text{L}$$

or

$$v_{H_2O} = 5.00\ \cancel{\text{L}}\ \cancel{O_2} \times \frac{10\ \text{L}\ H_2O}{21\ \cancel{\text{L}}\ \cancel{O_2}}$$
$$v_{H_2O} = 2.38\ \text{L}$$

The volume of water vapour produced is 2.38 L.

6. Avogadro's idea is theoretical. It attempts to *explain* observed (empirical) gas behaviour by proposing that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules. This proposal is a product of intellect, not observation, and so is a theory, not a law.

7. $2\ NH_4NO_{3(s)} \rightarrow\ 2\ N_{2(g)} + 4\ H_2O_{(g)} + O_{2(g)}$

1.00 mol	v_{SATP}	v_{SATP}	v_{SATP}
	all gases:	24.8 L/mol (SATP)	

$$n_{N_2} = 1.00\text{ mol} \times \frac{2}{2}$$
$$n_{N_2} = 1.00\text{ mol}$$
$$v_{N_2} = 1.00\ \cancel{\text{mol}} \times \frac{24.8\text{ L}}{1\ \cancel{\text{mol}}}$$
$$v_{N_2} = 24.8\text{ L}$$

or

$$v_{N_2} = 1.00\ \cancel{\text{mol}\ NH_4NO_3} \times \frac{2\ \cancel{\text{mol}\ N_2}}{2\ \cancel{\text{mol}\ NH_4NO_3}} \times \frac{24.8\text{ L } N_2}{1\ \cancel{\text{mol}\ N_2}}$$
$$v_{N_2} = 24.8\text{ L}$$

The volume of nitrogen produced is 24.8 L.

$$n_{H_2O} = 1.00\text{ mol} \times \frac{4}{2}$$
$$n_{H_2O} = 2.00\text{ mol}$$
$$v_{H_2O} = 2.00\ \cancel{\text{mol}} \times \frac{24.8\text{ L}}{1\ \cancel{\text{mol}}}$$
$$v_{H_2O} = 49.6\text{ L}$$

or

$$v_{H_2O} = 1.00\ \cancel{\text{mol}\ NH_4NO_3} \times \frac{2\ \cancel{\text{mol}\ H_2O}}{2\ \cancel{\text{mol}\ NH_4NO_3}} \times \frac{24.8\text{ L } H_2O}{1\ \cancel{\text{mol}\ H_2O}}$$
$$v_{H_2O} = 49.6\text{ L}$$

The volume of water vapour produced is 49.6 L.

$$n_{O_2} = 1.00\text{ mol} \times \frac{1}{2}$$
$$n_{O_2} = 0.500\text{ mol}$$
$$v_{O_2} = 0.500\ \cancel{\text{mol}} \times \frac{24.8\text{ L}}{1\ \cancel{\text{mol}}}$$
$$v_{O_2} = 12.4\text{ L}$$

or

$$v_{O_2} = 1.00\ \cancel{\text{mol}\ NH_4NO_3} \times \frac{1\ \cancel{\text{mol}\ O_2}}{2\ \cancel{\text{mol}\ NH_4NO_3}} \times \frac{24.8\text{ L } O_2}{1\ \cancel{\text{mol}\ O_2}}$$
$$v_{O_2} = 12.4\text{ L}$$

The volume of oxygen produced is 12.4 L.
The total volume of gases produced is (24.8 + 49.6 + 12.4) L = 76.8 L.

8. (a) $n_{Ar} = ?$

$$p = (100.0 + 0.400)\text{ kPa} = 100.4\text{ kPa}$$
$$T = 20^\circ\text{C} = 293\text{ K}$$
$$v = 125\text{ mL} = 0.125\text{ L}$$
$$R = 8.31\text{ kPa} \cdot \text{L/(mol} \cdot \text{K)}$$
$$pv = nRT$$

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

$$= \frac{100.4\ \cancel{kPa} \times 0.125\ \cancel{L}}{\frac{8.31\ \cancel{kPa} \cdot \cancel{L}}{mol \cdot \cancel{K}} \times 293\ \cancel{K}}$$

$$n_{Ar} = 0.00515\ mol = 5.15\ mmol$$

The amount of argon gas in a bulb is 5.15 mmol.

