Pearson

Exercises

Review Questions

1. What are the basic postulates of kinetic molecular theory? How does the concept of pressure follow from kinetic molecular theory?
2. What is pressure? What causes pressure?
3. How does pressure change as a function of altitude?
4. Explain the risks associated with uncontrolled decompression.
5. What are the common units of pressure? List them in order of smallest to largest unit.
6. What is a manometer? How does it measure the pressure of a sample of gas?
7. Summarize each of the simple gas laws (Boyle's law, Charles's law, and Avogadro's law). For each law, explain the relationship between the two variables it addresses and also state which variables must be kept constant.
8. Explain the source of ear pain experienced due to a rapid change in altitude.
9. Why must scuba divers never hold their breath as they ascend to the surface?
10. Why is the second story of a house usually warmer than the ground story?
11. Explain why hot-air balloons float above the ground.
12. What is the ideal gas law? Why is it useful?
13. Explain how the ideal gas law contains within it the simple gas laws (show an example).
14. Define molar volume and give its value for a gas at STP.
15. How does the density of a gas depend on temperature? Pressure? How does it depend on the molar mass of the gas?
16. What is partial pressure? What is the relationship between the partial pressures of each gas in a sample and the total pressure of gas in the sample?
17. Explain how Boyle's law, Charles's law, Avogadro's law, and Dalton's law all follow from kinetic molecular theory.
18. Why do deep-sea divers breathe a mixture of helium and oxygen?
19. When a gas is collected over water, is the gas pure? Why or why not? How can the partial pressure of the collected gas be determined?
20. How is the kinetic energy of a gas related to temperature? How is the root mean square velocity of a gas related to its molar mass?
21. Describe how perfume molecules travel from the bottle to your nose. What is mean free path?
22. Explain the difference between diffusion and effusion. How is the effusion rate of a gas related to its molar mass?
23. If a reaction occurs in the gas phase at STP, the mass of a product can be determined from the volumes of reactants. Explain.
24. Deviations from the ideal gas law are often observed at high pressure and low temperature. Explain this in light of kinetic molecular theory.

Problems by Topic

Note: Answers to all odd-numbered Problems can be found in Appendix III. Exercises in the Problems by Topic section are paired, with each odd-numbered problem followed by a similar even-numbered problem. Exercises in the Cumulative Problems section are also paired but more loosely. Because of their nature, Challenge Problems and Conceptual Problems are unpaired.

Converting between Pressure Units

25. The pressure in Denver, Colorado (elevation 5280 ft or 1600 m), averages about 24.9 in Hg. Convert this

pressure to

a. atm

b. mmHg

c. psi

d. Pa

26. The pressure on top of Mount Everest (29,029 ft or 8848 m) averages about 235 mmHg. Convert this pressure to

a. torr

b. psi

c. in Hg

d. atm

27. The North American record for highest recorded barometric pressure is 31.85 in Hg, set in 1989 in Northway, Alaska. Convert this pressure to:

a. mmHg

b. atm

c. torr

d. kPa (kilopascals)

28. The world record for lowest pressure (at sea level) was 652.5 mmHg recorded inside Typhoon Tip on October 12, 1979, in the western Pacific Ocean. Convert this pressure to:

a. torr

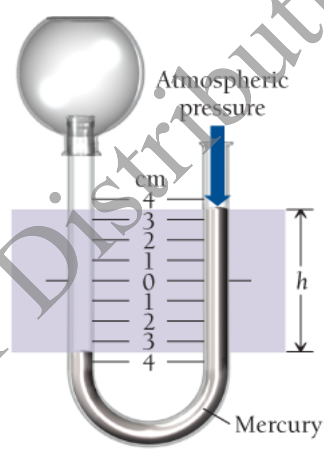
b. atm

c. in Hg

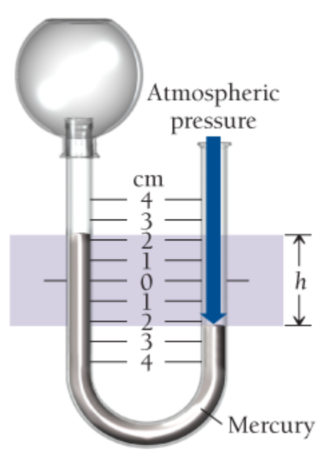
d. psi

29. If the barometric pressure is 762.4 mmHg, what is the pressure of the gas sample shown in each illustration?

a.

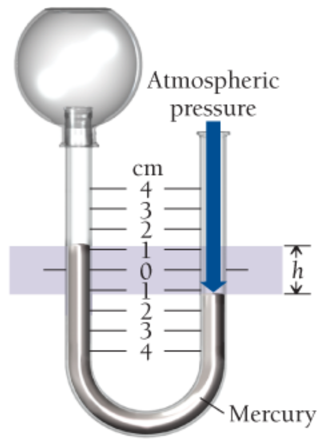


b.

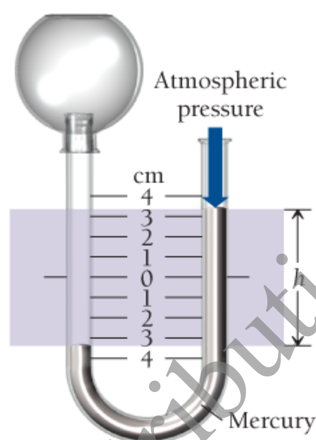


30. If the barometric pressure is 751.5 mmHg, what is the pressure of the gas sample shown in each illustration?

a.



b.



Simple Gas Laws

31. A sample of gas has an initial volume of 5.6 L at a pressure of 735 mmHg. If the volume of the gas is increased to 9.4 L, what is its pressure?

32. A sample of gas has an initial volume of 13.9 L at a pressure of 1.22 atm. If the sample is compressed to a volume of 10.3 L, what is its pressure?

33. A 48.3-mL sample of gas in a cylinder is warmed from 22 °C to 87 °C. What is its volume at the final temperature?

34. A syringe containing 1.55 mL of oxygen gas is cooled from 95.3 °C to 0.0 °C. What is the final volume of oxygen gas?

35. A balloon contains 0.158 mol of gas and has a volume of 2.46 L. If we add 0.113 mol of gas to the balloon (at the same temperature and pressure), what is its final volume?

