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

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

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

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

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

The volume of water vapour produced is 1.20 L.

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

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

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

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

or

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

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

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

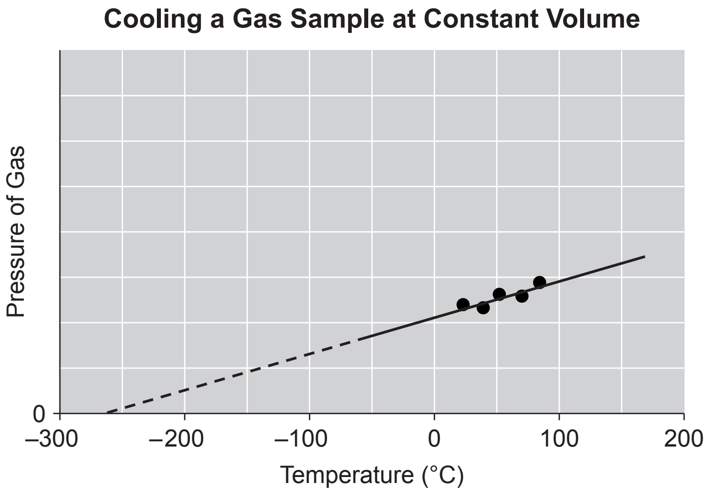
(Page 496)

Understanding Concepts

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

(b) Carbon dioxide gas is highly compressible because there are large spaces between the molecules. In solid carbon dioxide there is negligible space between the molecules.
(c) Molecular disorder is much greater in gaseous carbon dioxide, as the molecules are free to vibrate, rotate, and to move (change location — displace or translate) in any direction. In solid carbon dioxide the molecules can only vibrate in place.
(d) Nitrogen, oxygen, and argon are more abundant in the atmosphere than carbon dioxide.
Note: Question 1(d) assumes "dry" air (dealing only with the constituents that are constantly gaseous, and ignoring water vapour). Water vapour is actually much more abundant than carbon dioxide, even in extremely dry climates.

2. (a) As the temperature of a gas in a sealed, rigid container increases, the pressure increases in direct proportion.
(b) $p = kT$ (n & v constant), or $\frac{p_1}{T_1} = \frac{p_2}{T_2}$ (n & v constant)
(c)



3. Increasing the gas temperature means that the average speed of the molecules increases; so in a sealed, rigid container the gas molecules strike the walls of the container harder, increasing the pressure.
4. (a) Standard temperature is defined as 0°C.
(b) Standard pressure is defined as 101.325 kPa.
(c) Molar volume is the volume occupied by one mole of a gas at a specified temperature and pressure.
(d) The ideal gas is the concept of a gas with absolutely no intermolecular forces, and zero molecular size, that would behave exactly as described by the gas laws.

5. (a) $4.0 \cancel{\text{atm}} \times \frac{101.325 \text{ kPa}}{1 \cancel{\text{atm}}} = 4.1 \times 10^2 \text{ kPa} = 0.41 \text{ MPa}$

The air pressure in the tire is 0.41 MPa.

(b) $763 \cancel{\text{mm Hg}} \times \frac{101.325 \text{ kPa}}{760 \cancel{\text{mm Hg}}} = 102 \text{ kPa.}$

The pressure of argon in the bulb is 102 kPa.

(c) $450 \cancel{\text{atm}} \times \frac{101.325 \text{ kPa}}{1 \cancel{\text{atm}}} = 4.56 \times 10^4 \text{ kPa} = 45.6 \text{ MPa}$

The pressure of ammonia in the vessel is 45.6 MPa.

6. (a) $v_{CO} = 5.1 \text{ L}$

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

$n_{CO} = 5.1 \cancel{\text{L}} \times \frac{1 \text{ mol}}{24.8 \cancel{\text{L}}} = 0.2056451 \text{ mol}$

$n_{CO} = 0.21 \text{ mol}$

The amount of carbon monoxide is 0.21 mol.

(b) $v_{F_2} = 20.7\ mL$

$V_{STP} = 22.4\ L/mol$

$$n_{F_2} = 20.7\ m\cancel{L} \times \frac{1\ mol}{22.4\ \cancel{L}}$$

$$n_{F_2} = 0.924\ mmol$$

The amount of fluorine is 0.924 mol.

(c) $v_{NO_2} = 90\ kL$

$V_{SATP} = 24.8\ L/mol$

$$n_{NO_2} = 90\ k\cancel{L} \times \frac{1\ mol}{24.8\ \cancel{L}}$$

$$n_{NO_2} = 3.6\ kmol$$

The amount of nitrogen dioxide is 3.6 kmol.

7 (a) $n_{H_2} = 500\ mol$

$V_{SATP} = 24.8\ L/mol$

$$n_{H_2} = 500\ \cancel{mol} \times \frac{24.8\ L}{1\ \cancel{mol}}$$

$$n_{H_2} = 1.24 \times 10^4\ L = 12.4\ kL = 12.4\ m^3$$

The volume of hydrogen is 12.4 kL, or 12.4 m^3.

(b) $n_{H_2S} = 56\ kmol$

$V_{SATP} = 24.8\ L/mol$

$$n_{H_2S} = 56\ k\cancel{mol} \times \frac{24.8\ L}{1\ \cancel{mol}}$$

$$n_{H_2S} = 1.4 \times 10^3\ kL = 1.4\ ML$$

The volume of hydrogen sulfide is 1.4 ML.

