

- 5.8 For every 10 m of depth that a diver descends in water, they experience an additional 1 atm of pressure due to the weight of the water above her. The pressure regulator used in scuba diving delivers air at a pressure that matches the external pressure; otherwise the diver could not inhale the air. For example, when a diver is at a depth of 20 m below the surface, the regulator delivers air at a pressure of 3 atm to match the 3 atm of pressure around the diver (1 atm due to normal atmospheric pressure and 2 additional atmospheres due to the weight of the water at 20 m). Suppose that a diver inhaled a lungful of air at a pressure of 3 atm and swam quickly to the surface (where the pressure drops to 1 atm) while holding this breath. What would happen to the volume of air in the diver's lungs? Since the pressure decreases by a factor of 3, the volume of the air in the diver's lungs would increase by a factor of 3, severely damaging the diver's lungs and possibly killing the diver.
- 5.9 When we breathe, we expand the volume of our chest cavity, reducing the pressure on the outer surface of the lungs to less than 1 atm (Boyle's law). Because of this pressure differential, the lungs expand, the pressure in them falls, and air from outside our lungs then flows into them. Extra-long snorkels do not work because of the pressure exerted by water at an increased depth. A diver at 10 m experiences an external pressure of 2 atm. This is more than the muscles of the chest cavity can overcome—the chest cavity and lungs are compressed, resulting in an air pressure within them of more than 1 atm. If the diver had a snorkel that went to the surface—where the air pressure is 1 atm—air would flow out of his lungs, not into them. It would be impossible to breathe.
- 5.10 Charles's law explains why a hot-air balloon can take flight. The gas that fills a hot air balloon is warmed with a burner increasing its volume and lowering its density, and causing it to float in the colder, denser surrounding air. Charles's law also explains why the second floor of a house is usually a bit warmer than the ground floor because when air is heated its volume increases, resulting in a lower density. The warm, less dense air tends to rise in a room filled with colder, denser air.
- 5.11 The ideal gas law ($PV = nRT$) combines all of the relationships between the four variables relevant to gases (pressure, volume, number of moles, and temperature (in kelvin's)) in one simple expression.
- 5.12 We know that $V \propto 1/P$ (Boyle's law) $V \propto T$ (Charles's law) $V \propto n$ (Avogadro's law).
Combining these three expressions we get $V \propto nT/P$. Replace the proportional sign with an equal sign by incorporating R (the ideal gas constant) $V = RnT/P$. Rearranging, we get $PV = nRT$.
- 5.13 The molar volume of an ideal gas is the volume occupied by one mole of gas at $T = 0^\circ\text{C}$ (273 K) and $P = 1.00$ atm. Substituting these values into the ideal gas law, one can calculate this value as 22.414 L.
- 5.14 Since $d = \frac{PM}{RT}$ this means that the density will decrease as temperature increases. It will increase as pressure increases or as the molar mass of the gas increases.
- 5.15 The pressure due to any individual component in a gas mixture is called the partial pressure (P_n) of that component and can be calculated from the ideal gas law by assuming that each gas component acts independently. The sum of the partial pressures of the components in a gas mixture must equal the total pressure: $P_{\text{total}} = P_a + P_b + P_c + \dots$ where P_{total} is the total pressure and $P_a, P_b, P_c \dots$ are the partial pressures of the components.
- 5.16 Too much oxygen can also cause physiological problems. Scuba divers breathe pressurized air. At 30 m, a scuba diver breathes air at a total pressure of 4.0 atm, making P_{O_2} about 0.84 atm. This elevated partial pressure of oxygen raises the density of oxygen molecules in the lungs, resulting in a higher concentration of oxygen in body tissues. When P_{O_2} increases beyond 1.4 atm, the increased oxygen concentration in body tissues causes a condition called oxygen toxicity, which results in muscle twitching, tunnel vision, and convulsions.
- 5.17 No, when collecting a gas over water, it will contain some water molecules. The vapor pressure of water can be gotten from Table 5.4. Therefore, $P_{\text{Gas}} = P_{\text{Total}} - P_{\text{H}_2\text{O}}$.
- 5.18 In Chapter 4, we learned how the coefficients in chemical equations can be used as conversion factors between number of moles of reactants and number of moles of products in a chemical reaction; and that the molar mass can be used to convert the number of moles to the mass. At STP, each mole of gas occupies 22.414 L. The mass of the product will be as follows:

$$\text{Volume of limiting reagent (L)} \times \frac{1 \text{ mol limiting reagent}}{22.414 \text{ L}} \times \frac{c \text{ mol product}}{a \text{ mol limiting reagent}} \times \frac{g \text{ product}}{1 \text{ mol product}}$$

for the reaction:

$a A + b B \rightarrow c C + d D$, where A is the limiting reagent and C is the product of interest.

5.19 The basic postulates of kinetic molecular theory are as follows: (1) The size of a particle is negligibly small, (2) the average kinetic energy of a particle is proportional to the temperature in kelvins, and (3) the collision of one particle with another (or with the walls) is completely elastic. Pressure is defined as force divided by area. According to kinetic molecular theory, a gas is a collection of particles in constant motion. The motion results in collisions between the particles and the surfaces around them. As each particle collides with a surface, it exerts a force upon that surface. The result of many particles in a gas sample exerting forces on the surfaces around them is constant pressure.

5.20 Boyle's law states that, for a constant number of particles at constant temperature, the volume of a gas is inversely proportional to its pressure. If you decrease the volume of a gas, you force the gas particles to occupy a smaller space. It follows from kinetic molecular theory that, as long the temperature remains the same, the result is a greater number of collisions with the surrounding surfaces and therefore a greater pressure.

Charles's law states that, for a constant number of particles at constant pressure, the volume of a gas is proportional to its temperature. According to kinetic molecular theory, when you increase the temperature of a gas, the average speed, and thus the average kinetic energy, of the particles increases. Since this greater kinetic energy results in more frequent collisions and more force per collision, the pressure of the gas would increase if its volume were held constant (Gay-Lussac's law). The only way for the pressure to remain constant is for the volume to increase. The greater volume spreads the collisions out over a greater area, so that the pressure (defined as force per unit area) is unchanged.

Avogadro's law states that, at constant temperature and pressure, the volume of a gas is proportional to the number of particles. According to kinetic molecular theory, when you increase the number of particles in a gas sample, the number of collisions with the surrounding surfaces increases. Since the greater number of collisions would result in a greater overall force on surrounding surfaces, the only way for the pressure to remain constant is for the volume to increase so that the number of particles per unit volume (and thus the number of collisions) remains constant.

Dalton's law states that the total pressure of a gas mixture is the sum of the partial pressures of its components. In other words, according to Dalton's law, the components in a gas mixture act identically to, and independently of, one another. According to kinetic molecular theory, the particles have negligible size and they do not interact. Consequently, the only property that would distinguish one type of particle from another is its mass. However, even particles of different masses have the same average kinetic energy at a given temperature, so they exert the same force upon a collision with a surface. Consequently, adding components to a gas mixture—even different *kinds* of gases—has the same effect as simply adding more particles. The partial pressures of all the components sum to the overall pressure.

5.21 Postulate 2 of kinetic molecular theory states that the average kinetic energy is proportional to the temperature in kelvins. The root mean square velocity of a collection of gas particles is inversely proportional to the square root of the molar mass of the particles in kilograms per mole.

5.22 Gaseous particles travel at tremendous speeds along very haphazard paths. To a perfume molecule, the path from the perfume bottle in the bathroom to your nose 2 m away is much like the path through a busy shopping mall during a clearance sale. The molecule travels only a short distance before it collides with another molecule, changes direction, only to collide again, and so on. The average distance that a molecule travels between collisions is called its mean free path.

5.23 The process by which gas molecules spread out in response to a concentration gradient is called diffusion. Effusion is the process by which a gas escapes from a container into a vacuum through a small hole. The rate of effusion is inversely proportional to the square root of the molar mass of the gas.