36. A cylinder with a moveable piston contains 0.553 mol of gas and has a volume of 253 mL. What is its volume if we add 0.365 mol of gas to the cylinder? (Assume constant temperature and pressure.)

Ideal Gas Law

37. What volume does 0.118 mol of helium gas at a pressure of 0.97 atm and a temperature of 305 K occupy? Would the volume be different if the gas was argon (under the same conditions)?

38. What volume does 12.5 g of argon gas at a pressure of 1.05 atm and a temperature of 322 K occupy? Would the volume be different if the sample were 12.5 g of helium (under identical conditions)?

39. What is the pressure in a 10.0-L cylinder filled with 0.448 mol of nitrogen gas at a temperature of 315 K?

40. What is the pressure in a 15.0-L cylinder filled with 32.7 g of oxygen gas at a temperature of 302 K?

41. A cylinder contains 28.5 L of oxygen gas at a pressure of 1.8 atm and a temperature of 298 K. How much gas (in moles) is in the cylinder?

42. What is the temperature of 0.52 mol of gas at a pressure of 1.3 atm and a volume of 11.8 L?

43. An automobile tire has a maximum rating of 38.0 psi (gauge pressure). The tire is inflated (while cold) to a volume of 11.8 L and a gauge pressure of 36.0 psi at a temperature of 12.0 °C. When the car is driven on a hot day, the tire warms to 65.0 °C and its volume expands to 12.2 L. Does the pressure in the tire exceed its maximum rating? (*Note:* The *gauge pressure* is the *difference* between the total pressure and atmospheric pressure. In this case, assume that atmospheric pressure is 14.7 psi.)

44. A weather balloon is inflated to a volume of 28.5 L at a pressure of 748 mmHg and a temperature of 28.0 °C. The balloon rises in the atmosphere to an altitude of approximately 25,000 ft, where the pressure is 385 mmHg and the temperature is −15.0 °C. Assuming the balloon can freely expand, calculate the volume of the balloon at this altitude.

45. A piece of dry ice (solid carbon dioxide) with a mass of 28.8 g sublimes (converts from solid to gas) into a large balloon. Assuming that all of the carbon dioxide ends up in the balloon, what is the volume of the balloon at a temperature of 22 °C and a pressure of 742 mmHg?

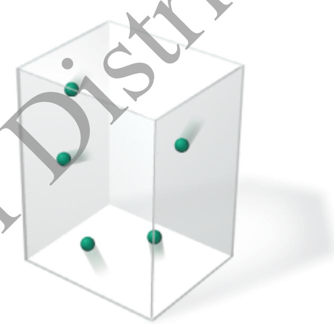
46. A 1.0-L container of liquid nitrogen is kept in a closet measuring 1.0 m by 1.0 m by 2.0 m. Assuming that the container is completely full, that the temperature is 25.0 °C, and that the atmospheric pressure is 1.0 atm, calculate the percent (by volume) of air that is displaced if all of the liquid nitrogen evaporates. (Liquid nitrogen has a density of 0.807 g/mL.)

47. A wine-dispensing system uses argon canisters to pressurize and preserve wine in the bottle. An argon canister for the system has a volume of 55.0 mL and contains 26.0 g of argon. Assuming ideal gas behavior, what is the pressure in the canister at 295 K? When the argon is released from the canister, it expands to fill the wine bottle. How many 750.0-mL wine bottles can be purged with the argon in the canister at a pressure of 1.20 atm and a temperature of 295 K?

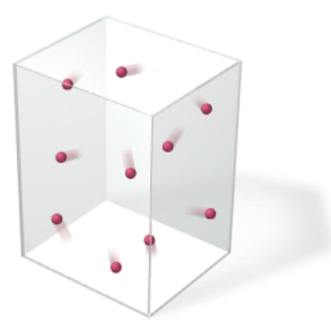
48. Pressurized carbon dioxide inflators can be used to inflate a bicycle tire in the event of a flat. These inflators use metal cartridges that contain 16.0 g of carbon dioxide. At 298 K, to what gauge pressure (in psi) can the carbon dioxide in the cartridge inflate a 3.45-L mountain bike tire? (*Note:* The *gauge pressure* is the *difference* between the total pressure and atmospheric pressure. In this case, assume that atmospheric pressure is 14.7 psi.)

49. Which gas sample illustrated here has the greatest pressure? Assume that all the samples are at the same temperature. Explain.

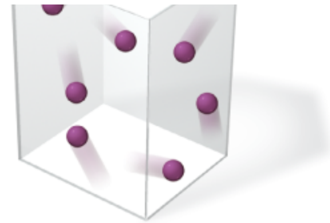
a.



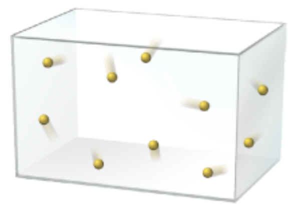
b.



c.



50. This picture represents a sample of gas at a pressure of 1 atm, a volume of 1 L, and a temperature of 25 °C. Draw a similar picture showing what would happen to the sample if the volume were reduced to 0.5 L and the temperature were increased to 250 °C. What would happen to the pressure?



51. Aerosol cans carry clear warnings against incineration because of the high pressures that can develop if they are heated. Suppose that a can contains a residual amount of gas at a pressure of 755 mmHg and a temperature of 25 °C. What would the pressure be if the can were heated to 1155 °C?

52. A sample of nitrogen gas in a 1.75-L container exerts a pressure of 1.35 atm at 25 °C. What is the pressure if the volume of the container is maintained constant and the temperature is raised to 355 °C?

Molar Volume, Density, and Molar Mass of a Gas

53. Use the molar volume of a gas at STP to determine the volume (in L) occupied by 33.6 g of neon at STP.

54. Use the molar volume of a gas at STP to calculate the density (in g/L) of nitrogen gas at STP.

55. What is the density (in g/L) of hydrogen gas at 20.0 °C and a pressure of 1655 psi?

56. A sample of N_2O gas has a density of 2.85 g/L at 298 K. What is the pressure of the gas (in mmHg)?

57. A 248-mL gas sample has a mass of 0.433 g at a pressure of 745 mmHg and a temperature of 28 °C. What is the molar mass of the gas?