(c) $n_{Ne} = 45.6\ mmol$

$V_{SATP} = 24.8\ L/mol$

$$n_{Ne} = 45.6\ m\cancel{mol} \times \frac{24.8\ L}{1\ \cancel{mol}}$$

$$n_{Ne} = 1.13 \times 10^3\ mL = 1.13\ L$$

The volume of neon is 1.13 L.

8. $n_{Cl_2} = 26.5\ kmol$

$p = 400\ kPa$

$T = 35°C = 308\ K$

$v = ?$

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

$pv = nRT$

$$v_{Cl_2} = \frac{nRT}{p}$$

$$= \frac{26.5\ k\cancel{mol} \times \frac{8.31\ k\cancel{Pa} \cdot L}{\cancel{mol} \cdot \cancel{K}} \times 308\ \cancel{K}}{400\ k\cancel{Pa}}$$

$$= 170\ kL$$

The volume of chlorine gas is 170 kL, or 170 m^3.

9. $n_{Br_2} = ?$
$p = 60 \text{ kPa}$
$T = 140°C = 413 \text{ K}$
$v = 18.8 \text{ L}$
$R = 8.31 \text{ kPa} \cdot \text{L/(mol} \cdot \text{K)}$

$$pv = nRT$$
$$n_{Br_2} = \frac{pv}{RT}$$
$$= \frac{60 \cancel{\text{kPa}} \times 18.8 \cancel{\text{L}}}{\frac{8.31 \cancel{\text{kPa}} \cdot \cancel{\text{L}}}{\text{mol} \cdot \cancel{\text{K}}} \times 413 \cancel{\text{K}}}$$
$$n_{Br_2} = 0.33 \text{ mol}$$

The amount of bromine is 0.33 mol.

10. $m_{Ar} = 4.2 \text{ kg}$
$V_{SATP} = 24.8 \text{ L/mol}$
$M_{Ar} = 39.95 \text{ g/mol}$
$v_{Ar} = ?$

$$n_{Ar} = 4.2 \text{ k}\cancel{\text{g}} \times \frac{1 \text{ mol}}{39.95 \cancel{\text{g}}}$$
$$n_{Ar} = 0.105 \text{ kmol}$$
$$v_{Ar} = 0.105 \text{ k}\cancel{\text{mol}} \times \frac{24.8 \text{ L}}{1 \cancel{\text{mol}}}$$
$$v_{Ar} = 2.6 \text{ kL}$$

or

$$v_{Ar} = 4.2 \text{ k}\cancel{\text{g}} \times \frac{1 \cancel{\text{mol}}}{39.95 \cancel{\text{g}}} \times \frac{24.8 \text{ L}}{1 \cancel{\text{mol}}}$$
$$v_{Ar} = 2.6 \text{ kL}$$

The volume of argon at SATP would be 2.6 kL, or 2.6 m^3.

11. $v = \text{(assume) } 1.00 \text{ L}$
$p = 100 \text{ kPa}$
$T = 200°C = 473 \text{ K}$
$M_{UF_6} = 352.03 \text{ g/mol}$
$R = 8.31 \text{ kPa} \cdot \text{L/(mol} \cdot \text{K)}$
$m_{UF_6} = ?$

$$pv = nRT$$
$$n_{UF_6} = \frac{pv}{RT}$$
$$= \frac{100 \cancel{\text{kPa}} \times 1.00 \cancel{\text{L}}}{\frac{8.31 \cancel{\text{kPa}} \cdot \cancel{\text{L}}}{\text{mol} \cdot \cancel{\text{K}}} \times 473 \cancel{\text{K}}}$$
$$n_{UF_6} = 0.0254 \text{ mol}$$
$$m_{UF_6} = 0.0254 \cancel{\text{mol}} \times \frac{352.03 \text{ g}}{1 \cancel{\text{mol}}}$$
$$m_{UF_6} = 8.96 \text{ g}$$

The mass of 1L is 8.96 g; therefore, the density of uranium hexafluoride gas is 8.96 g/L at the stated conditions.

12. You should be near the floor to avoid leaking natural gas. Methane molecules have a molar mass much lower than either oxygen or nitrogen, so methane will rise in air.
13. Volume and temperature are directly related for constant pressure and amount of air. Assume the air warms from 25°C (298 K) to 100°C (373 K); then

    the air volume will expand by $\frac{373\ \cancel{K}}{298\ \cancel{K}}$, or about $\frac{5}{4}$, and

    the density will decrease to $\frac{298\ \cancel{K}}{373\ \cancel{K}}$, or about $\frac{4}{5}$ of the original density.

14.

$$
\begin{aligned}
p_1 &= 200 \text{ atm} \\
T_1 &= 23°\text{C} = 296 \text{ K} \\
p_{\text{He}} &= ? \\
T_2 &= -17°\text{C} = 256 \text{ K} \\
\frac{p_1}{T_1} &= \frac{p_2}{T_2} \\
p_{\text{He}} &= \frac{T_2 p_1}{T_1} \\
&= \frac{256\ \cancel{K} \times 200 \text{ atm}}{296\ \cancel{K}} \\
p_{\text{He}} &= 173 \text{ atm}
\end{aligned}
$$

or

$$
\begin{aligned}
p_{\text{He}} &= 200 \text{ atm} \times \frac{256\ \cancel{K}}{296\ \cancel{K}} \\
p_{\text{He}} &= 173 \text{ atm}
\end{aligned}
$$

The final total pressure will be 173 atm.