- 5.24 Gases behave ideally when both of the following are true: (a) The volume of the gas particles is small compared to the space between them; and b) The forces between the gas particles are not significant. At high pressures the number of molecules increases, so the volume of the gas particles becomes larger; and since the spacing between the particles is smaller, the interactions become more significant. At low temperatures, the molecules are not moving as fast as at higher temperatures, so when they collide they have a greater opportunity to interact.
- 5.25 Sulfur oxides (SO_x): Sulfur oxides include SO_2 and SO_3 , which are produced chiefly during coal-fired electricity generation and industrial metal refining. Carbon monoxide (CO): Carbon monoxide is formed by the incomplete combustion of fossil fuels (petroleum, natural gas, and coal). It is emitted mainly by motor vehicles. Nitrogen oxides (NO_x): Nitrogen oxides include NO and NO_2 , which are emitted by motor vehicles, by fossil-fuel based electricity generation plants, and by any high temperature combustion process that occurs in air. Ozone (O_3): Ozone is produced when some of the products of fossil-fuel combustion, especially nitrogen oxides and unburned volatile organic compounds (VOCs), react in the presence of sunlight. The levels of all of these pollutants are decreasing over U.S. cities.
- 5.26 Ground-level ozone (in the lower atmosphere) is an eye and lung irritant and prolonged exposure has been shown to cause permanent lung damage. Stratospheric ozone (in the upper atmosphere) is a natural part of our environment that protects the Earth from harmful ultraviolet light. Stratospheric ozone does not harm us because we are not directly exposed to it.
- 5.27 Chlorofluorocarbons (CFCs) are blamed for destroying stratospheric ozone. When CFCs reach the stratosphere, UV light (which is less abundant below the ozone layer because the ozone absorbs it) breaks a carbon-chlorine bond in the CFC, generating a very reactive chlorine atom. This chlorine atom then reacts with ozone in a cyclic reaction that destroys two ozone molecules and regenerates itself to repeat the process. In this way, a single chlorine atom can destroy hundreds of ozone molecules. Legislation has been passed in many nations calling for a complete ban on CFC production beginning in 1996.
- 5.28 When the sun rises in the Antarctic spring (October), sunlight breaks the relatively weak Cl-Cl bond, releasing chlorine atoms into the stratosphere. The chlorine atoms then deplete ozone through a catalytic cycle. Normally the chlorine that enters our atmosphere from chlorofluorocarbons is neutralized in atmospheric chemical reservoirs. Conditions at the South Pole in the month of October happen to be just right for releasing that chlorine from its reservoirs, allowing it to continue to destroy ozone.

Converting Between Pressure Units

5.29 (a) Given: 24.9 in Hg Find: atm

Conceptual Plan: in Hg \rightarrow atm

$$\text{Solution: } 24.9 \text{ in Hg} \times \frac{1 \text{ atm}}{29.92 \text{ in Hg}} = 0.832 \text{ atm}$$

Check: The units (atm) are correct. The magnitude of the answer (<1) makes physical sense because we started with less than 29.92 in Hg.

(b) Given: 24.9 in Hg Find: mmHg

Conceptual Plan: Use answer from part (a) then convert atm \rightarrow mmHg

$$\text{Solution: } 0.832 \text{ atm} \times \frac{760 \text{ mmHg}}{1 \text{ atm}} = 632 \text{ mmHg}$$

Check: The units (mmHg) are correct. The magnitude of the answer (< 760 mmHg) makes physical sense because we started with less than 1 atm.

(c) Given: 24.9 in Hg Find: psi

Conceptual Plan: Use answer from part (a) then convert atm \rightarrow psi

$$\text{Solution: } 0.832 \text{ atm} \times \frac{14.7 \text{ psi}}{1 \text{ atm}} = 12.2 \text{ psi}$$

Check: The units (mm Hg) are correct. The magnitude of the answer (832 mm Hg) makes physical sense because the mercury column is higher on the right, indicating that the pressure is above barometric pressure. No significant figures to the right of the decimal point can be reported since the mercury height is known only to the 1's place.

- (b) **Given:** $P_{\text{bar}} = 762.4 \text{ mm Hg}$ and figure **Find:** P_{gas}
Conceptual plan: Measure height difference then convert cm Hg \rightarrow mm Hg \rightarrow mm Hg

$$\frac{10 \text{ mm Hg}}{1 \text{ cm Hg}} \quad P_{\text{gas}} = h + P_{\text{bar}}$$

Solution:

$$h = -4.4 \text{ cm Hg} \times \frac{10 \text{ mm Hg}}{1 \text{ cm Hg}} = -44 \text{ mm Hg} \quad P_{\text{gas}} = -44 \text{ mm Hg} + 762.4 \text{ mm Hg} = 718 \text{ mm Hg}$$

Check: The units (mm Hg) are correct. The magnitude of the answer (718 mm Hg) makes physical sense because the mercury column is higher on the left, indicating that the pressure is below barometric pressure. No significant figures to the right of the decimal point can be reported since the mercury height is known only to the 1's place.

- 5.34 (a) **Given:** $P_{\text{bar}} = 751.5 \text{ mm Hg}$ and figure **Find:** P_{gas}
Conceptual plan: Measure height difference then convert cm Hg \rightarrow mm Hg \rightarrow mm Hg

$$\frac{10 \text{ mm Hg}}{1 \text{ cm Hg}} \quad P_{\text{gas}} = h + P_{\text{bar}}$$

Solution:

$$h = -2.2 \text{ cm Hg} \times \frac{10 \text{ mm Hg}}{1 \text{ cm Hg}} = -22 \text{ mm Hg} \quad P_{\text{gas}} = -22 \text{ mm Hg} + 751.5 \text{ mm Hg} = 730. \text{ mm Hg}$$

Check: The units (mm Hg) are correct. The magnitude of the answer (730 mm Hg) makes physical sense because the mercury column is higher on the left, indicating that the pressure is below barometric pressure. No significant figures to the right of the decimal point can be reported since the mercury height is known only to the 1's place.

- (b) **Given:** $P_{\text{bar}} = 751.5 \text{ mm Hg}$ and figure **Find:** P_{gas}
Conceptual plan: Measure height difference then convert cm Hg \rightarrow mm Hg \rightarrow mm Hg

$$\frac{10 \text{ mm Hg}}{1 \text{ cm Hg}} \quad P_{\text{gas}} = h + P_{\text{bar}}$$

Solution:

$$h = 6.8 \text{ cm Hg} \times \frac{10 \text{ mm Hg}}{1 \text{ cm Hg}} = 68 \text{ mm Hg} \quad P_{\text{gas}} = 68 \text{ mm Hg} + 751.5 \text{ mm Hg} = 820. \text{ mm Hg}$$

Check: The units (mm Hg) are correct. The magnitude of the answer (820 mm Hg) makes physical sense because the mercury column is higher on the right, indicating that the pressure is above barometric pressure. No significant figures to the right of the decimal point can be reported since the mercury height is known only to the 1's place.

Simple Gas Laws

- 5.35 **Given:** $V_1 = 5.6 \text{ L}$, $P_1 = 735 \text{ mmHg}$, and $V_2 = 9.4 \text{ L}$ **Find:** P_2

Conceptual Plan: $V_1, P_1, V_2 \rightarrow P_2$
 $P_1 V_1 = P_2 V_2$

Solution:

$P_1 V_1 = P_2 V_2$ Rearrange to solve for P_2 .

$$P_2 = P_1 \frac{V_1}{V_2} = 735 \text{ mmHg} \times \frac{5.6 \text{ L}}{9.4 \text{ L}} = 437.872 \text{ mmHg} = 4.4 \times 10^2 \text{ mmHg}$$

Check: The units (mmHg) are correct. The magnitude of the answer (440 mmHg) makes physical sense because Boyle's Law indicates that as the volume increases, the pressure decreases.

- 5.36 **Given:** $V_1 = 13.9 \text{ L}$, $P_1 = 1.22 \text{ atm}$, and $V_2 = 10.3 \text{ L}$ **Find:** P_2

Conceptual Plan: $V_1, P_1, V_2 \rightarrow P_2$
 $P_1 V_1 = P_2 V_2$

Solution: $P_1 V_1 = P_2 V_2$ Rearrange to solve for P_2 .

$$P_2 = P_1 \frac{V_1}{V_2} = 1.22 \text{ atm} \times \frac{13.9 \text{ L}}{10.3 \text{ L}} = 1.646408 \text{ atm} = 1.65 \text{ atm}$$

Check: The units (atm) are correct. The magnitude of the answer (2 atm) makes physical sense because Boyles Law indicates that as the volume decreases, the pressure increases.