58. A 113-mL gas sample has a mass of 0.171 g at a pressure of 721 mmHg and a temperature of 32 °C. What is the molar mass of the gas?

59. A sample of gas has a mass of 38.8 mg. Its volume is 224 mL at a temperature of 55 °C and a pressure of 886 torr. Find the molar mass of the gas.

60. A sample of gas has a mass of 0.555 g. Its volume is 117 mL at a temperature of 85 °C and a pressure of 753 mmHg. Find the molar mass of the gas.

Partial Pressure

61. A gas mixture contains each of these gases at the indicated partial pressures: N_2, 215 torr; O_2, 102 torr; and He, 117 torr. What is the total pressure of the mixture? What mass of each gas is present in a 1.35-L sample of this mixture at 25.0 °C?

62. A gas mixture with a total pressure of 745 mmHg contains each of these gases at the indicated partial pressures: CO_2, 125 mmHg; Ar, 214 mmHg; and O_2, 187 mmHg. The mixture also contains helium gas. What is the partial pressure of the helium gas? What mass of helium gas is present in a 12.0-L sample of this mixture at 273 K?

63. We add a 1.20-g sample of dry ice to a 755-mL flask containing nitrogen gas at a temperature of 25.0 °C and a pressure of 725 mmHg. The dry ice sublimes (converts from solid to gas) and the mixture returns to 25.0 °C. What is the total pressure in the flask?

64. A 275-mL flask contains pure helium at a pressure of 752 torr. A second flask with a volume of 475 mL contains pure argon at a pressure of 722 torr. If the two flasks are connected through a stopcock and the stopcock is opened, what is the partial pressure of each gas and the total pressure?

65. A gas mixture contains 1.25 g N_2 and 0.85 g O_2 in a 1.55-L container at 18 °C. Calculate the mole fraction and partial pressure of each component in the gas mixture.

66. What is the mole fraction of oxygen gas in air (see Table 10.2)? What volume of air contains 10.0 g of oxygen gas at 273 K and 1.00 atm?

67. The hydrogen gas formed in a chemical reaction is collected over water at 30.0 °C at a total pressure of 732 mmHg. What is the partial pressure of the hydrogen gas collected in this way? If the total volume of gas collected is 722 mL, what mass of hydrogen gas is collected?

68. The air in a bicycle tire is bubbled through water and collected at 25 °C. If the total volume of gas collected is 5.45 L at a temperature of 25 °C and a pressure of 745 torr, how many moles of gas were in the bicycle tire?

69. The zinc within a copper-plated penny will dissolve in hydrochloric acid if the copper coating is filed down in several spots (so that the hydrochloric acid can get to the zinc). The reaction between the acid and the zinc is $2\,\mathrm{H}^+(aq) + \mathrm{Zn}(s) \rightarrow \mathrm{H}_2(g) + \mathrm{Zn}^{2+}(aq)$. When the zinc in a certain penny dissolves, the total volume of gas collected over water at 25 °C is 0.951 L at a total pressure of 748 mmHg. What mass of hydrogen gas is collected?

70. A heliox deep-sea diving mixture contains 2.0 g of oxygen to every 98.0 g of helium. What is the partial pressure of oxygen when this mixture is delivered at a total pressure of 8.5 atm?

Molecular Velocities and Effusion

71. Consider a 1.0-L sample of helium gas and a 1.0-L sample of argon gas, both at room temperature and atmospheric pressure.

a. Do the atoms in the helium sample have the same *average kinetic energy* as the atoms in the argon sample?

b. Do the atoms in the helium sample have the same *average velocity* as the atoms in the argon sample?

c. Do the argon atoms, because they are more massive, exert a greater pressure on the walls of the container? Explain.

d. Which gas sample has the faster rate of effusion?

72. A flask at room temperature contains exactly equal amounts (in moles) of nitrogen and xenon.

a. Which of the two gases exerts the greater partial pressure?

b. The molecules or atoms of which gas will have the greater average velocity?

c. The molecules of which gas will have the greater average kinetic energy?

d. If a small hole were opened in the flask, which gas would effuse more quickly?

73. Calculate the root mean square velocity and kinetic energy of F_2, Cl_2, and Br_2 at 298 K. Rank the three halogens with respect to their rate of effusion.

74. Calculate the root mean square velocity and kinetic energy of CO, CO_2, and SO_3 at 298 K. Which gas has the greatest velocity? The greatest kinetic energy? The greatest effusion rate?

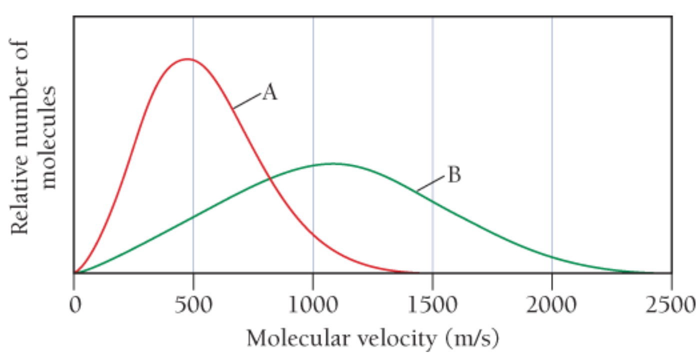
75. We obtain uranium-235 from U-238 by fluorinating the uranium to form UF_6 (which is a gas) and then taking advantage of the different rates of effusion and diffusion for compounds containing the two isotopes. Calculate the ratio of effusion rates for $^{238}\mathrm{UF}_6$ and $^{235}\mathrm{UF}_6$. The atomic mass of U-235 is 235.054 amu, and that of U-238 is 238.051 amu.

76. Calculate the ratio of effusion rates for Ar and Kr.

77. A sample of neon effuses from a container in 76 seconds. The same amount of an unknown noble gas requires 155 seconds. Identify the gas.