15.

$$
\begin{aligned}
p_1 &= 100 \text{ kPa} \\
T_1 &= 25°\text{C} = 298 \text{ K} \\
v_1 &= 5.00 \text{ L} \\
p_2 &= 91.5 \text{ kPa} \\
T_2 &= -15°\text{C} = 258 \text{ K} \\
v_{\text{He}} &= ? \\
\frac{p_1 v_1}{T_1} &= \frac{p_2 v_2}{T_2} \\
v_{\text{He}} &= \frac{T_2 p_1 v_1}{T_1 p_2} \\
&= \frac{258\ \cancel{K} \times 100\ \cancel{kPa} \times 5.00 \text{ L}}{298\ \cancel{K} \times 91.5\ \cancel{kPa}} \\
v_{\text{He}} &= 4.73 \text{ L}
\end{aligned}
$$

or

$$
\begin{aligned}
v_{\text{He}} &= 5.00 \text{ L} \times \frac{100\ \cancel{kPa}}{91.5\ \cancel{kPa}} \times \frac{258\ \cancel{K}}{298\ \cancel{K}} \\
v_{\text{He}} &= 4.73 \text{ L}
\end{aligned}
$$

The final volume of helium in the balloon will be 4.73 L.

16. $p_1 = 102$ kPa

$T_1 = –23°C = 250$ K

$v_1 = 1.00\ m^3$

$p_2 = 96$ kPa

$T_2 = 12°C = 285$ K

$v_{air} = ?$

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

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

$$= \frac{285\ \cancel{K} \times 102\ \cancel{kPa} \times 1.00\ m^3}{250\ \cancel{K} \times 96\ \cancel{kPa}}$$

$$v_{air} = 1.2\ m^3$$

or

$$v_{air} = 1.00\ m^3 \times \frac{102\ \cancel{kPa}}{96\ \cancel{kPa}} \times \frac{285\ \cancel{K}}{250\ \cancel{K}}$$

$$v_{air} = 1.2\ m^3$$

The final volume of the air will be $1.2\ m^3$, or 1.2 kL.

17. Warmed air has faster-moving molecules that expand to occupy a larger volume. This makes such air less dense than surrounding air, so it rises, pushed up by the denser air around it.

18. $p_{H_2} = p_{total} - p_{H_2O} = (99.6 – 2.64)$ kPa $= 97.0$ kPa

19. Initial $p_{N_2} = 78\%$ of 100 kPa = 78 kPa; $p_{Ar} = 1\%$ of 100 kPa = 1 kPa.
After reaction, since neither react and the container volume and temperature are constant, these partial pressures are both unchanged.

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

$v \qquad v \qquad 1.00$ L

All gas volumes measured at the same temperature and pressure.

$$v_{NH_3} = 1.00\ L \times \frac{4}{4}$$

$$v_{NH_3} = 1.00\ L$$

or

$$v_{NH_3} = 1.00\ \cancel{L}\ \cancel{NO} \times \frac{4\ L\ NH_3}{4\ \cancel{L}\ \cancel{NO}}$$

$$v_{NH_3} = 1.00\ L$$

The volume of ammonia reacted is 1.00 L.

$$v_{O_2} = 1.00\ L \times \frac{5}{4}$$

$$v_{O_2} = 1.25\ L$$

or

$$v_{O_2} = 1.00\ \cancel{L}\ \cancel{NO} \times \frac{5\ L\ O_2}{4\ \cancel{L}\ \cancel{NO}}$$

$$v_{O_2} = 1.25\ L$$

The volume of oxygen reacted is 1.25 L.

(b) Avogadro's theory states that equal amounts of gases occupy equal volumes at the same temperature and pressure conditions, so the ratio of moles in the equation will be the same as the ratio of volumes measured.

21. $4\ C_3H_5(NO_3)_{3(l)} \rightarrow 12\ CO_{2(g)} + 6\ N_{2(g)} + 10\ H_2O_{(g)} + O_{2(g)}$

100 g $\quad v \quad v \quad v \quad v$

227.11 g/mol $\quad$ All gases: 24.8 L/mol (SATP).

(a) $n_{C_3H_5(NO_3)_3} = 100\ \cancel{g} \times \frac{1\ \text{mol}}{227.11\ \cancel{g}}$

$n_{C_3H_5(NO_3)_3} = 0.440$ mol

(i) $n_{CO_2} = 0.440\ \text{mol} \times \frac{12}{4}$

$n_{CO_2} = 1.32$ mol

$v_{CO_2} = 1.32\ \cancel{\text{mol}} \times \frac{24.8\ \text{L}}{1\ \cancel{\text{mol}}}$

$v_{CO_2} = 32.8$ L

or

$$v_{CO_2} = 100\ \cancel{g}\ C_3H_{\cancel{5}}\cancel{(NO_3)_3} \times \frac{1\ \cancel{\text{mol}}\ C_3H_{\cancel{5}}\cancel{(NO_3)_3}}{} \times \frac{12\ \cancel{\text{mol}}\ \cancel{CO_2}}{} \times \frac{24.8\ \text{L}\ CO_2}{1\ \cancel{\text{mol}}\ \cancel{CO_2}}$$

$v_{CO_2} = 32.8$ L

The volume of carbon dioxide produced is 32.8 L.