- 5.37 **Given:** $V_1 = 48.3 \text{ mL}$, $T_1 = 22 \text{ }^\circ\text{C}$, and $T_2 = 87 \text{ }^\circ\text{C}$ **Find:** V_2
Conceptual Plan: $^\circ\text{C} \rightarrow \text{K}$ then $V_1, T_1, T_2 \rightarrow V_2$

$$\text{K} = ^\circ\text{C} + 273.15 \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$
Solution: $T_1 = 22 \text{ }^\circ\text{C} + 273.15 = 295 \text{ K}$ and $T_2 = 87 \text{ }^\circ\text{C} + 273.15 = 360 \text{ K}$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
 Rearrange to solve for V_2 . $V_2 = V_1 \frac{T_2}{T_1} = 48.3 \text{ mL} \times \frac{360 \text{ K}}{295 \text{ K}} = 58.9 \text{ mL}$
Check: The units (mL) are correct. The magnitude of the answer (59 mL) makes physical sense because Charles's Law indicates that as the volume increases, the temperature increases.
- 5.38 **Given:** $V_1 = 1.55 \text{ mL}$, $T_1 = 95.3 \text{ }^\circ\text{C}$, and $T_2 = 0.0 \text{ }^\circ\text{C}$ **Find:** V_2
Conceptual Plan: $^\circ\text{C} \rightarrow \text{K}$ then $V_1, T_1, T_2 \rightarrow V_2$

$$\text{K} = ^\circ\text{C} + 273.15 \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$
Solution: $T_1 = 95.3 \text{ }^\circ\text{C} + 273.15 = 368.5 \text{ K}$ and $T_2 = 0.0 \text{ }^\circ\text{C} + 273.15 = 273.2 \text{ K}$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
 Rearrange to solve for V_2 . $V_2 = V_1 \frac{T_2}{T_1} = 1.55 \text{ mL} \times \frac{273.2 \text{ K}}{368.5 \text{ K}} = 1.15 \text{ mL}$
Check: The units (mL) are correct. The magnitude of the answer (1.15 mL) makes physical sense because Charles's Law indicates that as the volume decreases, the temperature decreases.
- 5.39 **Given:** $V_1 = 2.46 \text{ L}$, $n_1 = 0.158 \text{ mol}$, and $\Delta n = 0.113 \text{ mol}$ **Find:** V_2
Conceptual Plan: $n_1 \rightarrow n_2$ then $V_1, n_1, n_2 \rightarrow V_2$

$$n_1 + \Delta n = n_2 \quad \frac{V_1}{n_1} = \frac{V_2}{n_2}$$
Solution: $n_2 = 0.158 \text{ mol} + 0.113 \text{ mol} = 0.271 \text{ mol}$

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$
 Rearrange to solve for V_2 . $V_2 = V_1 \frac{n_2}{n_1} = 2.46 \text{ L} \times \frac{0.271 \text{ mol}}{0.158 \text{ mol}} = 4.21937 \text{ L} = 4.22 \text{ L}$
Check: The units (L) are correct. The magnitude of the answer (4 L) makes physical sense because Avogadro's Law indicates that as the number of moles increases, the volume increases.
- 5.40 **Given:** $V_1 = 253 \text{ mL}$, $n_1 = 0.553 \text{ mol}$, and $\Delta n = 0.365 \text{ mol}$ **Find:** V_2
Conceptual Plan: $n_1 \rightarrow n_2$ then $V_1, n_1, n_2 \rightarrow V_2$

$$n_1 + \Delta n = n_2 \quad \frac{V_1}{n_1} = \frac{V_2}{n_2}$$
Solution: $n_2 = 0.553 \text{ mol} + 0.365 \text{ mol} = 0.918 \text{ mol}$

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$
 Rearrange to solve for V_2 . $V_2 = V_1 \frac{n_2}{n_1} = 253 \text{ mL} \times \frac{0.918 \text{ mol}}{0.553 \text{ mol}} = 419.989 \text{ mL} = 4.20 \times 10^2 \text{ mL}$
Check: The units (mL) are correct. The magnitude of the answer (420 L) makes physical sense because Avogadro's Law indicates that as the number of moles increases, the volume increases.

Ideal Gas Law

- 5.41 **Given:** $n = 0.118 \text{ mol}$, $P = 0.97 \text{ atm}$, and $T = 305 \text{ K}$ **Find:** V

Conceptual Plan: $n, P, T \rightarrow V$

$$PV = nRT$$

Solution: $PV = nRT$ Rearrange to solve for V . $V = \frac{nRT}{P} = \frac{0.118 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 305 \text{ K}}{0.97 \text{ atm}} = 3.0 \text{ L}$

The volume would be the same for argon gas because the ideal gas law does not care about the mass of the gas, only the number of moles of gas.

Check: The units (L) are correct. The magnitude of the answer (3 L) makes sense because, as you will see in the next section, one mole of an ideal gas under standard conditions (273 K and 1 atm) occupies 22.4 L. Although these are not standard conditions, they are close enough for a ballpark check of the answer. Since this gas sample contains 0.118 moles, a volume of 3 L is reasonable.

- 5.42 **Given:** 12.5 g argon or 12.5 g helium, $P = 1.05 \text{ atm}$, and $T = 322 \text{ K}$ **Find:** V

Conceptual Plan: $g \rightarrow n$ then $n, P, T \rightarrow V$

$$\frac{1 \text{ mol}}{39.95 \text{ g}} \text{ or } \frac{1 \text{ mol}}{4.003 \text{ g}} \quad PV = nRT$$

Solution: $12.5 \text{ g Ar} \times \frac{1 \text{ mol Ar}}{39.95 \text{ g Ar}} = 0.3128911 \text{ mol Ar}$ $PV = nRT$ Rearrange to solve for V .

$$V = \frac{nRT}{P} = \frac{0.3128911 \text{ mol Ar} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 322 \text{ K}}{1.05 \text{ atm}} = 7.87 \text{ L Ar}$$

$12.5 \text{ g He} \times \frac{1 \text{ mol He}}{4.003 \text{ g He}} = 3.122658 \text{ mol He}$ $PV = nRT$ Rearrange to solve for V .

$$V = \frac{nRT}{P} = \frac{3.122658 \text{ mol He} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 322 \text{ K}}{1.05 \text{ atm}} = 78.6 \text{ L He}$$

Check: The units (L) are correct. The magnitude of the answer (8 L and 80 L) makes sense because, as you will see in the next section, one mole of an ideal gas under standard conditions (273 K and 1 atm) occupies 22.4 L. Although these are not standard conditions, they are close enough for a ballpark check of the answer. Since the molar mass of the two gases are different by a factor of ten, the resulting volumes will differ by a factor of ten.

5.43

Given: $V = 10.0 \text{ L}$, $n = 0.448 \text{ mol}$, and $T = 315 \text{ K}$ **Find:** P

Conceptual Plan: $n, V, T \rightarrow P$

$$PV = nRT$$

Solution:

$$PV = nRT \text{ Rearrange to solve for } P. P = \frac{nRT}{V} = \frac{0.448 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 315 \text{ K}}{10.0 \text{ L}} = 1.16 \text{ atm}$$

Check: The units (atm) are correct. The magnitude of the answer (~1 atm) makes sense because, as you will see in the next section, one mole of an ideal gas under standard conditions (273 K and 1 atm) occupies 22.4 L. Although these are not standard conditions, they are close enough for a ballpark check of the answer. Since this gas sample contains 0.448 moles in a volume of 10 L, a pressure of 1 atm is reasonable.