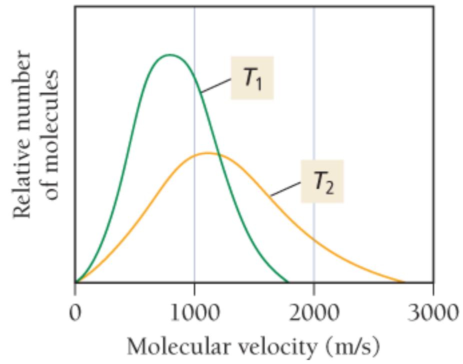
78. A sample of $\mathrm{N}_2\mathrm{O}$ effuses from a container in 42 seconds. How long will it take the same amount of gaseous I_2 to effuse from the same container under identical conditions?

79. This graph shows the distribution of molecular velocities for two different molecules (A and B) at the same temperature. Which molecule has the higher molar mass? Which molecule has the higher rate of effusion?



80. This graph shows the distribution of molecular velocities for the same molecule at two different temperatures (

T_1 and T_2). Which temperature is greater? Explain.



Reaction Stoichiometry Involving Gases

81. Consider the chemical reaction:

$$C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$$

How many liters of hydrogen gas are formed from the complete reaction of 15.7 g C? Assume that the hydrogen gas is collected at a pressure of 1.0 atm and a temperature of 355 K.

82. Consider the chemical reaction:

$$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$$

What mass of H_2O is required to form 1.4 L of O_2 at a temperature of 315 K and a pressure of 0.957 atm?

83. CH_3OH can be synthesized by the reaction:

$$CO(g) + 2\ H_2(g) \rightarrow CH_3OH(g)$$

What volume of H_2 gas (in L), at 748 mmHg and 86 °C, is required to synthesize 25.8 g CH_3OH? How many liters of CO gas, measured under the same conditions, are required?

84. Oxygen gas reacts with powdered aluminum according to the reaction:

$$4\ Al(s) + 3\ O_2(g) \rightarrow 2\ Al_2O_3(s)$$

What volume of O_2 gas (in L), measured at 782 mmHg and 25 °C, completely reacts with 53.2 g Al?

85. Automobile airbags inflate following serious impacts, which trigger the chemical reaction:

$$2\ NaN_3(s) \rightarrow 2\ Na(s) + 3\ N_2(g)$$

If an automobile airbag has a volume of 11.8 L, what mass of NaN_3 (in g) is required to fully inflate the airbag upon impact? Assume STP conditions.

86. Lithium reacts with nitrogen gas according to the reaction:

$$6\ Li(s) + N_2(g) \rightarrow 2\ Li_3N(s)$$

What mass of lithium (in g) reacts completely with 58.5 mL of N_2 gas at STP?

87. Hydrogen gas (a potential future fuel) can be formed by the reaction of methane with water according to the equation:

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3\ H_2(g)$$

In a particular reaction, 25.5 L of methane gas (at a pressure of 732 torr and a temperature of 25 °C) mixes with 22.8 L of water vapor (at a pressure of 702 torr and a temperature of 125 °C). The reaction produces 26.2 L of hydrogen gas at STP. What is the percent yield of the reaction?

88. Ozone is depleted in the stratosphere by chlorine from CF_3Cl according to this set of equations:

$$CF_3Cl + \text{UV light} \quad \rightarrow \quad CF_3 + Cl$$

$$\begin{aligned} \mathrm{Cl} + \mathrm{O_3} &\rightarrow \mathrm{ClO} + \mathrm{O_2} \\ \mathrm{O_3} + \text{UV light} &\rightarrow \mathrm{O_2} + \mathrm{O} \\ \mathrm{ClO} + \mathrm{O} &\rightarrow \mathrm{Cl} + \mathrm{O_2} \end{aligned}$$

What total volume of ozone at a pressure of 25.0 mmHg and a temperature of 225 K is destroyed when all of the chlorine from 15.0 g of CF_3Cl goes through ten cycles of the above reactions?

89. Chlorine gas reacts with fluorine gas to form chlorine trifluoride:

$$\mathrm{Cl_2}\,(g) + 3\ \mathrm{F_2}\,(g) \rightarrow 2\ \mathrm{ClF_3}\,(g)$$

A 2.00-L reaction vessel, initially at 298 K, contains chlorine gas at a partial pressure of 337 mmHg and fluorine gas at a partial pressure of 729 mmHg. Identify the limiting reactant and determine the theoretical yield of ClF_3 in grams.

90. Carbon monoxide gas reacts with hydrogen gas to form methanol:

$$\mathrm{CO}\,(g) + 2\ \mathrm{H_2}\,(g) \rightarrow \mathrm{CH_3OH}\,(g)$$

A 1.50-L reaction vessel, initially at 305 K, contains carbon monoxide gas at a partial pressure of 232 mmHg and hydrogen gas at a partial pressure of 397 mmHg. Identify the limiting reactant and determine the theoretical yield of methanol in grams.

Real Gases

91. Which postulate of the kinetic molecular theory breaks down under conditions of high pressure? Explain.

92. Which postulate of the kinetic molecular theory breaks down under conditions of low temperature? Explain.

93. Use the van der Waals equation and the ideal gas equation to calculate the volume of 1.000 mol of neon at a pressure of 500.0 atm and a temperature of 355.0 K. Explain why the two values are different. (*Hint:* One way to solve the van der Waals equation for *V* is to use successive approximations. Use the ideal gas law to get a preliminary estimate for *V*.)

Cumulative Problems

94. Use the van der Waals equation and the ideal gas equation to calculate the pressure exerted by 1.000 mol of Cl_2 in a volume of 5.000 L at a temperature of 273.0 K. Explain why the two values are different.

95. Pennies that are currently being minted are composed of zinc coated with copper. A student determines the mass of a penny to be 2.482 g and then makes several scratches in the copper coating (to expose the underlying zinc). The student puts the scratched penny in hydrochloric acid, where the following reaction occurs between the zinc and the HCl (the copper remains undissolved):

$$\mathrm{Zn}\,(s) + 2\ \mathrm{HCl}\,(aq) \rightarrow \mathrm{H_2}\,(g) + \mathrm{ZnCl_2}\,(aq)$$

The student collects the hydrogen produced over water at 25 °C. The collected gas occupies a volume of 0.899 L at a total pressure of 791 mmHg. Calculate the percent zinc (by mass) in the penny. (Assume that all the Zn in the penny dissolves.)