(ii) $n_{N_2} = 0.440\ \text{mol} \times \frac{6}{4}$

$n_{N_2} = 0.660$ mol

$v_{N_2} = 0.660\ \cancel{\text{mol}} \times \frac{24.8\ \text{L}}{1\ \cancel{\text{mol}}}$

$v_{N_2} = 16.4$ L

or

$$v_{N_2} = 100\ \cancel{g}\ C_3H_{\cancel{5}}\cancel{(NO_3)_3} \times \frac{1\ \cancel{\text{mol}}\ C_3H_{\cancel{5}}\cancel{(NO_3)_3}}{} \times \frac{6\ \cancel{\text{mol}}\ \cancel{N_2}}{} \times \frac{24.8\ \text{L}\ N_2}{1\ \cancel{\text{mol}}\ \cancel{N_2}}$$

$v_{N_2} = 16.4$ L

The volume of nitrogen produced is 16.4 L.

(iii) $n_{H_2O} = 0.440\ \text{mol} \times \frac{10}{4}$

$n_{H_2O} = 1.10$ mol

$v_{H_2O} = 1.10\ \cancel{\text{mol}} \times \frac{24.8\ \text{L}}{1\ \cancel{\text{mol}}}$

$v_{H_2O} = 27.3$ L

or

$$v_{H_2O} = 100\ \cancel{g}\ C_3H_{\cancel{5}}\cancel{(NO_3)_3} \times \frac{1\ \cancel{\text{mol}}\ C_3H_{\cancel{5}}\cancel{(NO_3)_3}}{} \times \frac{10\ \cancel{\text{mol}}\ \cancel{H_2O}}{4\ \cancel{\text{mol}}\ C_3H_5(\cancel{NO_3})_3} \times \frac{24.8\ \text{L}\ H_2O}{1\ \cancel{\text{mol}}\ \cancel{H_2O}}$$

$v_{H_2O} = 27.3$ L

The volume of water vapour produced is 27.3 L.

(iv) $n_{O_2} = 0.440\ \text{mol} \times \frac{1}{4}$

$n_{O_2} = 0.110 \text{ mol}$

$v_{O_2} = 0.110 \cancel{\text{mol}} \times \dfrac{24.8 \text{ L}}{1 \cancel{\text{mol}}}$

$v_{O_2} = 2.73 \text{ L}$

or

$v_{O_2} = 100 \cancel{\text{g}}\ C_3H_{\cancel{5}}\cancel{(NO_3)_3} \times \dfrac{1 \cancel{\text{mol}}\ C_3H_5\cancel{(NO_3)_3}}{} \times \dfrac{1 \cancel{\text{mol}}\ \cancel{O_2}}{4 \cancel{\text{mol}}\ C_3H_5(\cancel{NO_3})_3} \times \dfrac{24.8 \text{ L } O_2}{1 \cancel{\text{mol}}\ \cancel{O_2}}$

$v_{O_2} = 2.73 \text{ L}$

The volume of oxygen produced is 2.73 L.

(b) The gas volumes will be much greater at much higher temperature, if we assume the amount and pressure remain the same.

(c) $n_{gas} = 3.50 \text{ mol}$

$p_{gas} = ?$

$T = 900°C = 1173 \text{ K}$

$v = 2.00 \text{ L}$

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

$$pv = nRT$$

$$p_{gas} = \frac{nRT}{v}$$

$$= 3.50 \cancel{\text{mol}} \times \frac{8.31 \text{ kPa}\cdot\cancel{\text{L}}}{\cancel{\text{mol}}\cdot\cancel{\text{K}}} \times 1173 \cancel{\text{K}}/2.00 \cancel{\text{L}}$$

$$p_{gas} = 1.71 \times 10^4 \text{ kPa} = 17.1 \text{ MPa}$$

The pressure of the gas products is 17.1 MPa.

22. $2\ NH_{3(g)} + H_2SO_{4(aq)} \rightarrow (NH_4)_2SO_{4(s)}$

84 kL, 12°C = 285 K, 115 kPa $\qquad m$

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

$$pv = nRT$$

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

$$= \frac{115 \cancel{\text{kPa}} \times 84 \text{ k}\cancel{\text{L}}}{\dfrac{8.31 \cancel{\text{kPa}} \cdot \cancel{\text{L}}}{1 \text{ mol} \cdot \cancel{\text{K}}} \times 285 \cancel{\text{K}}}$$

$$n_{NH_3} = 4.1 \text{ kmol}$$

$$n_{(NH_4)_2SO_4} = 4.1 \text{ kmol} \times \frac{1}{2}$$

$$n_{(NH_4)_2SO_4} = 2.0 \text{ kmol}$$

$$m_{(NH_4)_2SO_4} = 2.0 \text{ k}\cancel{\text{mol}} \times \frac{132.16 \text{ g}}{1 \cancel{\text{mol}}}$$

$$m_{(NH_4)_2SO_4} = 2.7 \times 10^2 \text{ kg} = 0.27 \text{ Mg} = 0.27 \text{ t}$$

or

$$m_{(NH_4)_2SO_4} = 84 \text{ k}\cancel{\text{L}}\ \cancel{NH_3} \times \frac{1 \cancel{\text{mol}}\ \cancel{NH_3} \cdot \cancel{\text{K}}}{8.31 \cancel{\text{kPa}} \cdot 1 \cancel{\text{L}}\ \cancel{NH_3}} \times \frac{115 \cancel{\text{kPa}}}{285 \cancel{\text{K}}}$$

$$\text{(continued)} \times \frac{1 \cancel{\text{mol}}\ \cancel{(NH_4)_2SO_4}}{2 \cancel{\text{mol}}\ \cancel{NH_3}} \times \frac{132.16 \text{ g } (NH_4)_2SO_4}{}$$