5.44

Given: $V = 15.0 \text{ L}$, 32.7 g oxygen, and $T = 302 \text{ K}$ **Find:** P

Conceptual Plan: $g \rightarrow n$ then $n, P, T \rightarrow V$

$$\frac{1 \text{ mol}}{32.00 \text{ g}} \quad PV = nRT$$

Solution: $32.7 \text{ g O}_2 \times \frac{1 \text{ mol O}_2}{32.00 \text{ g O}_2} = 1.021875 \text{ mol O}_2$ $PV = nRT$ Rearrange to solve for P .

$$P = \frac{nRT}{V} = \frac{1.021875 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 302 \text{ K}}{15.0 \text{ L}} = 1.688282 \text{ atm} = 1.69 \text{ atm}$$

Check: The units (atm) are correct. The magnitude of the answer (~1.7 atm) makes sense because, as you will see in the next section, one mole of an ideal gas under standard conditions (273 K and 1 atm) occupies 22.4 L. Although these are not standard conditions, they are close enough for a ballpark check of the answer. Since this gas sample contains ~1 mole in a volume of 15 L, a pressure of 1.7 atm is reasonable.

5.45

Given: $V = 28.5 \text{ L}$, $P = 1.8 \text{ atm}$, and $T = 298 \text{ K}$ **Find:** n

Conceptual Plan: $V, P, T \rightarrow n$

$$PV = nRT$$

$$\text{Solution: } PV = nRT \text{ Rearrange to solve for } n. n = \frac{PV}{RT} = \frac{1.8 \text{ atm} \times 28.5 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298 \text{ K}} = 2.1 \text{ mol}$$

Check: The units (mol) are correct. The magnitude of the answer (2 mol) makes sense because, as you will see in the next section, one mole of an ideal gas under standard conditions (273 K and 1 atm) occupies 22.4 L. Although these are not standard conditions, they are close enough for a ballpark check of the answer. Since this gas sample has a volume of 28.5 L, and a pressure of 1.8 atm, ~2 mol is reasonable.

5.46

Given: $V = 11.8 \text{ L}$, $P = 1.3 \text{ atm}$, and $n = 0.52 \text{ mol}$ **Find:** T

Conceptual Plan: $V, P, n \rightarrow T$

$$PV = nRT$$

Solution: $PV = nRT$ Rearrange to solve for T . $T = \frac{PV}{nR} = \frac{1.3 \text{ atm} \times 11.8 \text{ L}}{0.52 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}} = 360 \text{ K}$

Check: The units (T) are correct. The magnitude of the answer (360 K) makes sense because, as you will see in the next section, one mole of an ideal gas under standard conditions (273 K and 1 atm) occupies 22.4 L. Although these are not standard conditions, they are close enough for a ballpark check of the answer. Since this gas sample has 0.52 mol, a volume of 11.8 L, and a pressure of 1.3 atm, 360 K is reasonable.

5.47 **Given:** $P_1 = 36.0$ psi (gauge P), $V_1 = 11.8$ L, $T_1 = 12.0$ °C, $V_2 = 12.2$ L, and $T_2 = 65.0$ °C

Find: P_2 and compare to $P_{\text{max}} = 38.0$ psi (gauge P)

Conceptual Plan: °C → K and gauge P → psi → atm then $P_1, V_1, T_1, V_2, T_2 \rightarrow P_2$

$$\text{K} = \text{°C} + 273.15 \quad \text{psi} = \text{gauge P} + 14.7 \quad \frac{1 \text{ atm}}{14.7 \text{ psi}} \quad \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Solution: $T_1 = 12.0$ °C + 273.15 = 285.2 K and $T_2 = 65.0$ °C + 273.15 = 338.2 K

$$P_1 = 36.0 \text{ psi (gauge P)} + 14.7 = 50.7 \text{ psi} \times \frac{1 \text{ atm}}{14.7 \text{ psi}} = 3.44898 \text{ atm}$$

$$P_{\text{max}} = 38.0 \text{ psi (gauge P)} + 14.7 = 52.7 \text{ psi} \times \frac{1 \text{ atm}}{14.7 \text{ psi}} = 3.59 \text{ atm}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \text{ Rearrange to solve for } P_2. P_2 = P_1 \frac{V_1}{V_2} \frac{T_2}{T_1} = 3.44898 \text{ atm} \times \frac{11.8 \text{ L}}{12.2 \text{ L}} \times \frac{338.2 \text{ K}}{285.2 \text{ K}} = 3.96 \text{ atm}$$

This exceeds the maximum tire rating of 3.59 atm or 38.0 psi (gauge P).

Check: The units (atm) are correct. The magnitude of the answer (3.95 atm) makes physical sense because the relative increase in T is greater than the relative increase in V , so P should increase.

5.48 **Given:** $P_1 = 748$ mmHg, $V_1 = 28.5$ L, $T_1 = 28.0$ °C, $P_2 = 385$ mmHg, and $T_2 = -15.0$ °C **Find:** V_2

Conceptual Plan: °C → K then $P_1, V_1, T_1, V_2, T_2 \rightarrow P_2$

$$\text{K} = \text{°C} + 273.15 \quad \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Solution: $T_1 = 28.0$ °C + 273.15 = 301.2 K and $T_2 = -15.0$ °C + 273.15 = 258.2 K

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \text{ Rearrange to solve for } V_2. V_2 = V_1 \frac{P_1}{P_2} \frac{T_2}{T_1} = 28.5 \text{ L} \times \frac{748 \text{ mmHg}}{385 \text{ mmHg}} \times \frac{258.2 \text{ K}}{301.2 \text{ K}} = 47.5 \text{ L}$$

Check: The units (L) are correct. The magnitude of the answer (47 L) makes physical sense because the relative decrease in P is greater than the relative decrease in T , so V should increase.

5.49 **Given:** $m(\text{CO}_2) = 28.8$ g, $P = 742$ mmHg, and $T = 22$ °C **Find:** V

Conceptual Plan: °C → K and mmHg → atm and g → mol then $n, P, T \rightarrow V$

$$\text{K} = \text{°C} + 273.15 \quad \frac{1 \text{ atm}}{760 \text{ mmHg}} \quad \frac{1 \text{ mol}}{44.01 \text{ g}} \quad PV = nRT$$

Solution: $T_1 = 22$ °C + 273.15 = 295 K, $P = 742 \text{ mmHg} \times \frac{1 \text{ atm}}{760 \text{ mmHg}} = 0.976316 \text{ atm}$,

$$n = 28.8 \text{ g} \times \frac{1 \text{ mol}}{44.01 \text{ g}} = 0.654397 \text{ mol} \quad PV = nRT \text{ Rearrange to solve for } V.$$

$$V = \frac{nRT}{P} = \frac{0.654397 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 295 \text{ K}}{0.976316 \text{ atm}} = 16.2 \text{ L}$$

Check: The units (L) are correct. The magnitude of the answer (16 L) makes sense because one mole of an ideal gas under standard conditions (273 K and 1 atm) occupies 22.4 L. Although these are not standard conditions, they are close enough for a ballpark check of the answer. Since this gas sample contains 0.65 moles, a volume of 16 L is reasonable.

5.50 **Given:** 1.0 L of liquid N_2 w/d = 0.807 g/mL, $T = 25.0$ °C, $P = 1.0$ atm, and closet is 1.0 m x 1.0 m x 2.0 m

Find: % of closet displaced by evaporated liquid

Conceptual Plan: °C → K and L → mL → g → mol then $n, P, T \rightarrow V_{\text{evap}}$

$$\text{K} = \text{°C} + 273.15 \quad \frac{1000 \text{ mL}}{1 \text{ L}} \quad d = m/V \quad \frac{1 \text{ mol}}{28.02 \text{ g}} \quad PV = nRT$$

then l, w, h → $V_{\text{closet}} \text{ m}^3 \rightarrow \text{cm}^3 \rightarrow \text{L}$ finally $V_{\text{evap}} V_{\text{closet}} \rightarrow \% V$ displaced

$$V = lwh \quad \frac{(100 \text{ cm})^3}{(1 \text{ m})^3} \quad \frac{1 \text{ L}}{1000 \text{ mL}} \quad \% V \text{ displaced} = \frac{V_{\text{evap}}}{V_{\text{closet}}} \times 100\%$$