96. A 2.85-g sample of an unknown chlorofluorocarbon decomposes and produces 564 mL of chlorine gas at a pressure of 752 mmHg and a temperature of 298 K. What is the percent chlorine (by mass) in the unknown chlorofluorocarbon?

97. The mass of an evacuated 255-mL flask is 143.187 g. The mass of the flask filled with 267 torr of an unknown gas at 25 °C is 143.289 g. Calculate the molar mass of the unknown gas.

98. A 118-mL flask is evacuated and found to have a mass of 97.129 g. When the flask is filled with 768 torr of helium gas at 35 °C, it has a mass of 97.171 g. Is the helium gas pure?

99. A gaseous hydrogen- and carbon-containing compound is decomposed and found to contain 82.66% carbon and 17.34% hydrogen by mass. The mass of 158 mL of the gas, measured at 556 mmHg and 25 °C, is 0.275 g. What is the molecular formula of the compound?

100. A gaseous hydrogen- and carbon-containing compound is decomposed and found to contain 85.63% C and 14.37% H by mass. The mass of 258 mL of the gas, measured at STP, is 0.646 g. What is the molecular formula of the compound?

101. Consider the reaction:

$$2\ \mathrm{NiO}\,(s) \rightarrow 2\ \mathrm{Ni}\,(s) + \mathrm{O_2}\,(g)$$

If O_2 is collected over water at 40.0 °C and a total pressure of 745 mmHg, what volume of gas is collected for the complete reaction of 24.78 g of NiO?

102. Consider the reaction:

$$2\ \mathrm{Ag_2O}\,(s) \rightarrow 4\ \mathrm{Ag}\,(s) + \mathrm{O_2}\,(g)$$

If this reaction produces 15.8 g of Ag(s), what total volume of gas can be collected over water at a temperature of 25 °C and a total pressure of 752 mmHg?

103. When hydrochloric acid is poured over potassium sulfide, 42.9 mL of hydrogen sulfide gas is produced at a pressure of 752 torr and 25.8 °C. Write an equation for the gas-evolution reaction and determine how much potassium sulfide (in grams) reacted.

104. Consider the reaction:

$$2\ \mathrm{SO_2}\,(g) + \mathrm{O_2}\,(g) \rightarrow 2\ \mathrm{SO_3}\,(g)$$

a. If 285.5 mL of SO_2 reacts with 158.9 mL of O_2 (both measured at 315 K and 50.0 mmHg), what is the limiting reactant and the theoretical yield of SO_3?

b. If 187.2 mL of SO_3 is collected (measured at 315 K and 50.0 mmHg), what is the percent yield for the reaction?

105. Ammonium carbonate decomposes upon heating according to the balanced equation:

$$\mathrm{(NH_4)_2CO_3}\,(s) \rightarrow 2\ \mathrm{NH_3}\,(g) + \mathrm{CO_2}\,(g) + \mathrm{H_2O}\,(g)$$

Calculate the total volume of gas produced at 22 °C and 1.02 atm by the complete decomposition of 11.83 g of ammonium carbonate.

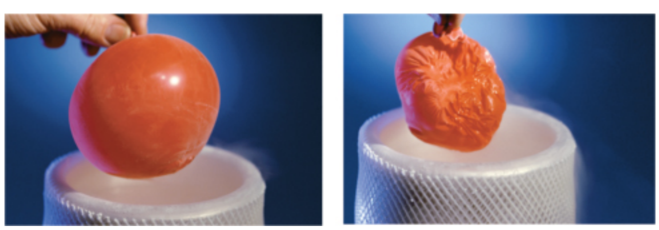
106. Ammonium nitrate decomposes explosively upon heating according to the balanced equation:

$$2\ \mathrm{NH_4NO_3}\,(s) \rightarrow 2\ \mathrm{N_2}\,(g) + \mathrm{O_2}\,(g) + 4\ \mathrm{H_2O}\,(g)$$

Calculate the total volume of gas (at 125 °C and 748 mmHg) produced by the complete decomposition of 1.55 kg of ammonium nitrate.

107. Olympic cyclists fill their tires with helium to make them lighter. Calculate the mass of air in an air-filled tire and the mass of helium in a helium-filled tire. What is the mass difference between the two? Assume that the volume of the tire is 855 mL, that it is filled to a total pressure of 125 psi, and that the temperature is 25 °C. Also, assume an average molar mass for air of 28.8 g/mol.

108. In a common classroom demonstration, a balloon is filled with air and submerged in liquid nitrogen. The balloon contracts as the gases within the balloon cool. Suppose a balloon initially contains 2.95 L of air at a temperature of 25.0 °C and a pressure of 0.998 atm. Calculate the expected volume of the balloon upon cooling to −196 °C (the boiling point of liquid nitrogen). When the demonstration is carried out, the actual volume of the balloon decreases to 0.61 L. How does the observed volume of the balloon compare to your calculated value? Explain the difference.



109. Gaseous ammonia is injected into the exhaust stream of a coal-burning power plant to reduce the pollutant NO to N_2 according to the reaction:

$$4\ \mathrm{NH_3}\,(g) + 4\ \mathrm{NO}\,(g) + \mathrm{O_2}\,(g) \rightarrow 4\ \mathrm{N_2}\,(g) + 6\ \mathrm{H_2O}\,(g)$$

Suppose that the exhaust stream of a power plant has a flow rate of 335 L/s at a temperature of 955 K, and that the exhaust contains a partial pressure of NO of 22.4 torr. What should be the flow rate of ammonia delivered at 755 torr and 298 K into the stream to react completely with the NO if the ammonia is 65.2% pure (by volume)?