(b) $p_1 = 100.4\ kPa$

$T_1 = 20^\circ C = 293\ K$

$p_2 = ?$

$T_2 = 200^\circ C = 473\ K$

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

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

$$= \frac{473\ \cancel{K} \times 100.4\ kPa}{293\ \cancel{K}}$$

$$p_{Ar} = 162\ kPa$$

or

$$p_{Ar} = 100.4\ kPa \times \frac{473\ \cancel{K}}{293\ \cancel{K}}$$

$$p_{Ar} = 162\ kPa$$

The final argon pressure at the higher temperature will be 162 kPa.

(c) $n_{Ar} = ?$

$p = 100.4\ kPa$

$T = 20^\circ C = 293\ K$

$v = 0.915\ L$

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

$pv = nRT$

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

$$= \frac{100.4\ \cancel{kPa} \times 0.915\ \cancel{L}}{\frac{8.31\ \cancel{kPa} \cdot \cancel{L}}{mol \cdot \cancel{K}} \times 293\ \cancel{K}}$$

$n_{Ar} = 0.0377\ mol$ (in each fluorescent tube)

$n_{Ar} = ?$

$m_{Ar} = 50\ kg$

$M_{Ar} = 39.95\ g/mol$

$$n_{Ar} = 50.0\ \cancel{kg} \times \frac{1\ mol}{39.95\ \cancel{g}}$$

$n_{Ar} = 1.25\ kmol$ (in the steel tank)

$$\#_{tubes} = 1.25\ k\cancel{mol} \times \frac{1\ tube}{0.0377\ \cancel{mol}}$$

$\#_{tubes} = 33.2 \text{ ktubes } (3.32 \times 10^4 \text{ tubes})$

9. $2\,ZnS_{(s)} + 3\,O_{2(g)} \rightarrow 2\,ZnO_{(s)} + 2\,SO_{2(g)}$

1.00 t = 1.00 Mg — v_{SATP}

97.44 g/mol — 24.8 L/mol

$$n_{ZnS} = 1.00\ \text{M}\cancel{\text{g}} \times \frac{1\ \text{mol}}{97.44\ \cancel{\text{g}}}$$

$$n_{ZnS} = 0.0103\ \text{Mmol} = 10.3\ \text{kmol}$$

$$n_{SO_2} = 10.3\ \text{kmol} \times \frac{2}{2}$$

$$n_{SO_2} = 10.3\ \text{kmol}$$

$$v_{SO_2} = 10.3\ \text{k}\cancel{\text{mol}} \times \frac{24.8\ \text{L}}{1\ \cancel{\text{mol}}}$$

$$v_{SO_2} = 255\ \text{kL} = 255\ \text{m}^3$$

or

$$v_{SO_2} = 1.00\ \text{M}\cancel{\text{g}}\ \cancel{\text{ZnS}} \times \frac{1\ \cancel{\text{mol}}\ \cancel{\text{ZnS}}}{97.44\ \cancel{\text{g}}\ \cancel{\text{ZnS}}} \times \frac{2\ \cancel{\text{mol}}\ \cancel{\text{SO}_2}}{2\ \cancel{\text{mol}}\ \cancel{\text{ZnS}}} \times \frac{24.8\ \text{L SO}_2}{1\ \cancel{\text{mol}}\ \cancel{\text{SO}_2}}$$

$$v_{SO_2} = 0.255\ \text{ML} = 255\ \text{kL} = 255\ \text{m}^3$$

The volume of sulfur dioxide produced will be 255 kL, or 255 m^3.