- 5.63 **Given:** $m = 38.8 \text{ mg}$, $V = 224 \text{ mL}$, $T = 55 \text{ }^\circ\text{C}$, and $P = 886 \text{ torr}$ **Find:** M
Conceptual Plan: $\text{mg} \rightarrow \text{g mL} \rightarrow \text{L }^\circ\text{C} \rightarrow \text{K torr} \rightarrow \text{atm}$ then $V, m \rightarrow d$ then $d, P, T \rightarrow M$
- $$\frac{1 \text{ g}}{1000 \text{ mg}} \quad \frac{1 \text{ L}}{1000 \text{ mL}} \quad \text{K} = ^\circ\text{C} + 273.15 \quad \frac{1 \text{ atm}}{760 \text{ torr}} \quad d = \frac{m}{V} \quad d = \frac{PM}{RT}$$
- Solution:** $m = 38.8 \text{ mg} \times \frac{1 \text{ g}}{1000 \text{ mg}} = 0.0388 \text{ g}$ $V = 224 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.224 \text{ L}$ $T = 55 \text{ }^\circ\text{C} + 273.15 = 328 \text{ K}$
- $$P = 886 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 1.165789 \text{ atm} \quad d = \frac{m}{V} = \frac{0.0388 \text{ g}}{0.224 \text{ L}} = 0.173214 \text{ g/L} \quad d = \frac{PM}{RT}$$
- $$\text{Rearrange to solve for } M. \quad M = \frac{dRT}{P} = \frac{0.173214 \frac{\text{g}}{\text{L}} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{K} \cdot \text{mol}} \times 328 \text{ K}}{1.165789 \text{ atm}} = 4.00 \text{ g/mol}$$
- Check:** The units (g/mol) are correct. The magnitude of the answer (4 g/mol) makes physical sense because this is a reasonable number for a molecular weight of a gas, especially since the density is on the low side.

- 5.64 **Given:** $m = 0.555 \text{ g}$, $V = 117 \text{ mL}$, $T = 85 \text{ }^\circ\text{C}$, and $P = 753 \text{ mmHg}$ **Find:** M
Conceptual Plan: $\text{mL }^\circ\text{C} \rightarrow \text{K mmHg} \rightarrow \text{atm}$ then $V, m \rightarrow d$ then $d, P, T \rightarrow M$
- $$\frac{1 \text{ L}}{1000 \text{ mL}} \quad \text{K} = ^\circ\text{C} + 273.15 \quad \frac{1 \text{ atm}}{760 \text{ mmHg}} \quad d = \frac{m}{V} \quad d = \frac{PM}{RT}$$
- Solution:** $V = 117 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.117 \text{ L}$ $T = 85 \text{ }^\circ\text{C} + 273.15 = 358 \text{ K}$
- $$P = 753 \text{ mmHg} \times \frac{1 \text{ atm}}{760 \text{ mmHg}} = 0.9907895 \text{ atm} \quad d = \frac{m}{V} = \frac{0.555 \text{ g}}{0.117 \text{ L}} = 4.74359 \text{ g/L} \quad d = \frac{PM}{RT}$$
- $$\text{Rearrange to solve for } M. \quad M = \frac{dRT}{P} = \frac{4.74359 \frac{\text{g}}{\text{L}} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{K} \cdot \text{mol}} \times 358 \text{ K}}{0.9907895 \text{ atm}} = 141 \text{ g/mol}$$
- Check:** The units (g/mol) are correct. The magnitude of the answer (141 g/mol) makes physical sense because this is a reasonable number for a molecular weight of a gas, especially since the density is on the high side.

Partial Pressure

- 5.65 **Given:** $P_{\text{N}_2} = 215 \text{ torr}$, $P_{\text{O}_2} = 102 \text{ torr}$, $P_{\text{He}} = 117 \text{ torr}$, $V = 1.35 \text{ L}$, and $T = 25.0 \text{ }^\circ\text{C}$
Find: P_{Total} , m_{N_2} , m_{O_2} , m_{He}
Conceptual Plan: $^\circ\text{C} \rightarrow \text{K and torr} \rightarrow \text{atm}$ and $P, V, T \rightarrow n$ then $\text{mol} \rightarrow \text{g}$
- $$\text{K} = ^\circ\text{C} + 273.15 \quad \frac{1 \text{ atm}}{760 \text{ torr}} \quad PV = nRT \quad M$$
- and $P_{\text{N}_2}, P_{\text{O}_2}, P_{\text{He}} \rightarrow P_{\text{Total}}$
- $$P_{\text{Total}} = P_{\text{N}_2} + P_{\text{O}_2} + P_{\text{He}}$$
- Solution:** $T_1 = 25.0 \text{ }^\circ\text{C} + 273.15 = 298.2 \text{ K}$, $PV = nRT$ Rearrange to solve for n .
- $$n = \frac{PV}{RT} \quad P_{\text{N}_2} = 215 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 0.2828947 \text{ atm} \quad n_{\text{N}_2} = \frac{0.2828947 \text{ atm} \times 1.35 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298.2 \text{ K}} = 0.01560700 \text{ mol}$$
- $$0.01560700 \text{ mol} \times \frac{28.02 \text{ mol}}{1 \text{ mol}} = 0.437 \text{ g N}_2$$
- $$P_{\text{O}_2} = 102 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 0.1342105 \text{ atm} \quad n_{\text{O}_2} = \frac{0.1342105 \text{ atm} \times 1.35 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298.2 \text{ K}} = 0.007404252 \text{ mol}$$
- $$0.007404252 \text{ mol} \times \frac{32.00 \text{ mol}}{1 \text{ mol}} = 0.237 \text{ g O}_2$$
- $$P_{\text{He}} = 117 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 0.1539474 \text{ atm} \quad n_{\text{He}} = \frac{0.1539474 \text{ atm} \times 1.35 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298.2 \text{ K}} = 0.008493113 \text{ mol}$$
- $$0.008493113 \text{ mol} \times \frac{4.003 \text{ mol}}{1 \text{ mol}} = 0.0340 \text{ g He and}$$
- $$P_{\text{Total}} = P_{\text{N}_2} + P_{\text{O}_2} + P_{\text{He}} = 0.283 \text{ atm} + 0.134 \text{ atm} + 0.154 \text{ atm} = 0.571 \text{ atm or}$$
- $$P_{\text{Total}} = P_{\text{N}_2} + P_{\text{O}_2} + P_{\text{He}} = 215 \text{ torr} + 102 \text{ torr} + 117 \text{ torr} = 434 \text{ torr}$$

Check: The units (g and atm) are correct. The magnitude of the answer (1 g) makes sense because gases are not very dense and these pressures are < 1 atm. Since all of the pressures are small, the total is < 1 atm.

5.66 **Given:** $P_{\text{Total}} = 745 \text{ mmHg}$, $P_{\text{CO}_2} = 125 \text{ mmHg}$, $P_{\text{Ar}} = 214 \text{ mmHg}$, $P_{\text{O}_2} = 187 \text{ mmHg}$, $V = 12.0 \text{ L}$, and $T = 273 \text{ K}$
Find: P_{He} and m_{He}

Conceptual Plan: $P_{\text{Total}}, P_{\text{CO}_2}, P_{\text{Ar}}, P_{\text{O}_2} \rightarrow P_{\text{He}}$ then $\text{mmHg} \rightarrow \text{atm}$ then $P, V, T \rightarrow n$ then $\text{mol} \rightarrow \text{g}$

Solution: $P_{\text{Total}} = P_{\text{CO}_2} + P_{\text{Ar}} + P_{\text{O}_2} + P_{\text{He}}$ Rearrange to solve for P_{He} .

$$P_{\text{He}} = P_{\text{Total}} - P_{\text{CO}_2} - P_{\text{Ar}} - P_{\text{O}_2} = 745 \text{ mmHg} - 125 \text{ mmHg} - 214 \text{ mmHg} - 187 \text{ mmHg} = 219 \text{ mmHg}$$

$$P_{\text{He}} = 219 \text{ mmHg} \times \frac{1 \text{ atm}}{760 \text{ mmHg}} = 0.288 \text{ atm} \quad PV = nRT \quad \text{Rearrange to solve for } n. \quad n = \frac{PV}{RT}$$

$$n_{\text{He}} = \frac{0.288 \text{ atm} \times 12.0 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 273 \text{ K}} = 0.1543539 \text{ mol} \quad 0.1543539 \text{ mol} \times \frac{4.003 \text{ g}}{1 \text{ mol}} = 0.618 \text{ g He}$$

Check: The units (g) are correct. The magnitude of the answer (1 g) makes sense because gases are not very dense and these pressures are < 1 atm.