110. The emission of NO_2 by fossil fuel combustion can be prevented by injecting gaseous urea into the combustion mixture. The urea reduces NO (which oxidizes in air to form NO_2) according to the reaction:

$$2\ CO(NH_2)_2\,(g) + 4\ NO\,(g) + O_2\,(g) \rightarrow 4\ N_2\,(g) + 2\ CO_2\,(g) + 4\ H_2O\,(g)$$

Suppose that the exhaust stream of an automobile has a flow rate of 2.55 L/s at 655 K and contains a partial pressure of NO of 12.4 torr. What total mass of urea is necessary to react completely with the NO formed during 8.0 hours of driving?

111. An ordinary gasoline can measuring 30.0 cm by 20.0 cm by 15.0 cm is evacuated with a vacuum pump. Assuming that virtually all of the air can be removed from inside the can and that atmospheric pressure is 14.7 psi, what is the total force (in pounds) on the surface of the can? Do you think that the can will withstand the force?

112. Twenty-five milliliters of liquid nitrogen (density $= 0.807$ g/mL) is poured into a cylindrical container with a radius of 10.0 cm and a length of 20.0 cm. The container initially contains only air at a pressure of 760.0 mmHg (atmospheric pressure) and a temperature of 298 K. If the liquid nitrogen completely vaporizes, what is the total force (in lb) on the interior of the container at 298 K?

113. A 160.0-L helium tank contains pure helium at a pressure of 1855 psi and a temperature of 298 K. How many 3.5-L helium balloons will the helium in the tank fill? (Assume an atmospheric pressure of 1.0 atm and a temperature of 298 K.)

114. An 11.5-mL sample of liquid butane (density $= 0.573$ g/mL) is evaporated in an otherwise empty container at a temperature of 28.5 °C. The pressure in the container following evaporation is 892 torr. What is the volume of the container?

115. A scuba diver creates a spherical bubble with a radius of 2.5 cm at a depth of 30.0 m where the total pressure (including atmospheric pressure) is 4.00 atm. What is the radius of the bubble when it reaches the surface of the water? (Assume that the atmospheric pressure is 1.00 atm and the temperature is 298 K.)

116. A particular balloon can be stretched to a maximum surface area of 1257 cm^2. The balloon is filled with 3.0 L of helium gas at a pressure of 755 torr and a temperature of 298 K. The balloon is then allowed to rise in the atmosphere. If the atmospheric temperature is 273 K, at what pressure will the balloon burst? (Assume the balloon is a sphere.)

117. A catalytic converter in an automobile uses a palladium or platinum catalyst (a substance that increases the rate of a reaction without being consumed by the reaction) to convert carbon monoxide gas to carbon dioxide according to the reaction:

$$2\ CO\,(g) + O_2\,(g) \rightarrow 2\ CO_2\,(g)$$

A chemist researching the effectiveness of a new catalyst combines a 2.0 : 1.0 mole ratio mixture of carbon monoxide and oxygen gas (respectively) over the catalyst in a 2.45-L flask at a total pressure of 745 torr and a temperature of 552 °C. When the reaction is complete, the pressure in the flask has dropped to 552 torr. What percentage of the carbon monoxide was converted to carbon dioxide?

118. A quantity of N_2 occupies a volume of 1.0 L at 300 K and 1.0 atm. The gas expands to a volume of 3.0 L as the result of a change in both temperature and pressure. Find the density of the gas at these new conditions.

119. A mixture of CO(*g*) and $O_2\,(g)$ in a 1.0-L container at 1.0×10^3 K has a total pressure of 2.2 atm. After some time the total pressure falls to 1.9 atm as the result of the formation of CO_2. Determine the mass (in grams) of CO_2 that forms.

120. The radius of a xenon atom is 1.3×10^{-8} cm. A 100-mL flask is filled with Xe at a pressure of 1.0 atm and a temperature of 273 K. Calculate the fraction of the volume that is occupied by Xe atoms. (*Hint:* The atoms are spheres.)

121. A natural-gas storage tank is a cylinder with a moveable top whose volume can change only as its height changes. Its radius remains fixed. The height of the cylinder is 22.6 m on a day when the temperature is 22 °C. The next day the height of the cylinder increases to 23.8 m when the gas expands because of a heat wave. Find the temperature on the second day, assuming that the pressure and amount of gas in the storage tank have not changed.

122. A mixture of 8.0 g CH_4 and 8.0 g Xe is placed in a container, and the total pressure is found to be 0.44 atm. Determine the partial pressure of CH_4.

123. A steel container of volume 0.35 L can withstand pressures up to 88 atm before exploding. What mass of helium can be stored in this container at 299 K?

124. Binary compounds of alkali metals and hydrogen react with water to liberate $H_2(g)$. The H_2 from the reaction of a sample of NaH with an excess of water fills a volume of 0.490 L above the water. The temperature of the gas is 35 °C, and the total pressure is 758 mmHg. Determine the mass of H_2 that was liberated and the mass of NaH that reacted.

125. In a given diffusion apparatus, 15.0 mL of HBr gas diffused in 1.0 min. In the same apparatus and under the same conditions, 20.3 mL of an unknown gas diffused in 1.0 min. The unknown gas is a hydrocarbon. Find its molecular formula.

126. A sample of $N_2O_3(g)$ has a pressure of 0.017 atm. The temperature (in K) is doubled, and the N_2O_3 undergoes complete decomposition to $NO_2(g)$ and NO(*g*). Find the total pressure of the mixture of gases assuming constant volume and no additional temperature change.

127. When 0.583 g of neon is added to an 800-cm^3 bulb containing a sample of argon, the total pressure of the gases is 1.17 atm at a temperature of 295 K. Find the mass of the argon in the bulb.

128. A gas mixture composed of helium and argon has a density of 0.670 g/L at 755 mmHg and 298 K. What is the composition of the mixture by volume?

129. A gas mixture contains 75.2% nitrogen and 24.8% krypton by mass. What is the partial pressure of krypton in the mixture if the total pressure is 745 mmHg?

Challenge Problems

130. A 10-L container is filled with 0.10 mol of $H_2(g)$ and heated to 3000 K, causing some of the $H_2(g)$ to decompose into H(*g*). The total pressure is 3.0 atm. Find the partial pressure of the H(*g*) that forms from H_2 at this temperature. (Assume two significant figures for the temperature.)