10. $2\,CaCO_{3(s)} + 2\,SO_{2(g)} + O_{2(g)} \rightarrow 2\,CaSO_{4(s)} + 2\,CO_{2(g)}$

m — 500 kL (STP) — v_{STP}

100.09 g/mol — 22.4 L/mol

(a)

$$v_{CO_2} = 500\ \text{kL} \times \frac{2}{2}$$

$$v_{CO_2} = 500\ \text{kL}$$

or

$$v_{CO_2} = 500\ \text{k}\cancel{\text{L}}\ \cancel{\text{SO}_2} \times \frac{2\ \text{L CO}_2}{2\ \cancel{\text{L}}\ \cancel{\text{SO}_2}}$$

$$v_{CO_2} = 500\ \text{kL}$$

The volume of carbon dioxide gas produced at STP is 500 kL.

(b)

$$n_{SO_2} = 500\ \text{k}\cancel{\text{L}} \times \frac{1\ \text{mol}}{22.4\ \cancel{\text{L}}}$$

$$n_{SO_2} = 22.3\ \text{kmol}$$

$$n_{CaCO_3} = 22.3\ \text{kmol} \times \frac{2}{2}$$

$$n_{CaCO_3} = 22.3\ \text{kmol}$$

$$m_{CaCO_3} = 22.3\ \text{k}\cancel{\text{mol}} \times \frac{100.09\ \text{g}}{1\ \cancel{\text{mol}}}$$

$$m_{CaCO_3} = 2.23 \times 10^3\ \text{kg} = 2.23\ \text{Mg} = 2.23\ \text{t}$$

or

$$m_{CaCO_3} = 500\ \text{k}\cancel{\text{L}}\ \cancel{\text{SO}_2} \times \frac{1\ \cancel{\text{mol}}\cancel{\text{SO}_2}}{22.4\ \cancel{\text{L}}\ \cancel{\text{SO}_2}} \times \frac{2\ \cancel{\text{mol}}\ \cancel{\text{CaCO}_3}}{2\ \cancel{\text{mol}}\ \cancel{\text{SO}_2}} \times \frac{100.09\ \text{g CaCO}_3}{1\ \cancel{\text{mol}}\ \cancel{\text{CaCO}_3}}$$

$$m_{CaCO_3} = 2.23 \times 10^3\ \text{kg} = 2.23\ \text{Mg} = 2.23\ \text{t}$$

The mass of calcium carbonate consumed is 2.23 t

11. $SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$

1.00 t = 1.00 Mg — v

80.06 g/mol 0.12 mmol/L

$n_{SO_3} = 1.00 \text{ M}\cancel{\text{g}} \times \dfrac{1 \text{ mol}}{80.06 \cancel{\text{g}}}$

$n_{SO_3} = 0.0125 \text{ Mmol}$

$n_{H_2SO_4} = 0.0125 \text{ Mmol} \times \dfrac{1}{1}$

$n_{H_2SO_4} = 0.0125 \text{ Mmol}$

$v_{H_2SO_4} = 0.0125 \text{ M}\cancel{\text{mol}} \times \dfrac{1 \text{ L}}{0.12 \text{ m}\cancel{\text{mol}}}$

$v_{H_2SO_4} = 1.0 \times 10^8 \text{ L} = 0.10 \text{ GL}$

or

$v_{H_2SO_4} = 1.00 \text{ M}\cancel{\text{g}}\ \cancel{SO_3} \times \dfrac{1 \cancel{\text{mol}}\ \cancel{SO_3}}{80.06 \cancel{\text{g}}\ \cancel{SO_3}} \times \dfrac{1 \cancel{\text{mol}}\ \cancel{H_2SO_4}}{1 \cancel{\text{mol}}\ \cancel{SO_3}} \times \dfrac{1 \text{ L } H_2SO_4}{0.12 \text{ m}\cancel{\text{mol}}\ \cancel{H_2SO_4}}$

$v_{H_2SO_4} = 1.0 \times 10^8 \text{ L} = 0.10 \text{ GL}$

The volume of sulfuric acid that could be formed is 0.10 GL.