5.67

Given: $m(\text{CO}_2) = 1.20 \text{ g}$, $V = 755 \text{ mL}$, $P_{\text{N}_2} = 725 \text{ mmHg}$, and $T = 25.0 \text{ }^\circ\text{C}$ **Find:** P_{Total}

Conceptual Plan: $\text{mL} \rightarrow \text{L}$ and $^\circ\text{C} \rightarrow \text{K}$ and $\text{g} \rightarrow \text{mol}$ and $n, P, T \rightarrow V$ then $\text{atm} \rightarrow \text{mmHg}$

Solution: $V = 755 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.755 \text{ L}$ $T = 25.0 \text{ }^\circ\text{C} + 273.15 = 298.2 \text{ K}$
 $n = 1.20 \text{ g} \times \frac{1 \text{ mol}}{44.01 \text{ g}} = 0.0272665 \text{ mol}$, $PV = nRT$ Rearrange to solve for P .

$$P = \frac{nRT}{V} = \frac{0.0272665 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298.2 \text{ K}}{0.755 \text{ L}} = 0.883735 \text{ atm}$$

$$P_{\text{CO}_2} = 0.883735 \text{ atm} \times \frac{760 \text{ mmHg}}{1 \text{ atm}} = 672 \text{ mmHg}$$

$$P_{\text{Total}} = P_{\text{CO}_2} + P_{\text{N}_2} = 672 \text{ mmHg} + 725 \text{ mmHg} = 1397 \text{ mmHg} \text{ or } 1397 \text{ Torr} \times \frac{1 \text{ atm}}{760 \text{ Torr}} = 1.84 \text{ atm}$$

Check: The units (mmHg) are correct. The magnitude of the answer (1400 mmHg) makes sense because it must be greater than 725 mmHg.

5.68

Given: $V_{1\text{He}} = 275 \text{ mL}$, $P_{1\text{He}} = 752 \text{ torr}$, $V_{1\text{Ar}} = 475 \text{ mL}$, and $P_{1\text{Ar}} = 722 \text{ torr}$ **Find:** $P_{2\text{He}}$, $P_{2\text{Ar}}$, and P_{Total}

Conceptual Plan: $V_{1\text{He}}, V_{1\text{Ar}} \rightarrow V_2$, $V_1, P_1, V_2 \rightarrow P_2$ then $P_{2\text{He}}, P_{2\text{Ar}} \rightarrow P_{\text{Total}}$

Solution: $V_{1\text{He}} + V_{1\text{Ar}} = V_2 = 275 \text{ mL} + 475 \text{ mL} = 750 \text{ mL}$, $P_1 V_1 = P_2 V_2$ Rearrange to solve for P_2 .

$$P_2 = P_1 \frac{V_1}{V_2} \quad P_{2\text{He}} = P_{1\text{He}} \frac{V_{1\text{He}}}{V_2} = 752 \text{ torr} \times \frac{275 \text{ mL}}{750 \text{ mL}} = 275.733 \text{ torr} = 276 \text{ torr He}$$

$$P_{2\text{Ar}} = P_{1\text{Ar}} \frac{V_{1\text{Ar}}}{V_2} = 722 \text{ torr} \times \frac{475 \text{ mL}}{750 \text{ mL}} = 457.267 \text{ torr} = 457 \text{ torr Ar}$$

$$P_{\text{Total}} = P_{2\text{He}} + P_{2\text{Ar}} = 275.733 \text{ torr} + 457.267 \text{ torr} = 733 \text{ torr total pressure}$$

Check: The units (torr) are correct. The magnitude of the answers makes physical sense because Boyles Law indicates that as the volume increases, the pressure decreases. Since both initial pressures are ~700 torr, the final total pressure should be about the same pressure.

5.69

Given: $m(\text{N}_2) = 1.25 \text{ g}$, $m(\text{O}_2) = 0.85 \text{ g}$, $V = 1.55 \text{ L}$, and $T = 18 \text{ }^\circ\text{C}$ **Find:** χ_{N_2} , χ_{O_2} , P_{N_2} , P_{O_2}

Conceptual Plan: $\text{g} \rightarrow \text{mol}$ then $n_{\text{N}_2}, n_{\text{O}_2} \rightarrow \chi_{\text{N}_2}$ and $n_{\text{N}_2}, n_{\text{O}_2} \rightarrow \chi_{\text{O}_2}$ $^\circ\text{C} \rightarrow \text{K}$

$$\chi_{\text{N}_2} = \frac{n_{\text{N}_2}}{n_{\text{N}_2} + n_{\text{O}_2}} \quad \chi_{\text{O}_2} = \frac{n_{\text{O}_2}}{n_{\text{N}_2} + n_{\text{O}_2}} \quad \text{K} = ^\circ\text{C} + 273.15$$

then $n, V, T \rightarrow P$

$$PV = nRT$$

Solution: $n_{\text{N}_2} = 1.25 \text{ g} \times \frac{1 \text{ mol}}{28.02 \text{ g}} = 0.0446110 \text{ mol}$, $n_{\text{O}_2} = 0.85 \text{ g} \times \frac{1 \text{ mol}}{32.00 \text{ g}} = 0.026563 \text{ mol}$,
 $T = 18^\circ\text{C} + 273.15 = 291 \text{ K}$, $\chi_{\text{N}_2} = \frac{n_{\text{N}_2}}{n_{\text{N}_2} + n_{\text{O}_2}} = \frac{0.0446110 \text{ mol}}{0.0446110 \text{ mol} + 0.026563 \text{ mol}} = 0.626792 = 0.627$,
 $\chi_{\text{O}_2} = \frac{n_{\text{O}_2}}{n_{\text{N}_2} + n_{\text{O}_2}} = \frac{0.026563 \text{ mol}}{0.0446110 \text{ mol} + 0.026563 \text{ mol}} = 0.373212$ We can also calculate this as
 $\chi_{\text{O}_2} = 1 - \chi_{\text{N}_2} = 1 - 0.626792 = 0.373208 = 0.373$ $PV = nRT$ Rearrange to solve for P . $P = \frac{nRT}{V}$
 $P_{\text{N}_2} = \frac{0.044611 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 291 \text{ K}}{1.55 \text{ L}} = 0.687 \text{ atm}$
 $P_{\text{O}_2} = \frac{0.026563 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 291 \text{ K}}{1.55 \text{ L}} = 0.409 \text{ atm}$

The units (none and atm) are correct. The magnitude of the answers makes sense because the mole would total 1 and since the weight of N_2 is greater than O_2 , its mole fraction is larger. The number so we expect the pressures to be $< 1 \text{ atm}$, given the V (1.55 L).

5.70

Given: $m = 10.0 \text{ g}$, $T = 273 \text{ K}$, and $P = 1.00 \text{ atm}$ **Find:** χ_{O_2} and V_{air}
Conceptual Plan: $\chi_{\text{O}_2} \text{ and } \text{g} \rightarrow \text{mol} \rightarrow V_{\text{O}_2} \rightarrow V_{\text{air}}$

$\chi_{\text{O}_2} = 21\% \times \frac{1}{100\%} = 0.21 = \chi_{\text{O}_2}$
 $10.0 \text{ g} \times \frac{1 \text{ mol}}{32.00 \text{ g}} \times \frac{22.414 \text{ L}}{1 \text{ mol}} = 7.00 \text{ L}$ V_{O_2} finally $7.00 \text{ L O}_2 \times \frac{100 \text{ L air}}{21 \text{ L O}_2} = 33 \text{ L air}$

Check: The units (none and L) are correct. The magnitude of the answer (0.21) makes sense because most of air is nitrogen. The magnitude of the answer (33 L) makes sense because one mole of an ideal gas under standard conditions (273 K and 1 atm) occupies 22.4 L and we have about 1/3 mol of O_2 and so over a mole of air.