$m_{(NH_4)_2SO_4} = 2.7 \times 10^2 \text{ kg} = 0.27 \text{ Mg} = 0.27 \text{ t}$

The mass of ammonium sulfate produced is 0.27 Mg, or 0.27 t.

23. **Prediction**

Assume 1 mole $CO_{2(g)}$ (exactly), then v_{SATP} = 24.8 L on Earth.
For average ambient conditions on Venus, the volume will be

$$p_1 = 100 \text{ kPa}$$
$$T_1 = 25°\text{C} = 298 \text{ K}$$
$$v_1 = 24.8 \text{ L}$$
$$p_2 = 7500 \text{ kPa}$$
$$T_2 = 800°\text{C} = 1073 \text{ K}$$
$$v_{CO_2} = ?$$

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$
$$v_{CO_2} = \frac{T_2 p_1 v_1}{T_1 p_2}$$
$$= \frac{1073 \cancel{\text{K}} \times 100 \cancel{\text{kPa}} \times 24.8 \text{ L}}{298 \cancel{\text{K}} \times 7500 \cancel{\text{kPa}}}$$
$$v_{CO_2} = 1.19 \text{ L}$$

or

$$v_{CO_2} = 24.8 \text{ L} \times \frac{100 \cancel{\text{kPa}}}{7500 \cancel{\text{kPa}}} \times \frac{1073 \cancel{\text{K}}}{298 \cancel{\text{K}}}$$
$$v_{CO_2} = 1.19 \text{ L}$$

According to the combined gas law, the molar volume of carbon dioxide gas should be 1.19 L/mol under Venus "standard" conditions.

24. (a) $C_6H_{12}O_{6(s)} + 6\ O_{2(g)} \rightarrow 6\ CO_{2(g)} + 6\ H_2O_{(g)}$

$$\begin{array}{cc} 50 \text{ mL} & v \end{array}$$

All gas volumes measured at the same temperature and pressure.

$$v_{CO_2} = 50 \text{ mL} \times \frac{6}{6}$$
$$v_{CO_2} = 50 \text{ mL}$$

or

$$v_{CO_2} = 50 \text{ m}\cancel{\text{L}}\ \cancel{O_2} \times \frac{6 \text{ L } CO_2}{6 \cancel{\text{L}}\ \cancel{O_2}}$$
$$v_{CO_2} = 50 \text{ mL}$$

The volume of carbon dioxide formed is 50 mL.

(b) Inspection of the equations shows the first reaction produces 6 moles of gas in total (consuming 6 while producing 12); and the second reaction produces only 4 moles of gas — so reaction 1 provides more leavening action for the same amount of glucose reacted.

Note: This assumes that all gaseous substances formed remain in the gas state.

(c) $m_{CO_2} = 1.0 \text{ g}$

$$V_{SATP} = 24.8 \text{ L/mol}$$
$$M_{CO_2} = 44.01 \text{ g/mol}$$
$$v_{CO_2} = ?$$
$$n_{CO_2} = 1.0 \cancel{\text{g}} \times \frac{1 \text{ mol}}{44.01 \cancel{\text{g}}}$$

n_{CO_2} = 0.023 mol

$v_{CO_2} = 0.023\ \cancel{\text{mol}} \times \dfrac{24.8\ \text{L}}{1\ \cancel{\text{mol}}}$

v_{CO_2} = 0.56 L

or

$v_{CO_2} = 1.0\ \cancel{\text{g}} \times \dfrac{1\ \cancel{\text{mol}}}{44.01\ \cancel{\text{g}}} \times \dfrac{24.8\ \text{L}}{1\ \cancel{\text{mol}}}$

v_{CO_2} = 0.56 L

The volume of carbon dioxide at SATP would be 0.56 L.

(d) m_{H_2O} = 1.0 g

M_{H_2O} = 18.02 g/mol

p = 103 kPa

T = 190ºC = 463 K

v = ?