12. $2\ H_2O_{(l)} \rightarrow 2\ H_{2(g)} + O_{2(g)}$

		50.0 mL	v
18.02 g/mol			

Both gases measured at 23°C = 296 K and 103 kPa.

(a) $v_{O_2} = 50.0 \text{ mL} \times \dfrac{1}{2}$

$v_{O_2} = 25.0 \text{ mL}$

or

$v_{O_2} = 50.0 \text{ m}\cancel{\text{L}}\ \cancel{H_2} \times \dfrac{1 \text{ L } O_2}{2 \cancel{\text{L}}\ \cancel{H_2}}$

$v_{O_2} = 25.0 \text{ mL}$

The volume of oxygen gas produced is 25.0 mL.

(b) p_1 = 103 kPa

T_1 = 23°C = 296 K

v_1 = 50.0 mL

p_2 = 101.325 kPa

T_2 = 0°C = 273 K

v_{H_2} = ?

$$\frac{p_1v_1}{T_1} = \frac{p_2v_2}{T_2}$$

$$v_{H_2} = \frac{T_2p_1v_1}{T_1p_2}$$

$$= \frac{273 \cancel{\text{K}} \times 103 \cancel{\text{kPa}} \times 50.0 \text{ mL}}{296 \cancel{\text{K}} \times 101.325 \cancel{\text{kPa}}}$$

$$v_{H_2} = 46.9 \text{ mL}$$

or

$$v_{H_2} = 50.0 \text{ mL} \times \frac{103 \cancel{\text{kPa}}}{101.325 \cancel{\text{kPa}}} \times \frac{273 \cancel{\text{K}}}{296 \cancel{\text{K}}}$$

$$v_{H_2} = 46.9 \text{ mL}$$

The volume of the hydrogen at STP would be 46.9 mL.

(c) *Note:* The mass of water may be calculated at this point in this question from the volume of either hydrogen or oxygen, and if using hydrogen values, from the volume at either set of pressure and temperature conditions.
For best accuracy, and to avoid perpetuating possible errors in preceding steps, calculating from original values is usually preferable, where possible.

$n_{H_2} = ?$

$p = 103 \text{ kPa}$

$T = 23^\circ\text{C} = 296 \text{ K}$

$v = 50.0 \text{ mL}$

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

$$pv = nRT$$

$$n_{H_2} = \frac{pv}{RT}$$

$$= \frac{103 \cancel{\text{kPa}} \times 50.0 \cancel{\text{mL}}}{\frac{8.31 \cancel{\text{kPa}} \cdot \cancel{\text{L}}}{\text{mol} \cdot \cancel{\text{K}}} \times 296 \cancel{\text{K}}}$$

$$n_{H_2} = 2.09 \text{ mmol}$$

$$n_{H_2O} = 2.09 \text{ mmol} \times \frac{2}{2}$$

$$n_{H_2O} = 2.09 \text{ mmol}$$

$$m_{H_2O} = 2.09 \text{ m}\cancel{\text{mol}} \times \frac{18.02 \text{ g}}{1 \cancel{\text{mol}}}$$

$$m_{H_2O} = 37.7 \text{ mg}$$

or

$$m_{H_2O} = 50.0 \cancel{\text{mL}} \cancel{H_2} \times \frac{1 \cancel{\text{mol}} \cancel{H_2} \cdot \cancel{\text{K}}}{8.31 \cancel{\text{kPa}} \cdot 1 \cancel{\text{L}} \cancel{H_2}} \times \frac{103 \cancel{\text{kPa}}}{296 \cancel{\text{K}}} \times \frac{2 \cancel{\text{mol}} \cancel{H_2O}}{2 \cancel{\text{mol}} \cancel{H_2}} \times \frac{18.02 \text{ g } H_2O}{1 \cancel{\text{mol}} \cancel{H_2O}}$$

$$m_{H_2O} = 37.7 \text{ mg}$$

The mass of water decomposed is 37.7 mg.