131. A mixture of $NH_3(g)$ and $N_2H_4(g)$ is placed in a sealed container at 300 K. The total pressure is 0.50 atm. The container is heated to 1200 K, at which time both substances decompose completely according to the equations: $2\ NH_3(g) \rightarrow N_2(g) + 3\ H_2(g)$; $N_2H_4(g) \rightarrow N_2(g) + 2\ H_2(g)$. After decomposition is complete, the total pressure at 1200 K is 4.5 atm. Find the percent of $N_2H_4(g)$ in the original mixture. (Assume two significant figures for the temperature.)

132. A quantity of CO gas occupies a volume of 0.48 L at 1.0 atm and 275 K. The pressure of the gas is lowered and its temperature is raised until its volume is 1.3 L. Determine the density of the CO under the new conditions.

133. When $CO_2(g)$ is put in a sealed container at 701 K and a pressure of 10.0 atm and is heated to 1401 K, the pressure rises to 22.5 atm. Some of the CO_2 decomposes to CO and O_2. Calculate the mole percent of CO_2 that decomposes.

134. The world burns approximately 3.5×10^{12} kg of fossil fuel per year. Use the combustion of octane as the representative reaction and determine the mass of carbon dioxide (the most significant greenhouse gas) formed per year. The current concentration of carbon dioxide in the atmosphere is approximately 394 ppm (by volume). By what percentage does the concentration increase each year due to fossil fuel combustion? Approximate the average properties of the entire atmosphere by assuming that the atmosphere extends from sea level to 15 km and that it has an average pressure of 381 torr and average temperature of 275 K. Assume Earth is a perfect sphere with a radius of 6371 km.

135. The atmosphere slowly oxidizes hydrocarbons in a number of steps that eventually convert the hydrocarbon into carbon dioxide and water. The overall reaction of a number of such steps for methane gas is:

$$CH_4(g) + 5\ O_2(g) + 5\ NO(g) \rightarrow CO_2(g) + H_2O(g) + 5\ NO_2(g) + 2\ OH(g)$$

Suppose that an atmospheric chemist combines 155 mL of methane at STP, 885 mL of oxygen at STP, and 55.5 mL of NO at STP in a 2.0-L flask. The flask stands for several weeks at 275 K. If the reaction reaches 90.0% of completion (90.0% of the limiting reactant is consumed), what is the partial pressure of each of the reactants and products in the flask at 275 K? What is the total pressure in the flask?

136. Two identical balloons are filled to the same volume, one with air and one with helium. The next day, the volume of the air-filled balloon has decreased by 5.0%. By what percent has the volume of the helium-filled balloon decreased? (Assume that the air is four-fifths nitrogen and one-fifth oxygen, and that the temperature did not change.)

137. A mixture of $CH_4(g)$ and $C_2H_6(g)$ has a total pressure of 0.53 atm. Just enough $O_2(g)$ is added to the mixture to bring about its complete combustion to $CO_2(g)$ and $H_2O(g)$. The total pressure of the two product gases is found to be 2.2 atm. Assuming constant volume and temperature, find the mole fraction of CH_4 in the mixture.

138. A sample of $C_2H_2\,(g)$ has a pressure of 7.8 kPa. After some time, a portion of it reacts to form $C_6H_6\,(g)$. The total pressure of the mixture of gases is then 3.9 kPa. Assume the volume and the temperature do not change. What fraction of $C_2H_2\,(g)$ has undergone reaction?

Conceptual Problems

139. When the driver of an automobile applies the brakes, the passengers are pushed toward the front of the car, but a helium balloon is pushed toward the back of the car. Upon forward acceleration, the passengers are pushed toward the back of the car, but the helium balloon is pushed toward the front of the car. Why?

140. Suppose that a liquid is 10 times denser than water. If you were to sip this liquid at sea level using a straw, what is the maximum length your straw can be?

141. The generic reaction occurs in a closed container:

$$\mathrm{A}\,(g) + 2\,\mathrm{B}\,(g) \rightarrow 2\,\mathrm{C}\,(g)$$

A reaction mixture initially contains 1.5 L of A and 2.0 L of B. Assuming that the volume and temperature of the reaction mixture remain constant, what is the percent change in pressure if the reaction goes to completion?

142. One mole of nitrogen and one mole of neon are combined in a closed container at STP. How big is the container?

143. Exactly equal amounts (in moles) of gas A and gas B are combined in a 1-L container at room temperature. Gas B has a molar mass that is twice that of gas A. Which statement is true for the mixture of gases and why?

a. The molecules of gas B have greater kinetic energy than those of gas A.
b. Gas B has a greater partial pressure than gas A.
c. The molecules of gas B have a greater average velocity than those of gas A.
d. Gas B makes a greater contribution to the average density of the mixture than gas A.

144. Which gas would you expect to deviate most from ideal behavior under conditions of low temperature: F_2, Cl_2, or Br_2? Explain.

145. The volume of a sample of a fixed amount of gas is decreased from 2.0 L to 1.0 L. The temperature of the gas in kelvins is then doubled. What is the final pressure of the gas in terms of the initial pressure?

146. Which gas sample has the greatest volume at STP?

a. 10.0 g Kr
b. 10.0 g Xe
c. 10.0 g He

147. Draw a depiction of a gas sample, as described by kinetic molecular theory, containing equal molar amounts of helium, neon, and krypton. Use different color dots to represent each element. Give each atom a "tail" to represent its velocity relative to the others in the mixture.

Questions for Group Work

Active Classroom Learning

Discuss these questions with the group and record your consensus answer.

148. Assign one of the three simple gas laws to each member of your group. For the assigned gas law, have each member write two equations, draw a graph, and describe it in a complete sentence. Have each group member present his or her law to the group.

149. Review the ideal gas law. Without referring back to the text, use algebra to write the ideal gas law and solve for each of the individual variables it contains. Have each group member solve for a different variable and present answers to the group.