R = 8.31 kPa · L/(mol · K)

$n_{H_2O} = 1.0\ \cancel{\text{g}} \times \dfrac{1\ \text{mol}}{18.02\ \cancel{\text{g}}}$

n_{H_2O} = 0.055 mol

$pv = nRT$

$v_{H_2O} = \dfrac{nRT}{p}$

$$= \frac{0.055\ \cancel{\text{mol}} \times \dfrac{8.31\ \cancel{\text{kPa}} \cdot \text{L}}{\cancel{\text{mol}} \cdot \cancel{\text{K}}} \times 463\ \cancel{\text{K}}}{103\ \cancel{\text{kPa}}}$$

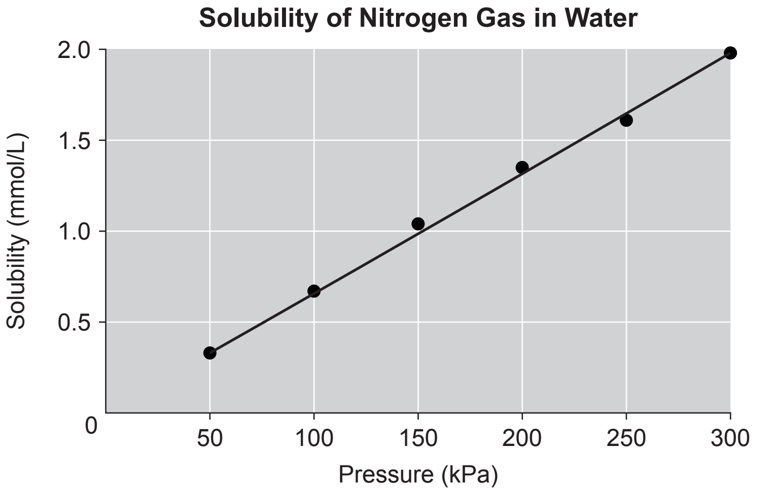
v_{H_2O} = 2.1 L

The volume of water vapour produced is 2.1 L.

Applying Inquiry Skills

25. **Analysis**

(a)



(b) The graph clearly shows that the solubility of nitrogen in water increases with increased pressure.

Synthesis

(c) From the graph, at 300 kPa the solubility is 1.98 mmol/L.

$v_{solution}$ = 5 L (assume an exact value)

$C_{solution}$ = 1.98 mmol/L

$$n_{N_2} = 5\ \cancel{L} \times \frac{1.98\ mmol}{1\ \cancel{L}}$$

$$n_{N_2} = 9.90\ mmol$$

The amount of nitrogen that could dissolve at 300 kPa is 9.90 mmol.

(d) From the graph, at 100 kPa the solubility is 0.67 mmol/L.

The difference in the solubility of nitrogen from 300 kPa to 100 kPa is (1.98 – 0.67)mmol/L = 1.31 mmol/L.

$v_{solution}$ = 5 L (assume an exact value)

$\Delta C_{solution}$ = 1.31 mmol/L

$$\Delta n_{N_2} = 5\ \cancel{L} \times \frac{1.31\ mmol}{1\ \cancel{L}}$$

$$\Delta n_{N_2} = 6.55\ mmol$$

The change in the amount of nitrogen dissolved is 6.55 mmol.

Δn_{N_2} = 6.55 mmol

p = 100 kPa

T = 25ºC = 298 K

v_{N_2} = ?

R = 8.31 kPa · L/(mol · K)

$$pv = nRT$$

$$v_{N_2} = \frac{nRT}{p}$$

$$= \frac{6.55\ m\cancel{mol} \times \dfrac{8.31\ \cancel{kPa} \cdot L}{\cancel{mol} \cdot \cancel{K}} \times 298\ \cancel{K}}{100\ \cancel{kPa}}$$

$$v_{N_2} = 162\ mL$$

The volume of nitrogen gas that will come out of solution is 162 mL.

26. **Analysis**

(a) m_{gas} = (457.64 – 454.26) g = 3.38 g

p_{gas} = (100.1 – 2.64) kPa = 97.5 kPa (corrected for p_{H_2O})

T = 22.0ºC = 295 K

v = 845 mL

M_{gas} = ?

$\underline{R}$ = 8.31 kPa · L/(mol · K)

$$pv = nRT$$

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

$$= \frac{97.5\ \cancel{kPa} \times 845\ m\cancel{L}}{\frac{8.31\ \cancel{kPa} \cdot \cancel{L}}{1\ mol \cdot \cancel{K}} \times 295\ \cancel{K}}$$

$$n_{gas} = 33.6\ mmol = 0.0336\ mol$$

$$M_{gas} = \frac{3.38\ g}{0.0336\ mol}$$

$$M_{gas} = 101\ g/mol$$

According to the ideal gas law, the molar mass of the gas is 101 g/mol; and we conclude that the substance tested must be $C_2H_3F_2Cl_{(g)}$, which has the closest molar mass to this experimental value — 100.50 g/mol.

27. (a) *Note:* While this question asks for yield (volume) of carbon dioxide, the text glossary definition of yield is clearly the *amount* of substance formed.
As well, since the distinction is not clearly emphasized in the question, it seems likely that students may calculate the percentage yield rather than the yield — so all three possible solutions are given here.

Analysis

(i) $p_{CO_2} = (98.5 - 2.81)\ kPa = 95.7\ kPa$ (corrected for p_{H_2O})

According to the evidence, the volume yield of carbon dioxide in this experiment is 748 mL at 23.0°C and 95.7 kPa.

(ii) $n_{CO_2} = ?$

$p = 95.7\ kPa$

$T = 23.0°C = 296\ K$

$v = 748\ mL$

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

$$pv = nRT$$

$$n_{CO_2} = \frac{pv}{RT}$$

$$= \frac{95.7\ \cancel{kPa} \times 748\ m\cancel{L}}{\frac{8.31\ \cancel{kPa} \cdot \cancel{L}}{1\ mol \cdot \cancel{K}} \times 296\ \cancel{K}}$$

$$n_{CO_2} = 29.1\ mmol$$

According to the evidence and the ideal gas law, the yield of carbon dioxide in this experiment is 29.1 mmol.