13. According to Dalton's law of partial pressures and Avogadro's theory, the partial pressure of any gas in a mixture must be proportional to its mole fraction. Since the mixture has 2.00 mol $N_{2(g)}$ and 3.00 mol $H_{2(g)}$, totalling 5.00 mol; and the total pressure is 200 kPa;

$$p_{H_2} = 200 \text{ kPa} \times \frac{3.00 \cancel{\text{mol}}}{5.00 \cancel{\text{mol}}}$$

$$p_{H_2} = 120 \text{ kPa}$$

$$p_{N_2} = p_{\text{total}} - p_{H_2} = (200 - 120) \text{ kPa} = 80 \text{ kPa}$$

The partial pressure of nitrogen is 80 kPa; and the partial pressure of hydrogen is 120 kPa.

14. a) When temperature increases, the molar volume of a gas increases.
b) When pressure increases, the molar volume of a gas decreases.

Applying Inquiry Skills

15. (a) **Prediction**

The molar volume of propane at STP will be 22.4 L/mol, just as for any other gas, according to Avogadro's theory. (Assume propane behaves like the ideal gas.)

(b) **Analysis**

$$m_{C_3H_8} = (426.79 - 424.92)\text{ g} = 1.87\text{ g}$$
$$p_1 = (98.23 - 2.49)\text{ kPa} = 95.74\text{ kPa}$$
$$v_1 = 1065\text{ mL}$$
$$T_1 = 21.0°\text{C} = 294\text{ K}$$
$$p_2 = 101.325\text{ kPa}$$
$$v_{C_3H_8} = ?$$
$$T_2 = 0°\text{C} = 273\text{ K}$$
$$M_{C_3H_8} = 44.11\text{ g/mol}$$
$$V_{STP} = ?$$

$$n_{C_3H_8} = 1.87\ \cancel{\text{g}} \times \frac{1\text{ mol}}{44.11\ \cancel{\text{g}}}$$
$$n_{C_3H_8} = 0.0424\text{ mol} = 42.4\text{ mmol}$$
$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$
$$v_{C_3H_8} = \frac{T_2 p_1 v_1}{}$$
$$= \frac{273\ \cancel{\text{K}} \times 95.74\ \cancel{\text{kPa}} \times 1065\text{ mL}}{294\ \cancel{\text{K}} \times 101.325\ \cancel{\text{kPa}}}$$
$$v_{C_3H_8} = 934\text{ mL}$$

or

$$v_{C_3H_8} = 1065\text{ mL} \times \frac{95.74\ \cancel{\text{kPa}}}{101.325\ \cancel{\text{kPa}}} \times \frac{273\ \cancel{\text{K}}}{}$$
$$v_{C_3H_8} = 934\text{ mL}$$

The volume of propane at STP would be 934 mL. Since this is an amount of 42.4 mmol, the molar volume can now be calculated as follows:

$$V_{STP} = \frac{934\ \cancel{\text{m}}\text{L}}{42.4\ \cancel{\text{m}}\text{mol}}$$
$$V_{STP} = 22.0\text{ L/mol}$$

According to the evidence from this investigation, the molar volume of propane at STP is 22.0 L/mol.

(c) **Evaluation**

$$\text{difference} = |22.4 - 22.0|\text{ L/mol} = 0.4\text{ L/mol}$$
$$\%\text{ difference} = \frac{0.4\ \cancel{\text{L/mol}}}{22.4\ \cancel{\text{L/mol}}} \times 100\% = 2\%$$

The prediction is judged to be verified, because the value calculated from the evidence is in close agreement with it, to within 2%.