5.71

Given: $T = 30.0^\circ\text{C}$, $P_{\text{Total}} = 732 \text{ mmHg}$, and $V = 722 \text{ mL}$ **Find:** P_{H_2} and m_{H_2}
Conceptual Plan: $T \rightarrow P_{\text{H}_2\text{O}}$ then $P_{\text{Total}}, P_{\text{H}_2\text{O}} \rightarrow P_{\text{H}_2}$ then $\text{mmHg} \rightarrow \text{atm}$ and $\text{mL} \rightarrow \text{L}$

Table 5.4 $P_{\text{Total}} = P_{\text{H}_2\text{O}} + P_{\text{H}_2}$ $\frac{1 \text{ atm}}{760 \text{ mmHg}}$ $\frac{1 \text{ L}}{1000 \text{ mL}}$
and $^\circ\text{C} \rightarrow \text{K}$, $P, V, T \rightarrow n$ then $\text{mol} \rightarrow \text{g}$
 $\text{K} = ^\circ\text{C} + 273.15$ $PV = nRT$ $\frac{2.016 \text{ g}}{1 \text{ mol}}$

Solution: Table 5.4 states that at 30°C , $P_{\text{H}_2\text{O}} = 31.86 \text{ mmHg}$ $P_{\text{Total}} = P_{\text{H}_2\text{O}} + P_{\text{H}_2}$
Rearrange to solve for P_{H_2} . $P_{\text{H}_2} = P_{\text{Total}} - P_{\text{H}_2\text{O}} = 732 \text{ mmHg} - 31.86 \text{ mmHg} = 700. \text{ mmHg}$
 $P_{\text{H}_2} = 700. \text{ mmHg} \times \frac{1 \text{ atm}}{760 \text{ mmHg}} = 0.921052 \text{ atm}$ $V = 722 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.722 \text{ L}$,

$T = 30.0^\circ\text{C} + 273.15 = 303.2 \text{ K}$, $PV = nRT$ Rearrange to solve for n . $n = \frac{PV}{RT}$

$n_{\text{H}_2} = \frac{0.921052 \text{ atm} \times 0.722 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 303.2 \text{ K}} = 0.0267277 \text{ mol}$ then $0.0267277 \text{ mol} \times \frac{2.016 \text{ g}}{1 \text{ mol}} = 0.0539 \text{ g H}_2$

Check: The units (g) are correct. The magnitude of the answer ($\ll 1 \text{ g}$) makes sense because gases are not very dense, hydrogen is light, the volume is small, and the pressure is $\sim 1 \text{ atm}$.

5.72

Given: $T = 25^\circ\text{C}$, $V = 5.45 \text{ L}$, and $P_{\text{Total}} = 745 \text{ mmHg}$ **Find:** n
Conceptual Plan: $T \rightarrow P_{\text{H}_2\text{O}}$ then $P_{\text{Total}}, P_{\text{H}_2\text{O}} \rightarrow P_{\text{air}}$ then $\text{mmHg} \rightarrow \text{atm}$ and $^\circ\text{C} \rightarrow \text{K}$

Table 5.4 $P_{\text{Total}} = P_{\text{H}_2\text{O}} + P_{\text{air}}$ $\frac{1 \text{ atm}}{760 \text{ mmHg}}$ $\text{K} = ^\circ\text{C} + 273.15$
 $P, V, T \rightarrow n$
 $PV = nRT$

Solution: Table 5.4 states that at 25°C $P_{\text{H}_2\text{O}} = 23.78 \text{ mmHg}$ $P_{\text{Total}} = P_{\text{H}_2\text{O}} + P_{\text{air}}$ Rearrange to solve for P_{air} . $P_{\text{air}} = P_{\text{Total}} - P_{\text{H}_2\text{O}} = 745 \text{ mmHg} - 23.78 \text{ mmHg} = 721 \text{ mmHg}$

$$P_{\text{air}} = 721 \text{ mmHg} \times \frac{1 \text{ atm}}{760 \text{ mmHg}} = 0.948684 \text{ atm} \quad T = 25^\circ\text{C} + 273.15 = 298 \text{ K}, \quad PV = nRT$$

$$\text{Rearrange to solve for } n. \quad n = \frac{PV}{RT} = \frac{0.948684 \text{ atm} \times 5.45 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298 \text{ K}} = 0.211 \text{ mol}$$

Check: The units (mol) are correct. The magnitude of the answer (0.2 mol) makes sense because 22.4 L of a gas at STP contains 1 mol. We have only 5.45 L, so the answer makes sense.

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Given: $T = 25^\circ\text{C}$, $P_{\text{Total}} = 748 \text{ mmHg}$, and $V = 0.951 \text{ L}$ **Find:** P_{H_2} and m_{H_2}

Conceptual Plan: $T \rightarrow P_{\text{H}_2\text{O}}$ then $P_{\text{Total}}, P_{\text{H}_2\text{O}} \rightarrow P_{\text{H}_2}$ then $\text{mmHg} \rightarrow \text{atm}$ and $\text{mL} \rightarrow \text{L}$

$$\text{Table 5.4} \quad P_{\text{Total}} = P_{\text{H}_2\text{O}} + P_{\text{H}_2} \quad \frac{1 \text{ atm}}{760 \text{ mmHg}} \quad \frac{1 \text{ L}}{1000 \text{ mL}}$$

and $^\circ\text{C} \rightarrow \text{K}$, $P, V, T \rightarrow n$ then $\text{mol} \rightarrow \text{g}$

$$\text{K} = ^\circ\text{C} + 273.15 \quad PV = nRT \quad \frac{2.016 \text{ g}}{1 \text{ mol}}$$

Solution: Table 5.4 states that at 25°C , $P_{\text{H}_2\text{O}} = 23.78 \text{ mmHg}$ $P_{\text{Total}} = P_{\text{H}_2\text{O}} + P_{\text{H}_2}$

Rearrange to solve for P_{H_2} , $P_{\text{H}_2} = P_{\text{Total}} - P_{\text{H}_2\text{O}} = 748 \text{ mmHg} - 23.78 \text{ mmHg} = 724 \text{ mmHg}$

$$P_{\text{H}_2} = 724 \text{ mmHg} \times \frac{1 \text{ atm}}{760 \text{ mmHg}} = 0.952632 \text{ atm} \quad T = 25^\circ\text{C} + 273.15 = 298 \text{ K}, \quad PV = nRT$$

$$\text{Rearrange to solve for } n. \quad n_{\text{H}_2} = \frac{PV}{RT} = \frac{0.952632 \text{ atm} \times 0.951 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298 \text{ K}} = 0.0370474 \text{ mol}$$

$$0.0370474 \text{ mol} \times \frac{2.016 \text{ g}}{1 \text{ mol}} = 0.0747 \text{ g H}_2$$

Check: The units (g) are correct. The magnitude of the answer ($\ll 1 \text{ g}$) makes sense because gases are not very dense, hydrogen is light, the volume is small, and the pressure is $\sim 1 \text{ atm}$.

74

Given: $m(\text{O}_2) = 2.0 \text{ g}$, $m(\text{He}) = 98.0 \text{ g}$, $P_{\text{Total}} = 8.5 \text{ atm}$ **Find:** P_{O_2}

Conceptual Plan: $\text{g} \rightarrow \text{mol}$ then $n_{\text{O}_2}, n_{\text{He}} \rightarrow \chi_{\text{O}_2}$ then $\chi_{\text{O}_2}, P_{\text{Total}} \rightarrow P_{\text{O}_2}$

$$\mathcal{M} \quad \chi_{\text{O}_2} = \frac{n_{\text{O}_2}}{n_{\text{O}_2} + n_{\text{He}}} \quad P_{\text{O}_2} = \chi_{\text{O}_2} P_{\text{Total}}$$

$$\text{Solution: } n_{\text{O}_2} = 2.0 \text{ g} \times \frac{1 \text{ mol}}{32.00 \text{ g}} = 0.0625 \text{ mol}, \quad n_{\text{He}} = 98.0 \text{ g} \times \frac{1 \text{ mol}}{4.003 \text{ g}} = 24.4816 \text{ mol},$$

$$\chi_{\text{O}_2} = \frac{n_{\text{O}_2}}{n_{\text{O}_2} + n_{\text{He}}} = \frac{0.0625 \text{ mol}}{0.0625 \text{ mol} + 24.4816 \text{ mol}} = 0.0025464$$

$$P_{\text{O}_2} = \chi_{\text{O}_2} P_{\text{Total}} = 0.0025464 \times 8.5 \text{ atm} = 0.022 \text{ atm}$$

Check: The units (atm) are correct. The magnitude of the answer (0.22 atm) makes sense because, at these depths, high oxygen pressures can cause toxicity.