(iii) $CaCO_{3(s)} + 2\ HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$

3.02 g $\qquad\qquad\qquad\qquad\qquad$ n

100.09 g/mol

$$n_{CaCO_3} = 3.02\ \cancel{g} \times \frac{1\ mol}{100.09\ \cancel{g}}$$

$$n_{CaCO_3} = 0.0302\ mol$$

$$n_{CO_2} = 0.0302\ mol \times \frac{1}{1}$$

$$n_{CO_2} = 0.0302\ mol = 30.2\ mmol$$

or

$$n_{CO_2} = 3.02\ \cancel{g\ CaCO_3} \times \frac{1\ \cancel{mol\ CaCO_3}}{100.09\ \cancel{g\ CaCO_3}} \times \frac{1\ mol\ CO_2}{1\ \cancel{mol\ CaCO_3}}$$

$$n_{CO_2} = 0.0302\ mol = 30.2\ mmol$$

$$\% \text{ yield } CO_2 = \frac{29.1 \cancel{\text{mmol}}(\text{actual})}{30.2 \cancel{\text{mmol}}(\text{theoretical})} \times 100\%$$

$$\% \text{ yield } CO_2 = 96.4\%$$

According to the evidence, the stoichiometric method, and the ideal gas law, the percentage yield of carbon dioxide in this experiment is 96.4%.

28. **Analysis**

(a) $Zn_{(s)} + 2\ HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$

0.29 g $\qquad\qquad\qquad\qquad n$

65.38 g/mol

$$n_{H_2} = ?$$

$$p = (98.7 - 2.34)\ \text{kPa} = 96.4\ \text{kPa}$$

$$T = 19.8°\text{C} = 293\ \text{K}$$

$$v = 94.5\ \text{mL}$$

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

$$pv = nRT$$

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

$$= \frac{96.4\ \cancel{\text{kPa}} \times 94.5\ \text{m}\cancel{\text{L}}}{\frac{8.31\ \cancel{\text{kPa}} \cdot \cancel{\text{L}}}{1\ \text{mol} \cdot \cancel{\text{K}}} \times 293\ \cancel{\text{K}}}$$

$$n_{H_2} = 3.74\ \text{mmol}$$

According to the evidence and the ideal gas law, the yield of hydrogen in this experiment is 3.74 mmol.

$$n_{Zn} = 0.29\ \cancel{\text{g}} \times \frac{1\ \text{mol}}{65.38\ \cancel{\text{g}}}$$

$$n_{Zn} = 0.0044\ \text{mol} = 4.4\ \text{mmol}$$

$$n_{H_2} = 4.4\ \text{mmol} \times \frac{1}{1}$$

$$n_{H_2} = 4.4\ \text{mmol}$$

or

$$n_{H_2} = 0.29\ \cancel{\text{g Zn}} \times \frac{1\ \cancel{\text{mol Zn}}}{65.38\ \cancel{\text{g Zn}}} \times \frac{1\ \text{mol}\ H_2}{1\ \cancel{\text{mol Zn}}}$$

$$n_{H_2} = 0.0302\ \text{mol} = 30.2\ \text{mmol}$$

$$\% \text{ yield } H_2 = \frac{3.74\ \cancel{\text{mmol}}(\text{actual})}{4.4\ \cancel{\text{mmol}}(\text{theoretical})} \times 100\%$$

$$\% \text{ yield } H_2 = 84\%$$

According to the evidence, the ideal gas law, and the stoichiometric method, the percentage yield of $H_{2(g)}$ is 84%.

(b) **Evaluation**

The design of the experiment is judged to be adequate. It is simple and provides evidence that makes it easy to answer the question. The procedure is acceptable, simple to use, and straightforward. The skills of the experimenter should be adequate, as no special skills are required. But the results are not acceptable, because although they provide a clear answer to the question, they vary from the prediction by 16%. Either the stoichiometric method, or the ideal gas law, or the skills of the experimenter in carrying out the procedure must be suspect. Some gas may have escaped, or perhaps the reaction was not truly complete, or the acid was not really in excess.

Applying Inquiry Skills

29. (a) Some criteria used to evaluate an experimental design are: whether it involves (as it should) only one manipulated variable; whether it involves a control (e.g., sample); whether all variables other than the manipulated and responding variables are held constant (controlled); whether the evidence produced is reliable, valid, and simple; whether the results produced are reproducible; whether the experiment is time-efficient while allowing repetition; whether the cost is reasonable; whether the design is the simplest possible to produce the desired evidence; and whether the design is environmentally responsible. (The selection of materials and procedure and the skill of the chemist may also affect the reliability and validity of the evidence.)

(b) The design for the stated experiment is seriously flawed. Ammonia is very soluble in water and so cannot be collected by displacing water. No reliable and valid evidence will be obtained.

(c) The easiest way to improve the design would be to collect the ammonia produced by displacing a liquid in which the ammonia will not dissolve, such as mercury. Any such liquid, however, may require more care because of toxic, corrosive, or flammable hazards; e.g., mercury vapour is toxic.