(d) **Evaluation**

Avogadro's theory is supported by the result of this investigation, because the result agrees well with the prediction made from this authority.

16. **Experimental Design**

A cylinder of compressed gas is used to release a noble gas, which is collected at ambient conditions by water displacement. The amount is calculated from volume, temperature, and pressure measurements. The molar mass is calculated from the amount and the measured mass, and is used to identify the gas.

17. One natural and one technological use or source for each of the following gases:

(a)	oxygen	from plant respiration	for welding
(b)	methane	from plant decomposition	for fuel
(c)	helium	from natural gas wells	for balloons
(d)	air	Earth's atmosphere	source of gases
(e)	water vapour	from animal respiration	for humidifiers
(f)	carbon dioxide	from combustion	fire extinguishers

Making Connections

18. (a) Freons were initially used as refrigerants, and soon became popular as aerosol propellants, and then later as the foaming agent for making foam plastics, and as a non-stick, non-toxic solvent for use by the electronics industry.
(b) The production of Freons is banned in many countries, including Canada, because these compounds react in the upper atmosphere to produce chlorine atoms — which, in turn, catalyze the decomposition of ozone. This increases environmental damage from ultraviolet rays.

(c) $m_{CF_2Cl_2} = 1.00 \text{ kg}$

$M_{CF_2Cl_2} = 120.91 \text{ g/mol}$

$V_{CF_2Cl_2} = 24.8 \text{ L/mol (SATP)}$

$n_{CF_2Cl_2} = 1.00 \text{ k}\cancel{\text{g}} \times \frac{1 \text{ mol}}{120.91 \cancel{\text{g}}}$

$n_{CF_2Cl_2} = 0.00827 \text{ kmol} = 8.27 \text{ mol}$

$v_{CF_2Cl_2} = 8.27 \cancel{\text{mol}} \times \frac{24.8 \text{ L}}{1 \cancel{\text{mol}}}$

$v_{CF_2Cl_2} = 205 \text{ L}$

or

$v_{CF_2Cl_2} = 1.00 \text{ k}\cancel{\text{g}} \times \frac{1 \cancel{\text{mol}}}{120.91 \cancel{\text{g}}} \times \frac{24.8 \text{ L}}{1 \cancel{\text{mol}}}$

$v_{CF_2Cl_2} = 0.205 \text{ kL} = 205 \text{ L}$

The volume of Freon at SATP would be 205 L.

19. $2\ C_2H_5SH_{(g)} + 9\ O_{2(g)} \rightarrow 4\ CO_{2(g)} + 6\ H_2O_{(g)} + 2\ SO_{2(g)}$

1.00 g		v	v	v
62.14 g/mol		All gases: 24.8 L/mol (SATP)		

$n_{C_2H_5SH} = 1.00 \cancel{\text{g}} \times \frac{1 \text{ mol}}{62.14 \cancel{\text{g}}}$

$n_{C_2H_5SH} = 0.0161 \text{ mol} = 16.1 \text{ mmol}$

$n_{CO_2} = 16.1 \text{ mmol} \times \frac{4}{2}$

$n_{CO_2} = 32.2 \text{ mmol}$

$v_{CO_2} = 32.2 \text{ m}\cancel{\text{mol}} \times \frac{24.8 \text{ L}}{1 \cancel{\text{mol}}}$

$v_{CO_2} = 798 \text{ mL}$

or

$v_{CO_2} = 1.00 \cancel{\text{g}}\ \cancel{C_2H_5SH} \times \frac{1 \cancel{\text{mol}}\ \cancel{C_2H_5SH}}{62.14 \cancel{\text{g}}\ \cancel{C_2H_5SH}} \times \frac{4 \cancel{\text{mol}}\ \cancel{CO_2}}{2 \cancel{\text{mol}}\ \cancel{C_2H_5SH}} \times \frac{24.8 \text{ L } CO_2}{1 \cancel{\text{mol}}\ \cancel{CO_2}}$

$v_{CO_2} = 0.798 \text{ L} = 798 \text{ mL}$

The volume of carbon dioxide produced is 798 mL.