Reaction Stoichiometry Involving Gases

5.75

Given: $m(\text{C}) = 15.7 \text{ g}$, $P = 1.0 \text{ atm}$, and $T = 355 \text{ K}$ **Find:** V

Conceptual Plan: $\text{g C} \rightarrow \text{mol C} \rightarrow \text{mol H}_2$ then $n(\text{mol H}_2), P, T \rightarrow V$

$$\frac{1 \text{ mol}}{12.01 \text{ g C}} \quad \frac{1 \text{ mol H}_2}{1 \text{ mol C}} \quad PV = nRT$$

$$\text{Solution: } 15.7 \text{ g C} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} \times \frac{1 \text{ mol H}_2}{1 \text{ mol C}} = 1.30724 \text{ mol H}_2, \quad PV = nRT \quad \text{Rearrange to solve for } V.$$

$$V = \frac{nRT}{P} = \frac{1.30724 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 355 \text{ K}}{1.0 \text{ atm}} = 38 \text{ L}$$

Check: The units (L) are correct. The magnitude of the answer (38 L) makes sense because we have more than one mole of gas, and so we expect more than 22 L.

5.76

Given: $V_{\text{O}_2} = 1.4 \text{ L}$, $T = 315 \text{ K}$, $P_{\text{O}_2} = 0.957 \text{ atm}$ **Find:** $\text{g H}_2\text{O}$

Conceptual Plan: $P(\text{mol O}_2), V(\text{mol O}_2), T \rightarrow n(\text{mol O}_2) \rightarrow \text{mol H}_2\text{O} \rightarrow \text{g H}_2\text{O}$

$$PV = nRT \quad \frac{2 \text{ mol H}_2\text{O}}{1 \text{ mol O}_2} \quad \frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}}$$

Solution: $PV = nRT$ Rearrange to solve for n . $n = \frac{PV}{RT} = \frac{0.957 \text{ atm} \times 1.4 \text{ L}}{0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 315 \text{ K}} = 0.051832 \text{ mol O}_2$

$$0.051832 \text{ mol O}_2 \times \frac{2 \text{ mol H}_2\text{O}}{1 \text{ mol O}_2} \times \frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 1.9 \text{ g H}_2\text{O}$$

Check: The units (g) are correct. The magnitude of the answer (2 g) makes sense because we have much less than a mole of oxygen.

5.77

Given: $P = 748 \text{ mmHg}$, $T = 86^\circ\text{C}$, and $m(\text{CH}_3\text{OH}) = 25.8 \text{ g}$, and **Find:** V_{H_2} and V_{CO}

Conceptual Plan: $\text{g CH}_3\text{OH} \rightarrow \text{mol CH}_3\text{OH} \rightarrow \text{mol H}_2$ and $\text{mmHg} \rightarrow \text{atm}$ and $^\circ\text{C} \rightarrow \text{K}$

$$\frac{1 \text{ mol CH}_3\text{OH}}{32.04 \text{ g CH}_3\text{OH}} \quad \frac{2 \text{ mol H}_2}{1 \text{ mol CH}_3\text{OH}} \quad \frac{1 \text{ atm}}{760 \text{ mmHg}} \quad \text{K} = ^\circ\text{C} + 273.15$$

then $n(\text{mol H}_2)$, $P, T \rightarrow V$ and $\text{mol H}_2 \rightarrow \text{mol CO}$ then $n(\text{mol CO})$, $P, T \rightarrow V$

$$PV = nRT \quad \frac{1 \text{ mol CO}}{2 \text{ mol H}_2} \quad PV = nRT$$

Solution: $25.8 \text{ g CH}_3\text{OH} \times \frac{1 \text{ mol CH}_3\text{OH}}{32.04 \text{ g CH}_3\text{OH}} \times \frac{2 \text{ mol H}_2}{1 \text{ mol CH}_3\text{OH}} = 1.61049 \text{ mol H}_2$

$$P_{\text{H}_2} = 748 \text{ mmHg} \times \frac{1 \text{ atm}}{760 \text{ mmHg}} = 0.984211 \text{ atm}, T = 86^\circ\text{C} + 273.15 = 359 \text{ K}, PV = nRT$$

Rearrange to solve for V . $V = \frac{nRT}{P}$ $V_{\text{H}_2} = \frac{1.61049 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 359 \text{ K}}{0.984211 \text{ atm}} = 48.2 \text{ L H}_2$

$$1.61049 \text{ mol H}_2 \times \frac{1 \text{ mol CO}}{2 \text{ mol H}_2} = 0.80525 \text{ mol CO}, V_{\text{CO}} = \frac{0.80525 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 359 \text{ K}}{0.984211 \text{ atm}} = 24.1 \text{ L CO}$$

Check: The units (L) are correct. The magnitude of the answer (48 L and 24 L) makes sense because we have more than one mole of hydrogen gas and half that of CO and so we expect significantly more than 22 L of hydrogen and half that for CO.

5.78

Given: $P = 782 \text{ mmHg}$, $T = 25^\circ\text{C}$, and $m(\text{Al}) = 53.2 \text{ g}$ **Find:** V_{O_2}

Conceptual Plan: $\text{g Al} \rightarrow \text{mol Al} \rightarrow \text{mol O}_2$ and $\text{mmHg} \rightarrow \text{atm}$ and $^\circ\text{C} \rightarrow \text{K}$ then

$$\frac{1 \text{ mol Al}}{26.98 \text{ g Al}} \quad \frac{3 \text{ mol O}_2}{4 \text{ mol Al}} \quad \frac{1 \text{ atm}}{760 \text{ mmHg}} \quad \text{K} = ^\circ\text{C} + 273.15$$

$n(\text{mol O}_2)$, $P, T \rightarrow V$

$$PV = nRT$$

Solution: $53.2 \text{ g Al} \times \frac{1 \text{ mol Al}}{26.98 \text{ g Al}} \times \frac{3 \text{ mol O}_2}{4 \text{ mol Al}} = 1.478873 \text{ mol O}_2$

$$P_{\text{O}_2} = 782 \text{ mmHg} \times \frac{1 \text{ atm}}{760 \text{ mmHg}} = 1.028947 \text{ atm}, T = 25^\circ\text{C} + 273.15 = 298 \text{ K}, PV = nRT$$

Rearrange to solve for V . $V_{\text{O}_2} = \frac{nRT}{P} = \frac{1.478873 \text{ mol} \times 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298 \text{ K}}{1.028947 \text{ atm}} = 35.1 \text{ L O}_2$

Check: The units (L) are correct. The magnitude of the answer (35 L) makes sense because we have more than one mole of oxygen gas and more than 1 atm, so we expect significantly more than 22 L.

5.79

Given: $V = 11.8 \text{ L}$, and STP **Find:** $m(\text{NaN}_3)$

Conceptual Plan: $V_{\text{N}_2} \rightarrow \text{mol N}_2 \rightarrow \text{mol NaN}_3 \rightarrow \text{g NaN}_3$

$$\frac{1 \text{ mol N}_2}{22.414 \text{ L N}_2} \quad \frac{2 \text{ mol NaN}_3}{3 \text{ mol N}_2} \quad \frac{65.03 \text{ g NaN}_3}{1 \text{ mol NaN}_3}$$

Solution: $11.8 \text{ L N}_2 \times \frac{1 \text{ mol N}_2}{22.414 \text{ L N}_2} \times \frac{2 \text{ mol NaN}_3}{3 \text{ mol N}_2} \times \frac{65.03 \text{ g NaN}_3}{1 \text{ mol NaN}_3} = 22.8 \text{ g NaN}_3$

Check: The units (g) are correct. The magnitude of the answer (23 g) makes sense because, we have about a half a mole of nitrogen gas, which translates to even fewer moles of NaN_3 and so we expect significantly less than 65 g.