Making Connections

30.(a) $4\ C_6H_3N_3O_{7(s)} + 25\ O_{2(g)} \rightarrow 24\ CO_{2(g)} + 6\ H_2O_{(g)} + 12\ NO_{2(g)}$

2000 t = 2000 Mg $\quad v \quad v \quad v$

229.12 g/mol (all gases at 100 kPa and 1000°C = 1273 K)

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

$$n_{C_6H_3N_3O_7} = 2000\ \text{M}\cancel{\text{g}} \times \frac{1\ \text{mol}}{229.12\ \cancel{\text{g}}}$$

$$n_{C_6H_3N_3O_7} = 8.73\ \text{Mmol}$$

(i)

$$n_{CO_2} = 8.73\ \text{Mmol} \times \frac{24}{4}$$

$$n_{CO_2} = 52.4\ \text{Mmol}$$

$$pv = nRT$$

$$v_{CO_2} = \frac{nRT}{p}$$

$$= \frac{52.4\ \text{M}\cancel{\text{mol}} \times \frac{8.31\ \cancel{\text{kPa}} \cdot \text{L}}{1\ \cancel{\text{mol}} \cdot \cancel{\text{K}}} \times 1273\ \cancel{\text{K}}}{100\ \cancel{\text{kPa}}}$$

$$v_{CO_2} = 5.54 \times 10^3\ \text{ML} = 5.54\ \text{GL}$$

or

$$v_{CO_2} = 2000\ \text{M}\cancel{\text{g}}\ C_6\cancel{H_3N_3}O_7 \times \frac{1\ \cancel{\text{mol}}\ C_6\cancel{H_3N_3}O_7}{229.12\ \cancel{\text{g}}\ C_6\cancel{H_3N_3}O_7} \times \frac{24\ \cancel{\text{mol}}\ \cancel{CO_2}}{4\ \cancel{\text{mol}}\ C_6\cancel{H_3N_3}O_7}$$

(continued) $$\times \frac{8.31\ \cancel{\text{kPa}} \cdot \text{L}\ CO_2}{1\ \cancel{\text{mol}}\ \cancel{CO_2} \cdot \cancel{\text{K}}} \times \frac{1273\ \cancel{\text{K}}}{100\ \cancel{\text{kPa}}}$$

The volume of carbon dioxide produced is 5.54 GL.

Since temperatures and pressures are equal, the other two gas volumes may now be calculated using the law of combining volumes.

(ii)

$$v_{H_2O} = 5.54\ \text{GL} \times \frac{6}{24}$$

$$v_{H_2O} = 1.39\ \text{L}$$

or

$$v_{H_2O} = 5.54\ \text{G}\cancel{\text{L}}\ \cancel{CO_2} \times \frac{6\ \text{L}\ H_2O}{24\ \cancel{\text{L}}\ \cancel{CO_2}}$$

$$v_{H_2O} = 1.39\ \text{GL}$$

The volume of water vapour produced is 1.39 GL.

(iii) $v_{NO_2} = 5.54 \text{ GL} \times \frac{12}{24}$

$v_{NO_2} = 2.77 \text{ GL}$

or

$$v_{NO_2} = 5.54 \text{ G}\cancel{\text{L}}\ \cancel{\text{CO}_2} \times \frac{12 \text{ L NO}_2}{24\ \cancel{\text{L}}\ \cancel{\text{CO}_2}}$$

$v_{NO_2} = 2.77 \text{ GL}$

The volume of nitrogen dioxide produced is 2.77 GL.

(b) Obviously, any system for transporting highly hazardous material should, if possible, be kept well away from other transport vehicles and areas of high population.

31. The following gases are commonly considered air pollutants: sulfur dioxide, ozone, nitrogen dioxide, and carbon monoxide.
   (a) One harmful effect (of several) of:
      $SO_{2(g)}$ forms acid rain
      $O_{3(g)}$ causes lung damage
      $NO_{2(g)}$ produces smog
      $CO_{(g)}$ highly toxic
   (b) One beneficial use (of several) of:
      $SO_{2(g)}$ chemical production (sulfuric acid, sulfites, etc.)
      $O_{3(g)}$ purifying drinking water
      $NO_{2(g)}$ rocket fuel oxidizer (Space Shuttle)
      $CO_{(g)}$ chemical industry

32. (a) Students can record barometric pressure from a home or school barometer, as well as sources reported in the media.
   (b) In summer, rising pressure usually indicates clear weather, and falling pressure clouds and rain. The more rapid the change, the more likely a dramatic weather change.
   (c) Air is compressed by its own weight, so is at higher pressure the lower the altitude. Air pressure drops on average, by about 11.5 Pa/m, for altitude increases up to 1000 m above sea level.
   (d) Locally reported pressures are adjusted for altitude correction to give the value as though the area were at sea level. This makes "normal" pressure readings approximately the same everywhere.

33. (a) A large amount of methane rising through the ocean would create a large area of bubbles that would not be dense enough to float a ship. Vessels caught in such an area would sink abruptly.
   (b) Methane rising through the atmosphere would create an area of gas much less dense than air. Airplanes caught in such an area would lose lift and would drop in altitude abruptly, crashing if the drop took them down to the surface of the water.

Exploring

34. The report should include interesting points and applications, such as the use of amyl nitrite vapour to reduce blood pressure in 1867, or the discovery that replacing nitrogen with helium makes high-pressure "air" in scuba tanks safer to use.