$n_{H_2O} = 16.1 \text{ mmol} \times \frac{6}{2}$

$$n_{H_2O} = 48.3 \text{ mmol}$$

or $$v_{H_2O} = 48.3 \text{ }\cancel{\text{mmol}} \times \frac{24.8 \text{ L}}{1 \text{ }\cancel{\text{mol}}}$$

$$v_{H_2O} = 1.20 \times 10^3 \text{ mL} = 1.20 \text{ L}$$

$$v_{H_2O} = 1.00 \text{ }\cancel{\text{g}}\text{ }\cancel{C_2H_5SH} \times \frac{1 \text{ }\cancel{\text{mol}}\text{ }\cancel{C_2H_5SH}}{62.14 \text{ }\cancel{\text{g}}\text{ }\cancel{C_2H_5SH}} \times \frac{6 \text{ }\cancel{\text{mol}}\text{ }\cancel{H_2O}}{2 \text{ }\cancel{\text{mol}}\text{ }\cancel{C_2H_5SH}} \times \frac{24.8 \text{ L } H_2O}{1 \text{ }\cancel{\text{mol}}\text{ }\cancel{H_2O}}$$

$$v_{H_2O} = 1.20 \text{ L}$$

The volume of water vapour produced is 1.20 L.

$$n_{SO_2} = 16.1 \text{ mmol} \times \frac{2}{2}$$

$$n_{SO_2} = 16.1 \text{ mmol}$$

$$v_{SO_2} = 16.1 \text{ m}\cancel{\text{mol}} \times \frac{24.8 \text{ L}}{1 \text{ }\cancel{\text{mol}}}$$

$$v_{SO_2} = 399 \text{ mL}$$

or

$$v_{SO_2} = 1.00 \text{ }\cancel{\text{g}}\text{ }\cancel{C_2H_5SH} \times \frac{1 \text{ }\cancel{\text{mol}}\text{ }\cancel{C_2H_5SH}}{62.14 \text{ }\cancel{\text{g}}\text{ }\cancel{C_2H_5SH}} \times \frac{2 \text{ }\cancel{\text{mol}}\text{ }\cancel{SO_2}}{2 \text{ }\cancel{\text{mol}}\text{ }\cancel{C_2H_5SH}} \times \frac{24.8 \text{ L } SO_2}{1 \text{ }\cancel{\text{mol}}\text{ }\cancel{SO_2}}$$

$$v_{SO_2} = 0.399 \text{ L} = 399 \text{ mL}$$

The volume of sulfur dioxide produced is 399 mL.

(b) Ethanethiol added to natural gas increases safety when the natural gas is used as a heating fuel, since any leak can be detected quickly, before the area becomes an explosion hazard. However, the compound is hazardous to handle in undiluted form before it is mixed with natural gas, and it produces the pollutant sulfur dioxide when burned.

20. A typical answer might include discussion of the production of nitrogen oxides, symbolized NO_X, by heavy vehicle traffic in metropolitan areas. NO_X encourages smog formation, reacting with sunlight and oxygen to cause an increase in ground-level ozone. Ozone, $O_{3(g)}$, is thought to be the primary agent causing smog damage to vegetation, and is a toxic and irritant gas to humans, interfering with lung function.

UNIT 4 PERFORMANCE TASK

Report

The report will require extensive student research, the results of which cannot be simulated here. The report should cover the main points:

- historical development of the technology;
- scientific principles used in the technology, especially those relating to gases;
- risks and benefits (to society and the environment) of use of the technology;
- a summary of a related career.

UNIT 4 REVIEW

(Page 496)

Understanding Concepts

1. (a) The intermolecular forces in solid carbon dioxide must be very weak, because the molecules separate completely at very low temperature.