150. Hydrogen peroxide (H_2O_2) decomposes in the presence of a catalyst to form water and oxygen. The catalyst is added to 5.00 mL of a hydrogen peroxide solution at 25.0 °C, and 49.5 mL of gas is collected over water at a total pressure of 763.8 mmHg.

a. Write and balance the chemical reaction. (*Note:* catalysts do not appear in balanced chemical equations.)
b. Look up the vapor pressure of water under these conditions.

b. Look up the vapor pressure of water under these conditions.

c. What is the partial pressure of oxygen collected over the water?

d. How many moles of oxygen are collected?

e. How many grams of hydrogen peroxide were in the original sample?

f. What is the concentration (in mol/L) of the hydrogen peroxide solution?

g. Which part of this process is conceptually most difficult for your group?

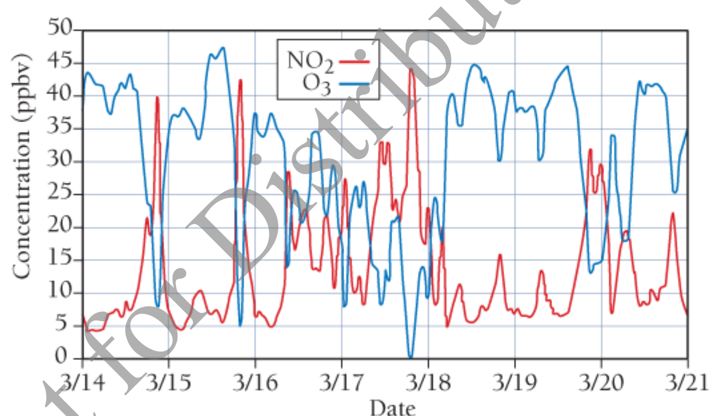
151. A box contains equal amounts of helium, argon, and krypton (all gases) at 25 °C. Using complete sentences, describe the temperatures, masses, average velocities, and average kinetic energy of the three kinds of gas in the mixture. What do they have in common? What are the differences? How are these properties related?

152. Calculate the pressure exerted by 1 mol of an ideal gas in a box that is 0.500 L and at 298 K. Have each group member calculate the pressure of 1 mol of the following real gases in the same box at the same temperature: He, Ne, H_2, CH_4, and CO_2 using the van der Waals equation. Compare group members′ answers and compare all answers with the pressure of an ideal gas. Assuming that the van der Waals equation predictions are accurate, account for why the pressure of each gas is higher or lower than that predicted for an ideal gas.

Data Interpretation and Analysis

153. When fuels are burned in air, such as in an automobile engine, some of the nitrogen in the air oxidizes to form nitrogen oxide gases such as NO and NO_2 (known collectively as NO_x). The U.S. Environmental Protection Agencey (EPA) sets standards for air quality of several pollutants including NO_2. According to the EPA, NO_2 levels in U.S. cities are not to exceed a yearly average of 53 ppb or a 1-hour average of 100 ppb. Another pollutant associated with automobile exhaust is ozone (O_3). The EPA standard for ozone is an 8-hour average of 70 ppb. Breathing air with elevated levels of NO_2 or O_3 can cause asthma and other respiratory problems. The graph shows the average concentration of nitrogen dioxide (NO_2) and ozone (O_3) gases in units of parts per billion by volume (ppbv) over seven days in a large city.

Study the graph and answer the following questions:



Concentration of NO_2 and O_3 over Seven Days

Source: http://www.cas.manchester.ac.uk/resprojects/holmemoss/results/fig2/

a. What type of relationship exists between nitrogen dioxide and ozone between March 14 and March 16?

b. Calculate the number of moles of NO_2 in 1.00 m^3 produced on March 14. Assume an average temperature of 25.0 °C and a pressure of 1 atm. Note that the number of moles of NO_2 produced is the difference between the existing amount at the start of the day and the peak amount.

c. Calculate the number of moles of O_3 in 1.00 m^3 consumed on March 14. Assume an average temperature of 25.0 °C and a pressure of 1 atm. Note that the number of moles of O_3 consumed is the difference between the existing amount at the start of the day and the minimum amount.

d. What is the mole-to-mole ratio of O_3 consumed to NO_2 produced?

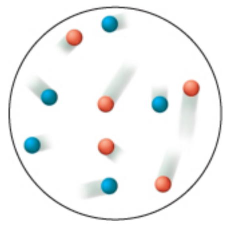
e. The following chemical equations model the interactions of nitrogen dioxide gas and ozone gas. Can this set of equations account for the trends observed in the graph? Explain your answer.

$$N_2 + O_2 \rightarrow 2NO$$
$$NO + O_3 \rightarrow NO_2 + O_2 + \text{light}$$

Do the concentrations of NO_2 or O_3 represented in the graph exceed the standards set by the EPA?

Answers to Conceptual Connections

Cc 10.1 Although the velocity "tails" of each atom will have different lengths, the average length of the tails on the argon atoms in your drawing should be longer than the average length of the tails on the xenon atoms. Because the argon atoms are lighter, they must on average move faster than the xenon atoms to have the same kinetic energy.



Cc 10.2 (e) The final volume of the gas is the same as the initial volume because doubling the pressure *decreases* the volume by a factor of 2, but doubling the temperature *increases* the volume by a factor of 2. The two changes in volume are equal in magnitude but opposite in sign, resulting in a final volume that is equal to the initial volume.

Cc 10.3 **(a)** Because 1 g of H_2 contains the greatest number of moles (due to H_2 having the lowest molar mass of the listed gases), and 1 mol of *any* ideal gas occupies the same volume, the H_2 occupies the greatest volume.

Cc 10.4 $\mathrm{Ne} < \mathrm{O_2} < \mathrm{F_2} < \mathrm{Cl_2}$; Because each gas occupies the same volume at STP (assuming ideal behavior), the densities increase with increasing molar mass.

Cc 10.5 $P_{\mathrm{He}} = 1.5\ \mathrm{atm}$; $\mathrm{P_{Ne}} = 1.5\ \mathrm{atm}$. Because the number of moles of each gas are equal, the mole fraction of each gas is 0.50 and the partial pressure of each gas is simply $0.50 \times P_{\mathrm{tot}}$.

Cc 10.6 **(c)** Because the temperature and the volume are both constant, the ideal gas law tells us that the pressure depends solely on the number of particles. Sample **(c)** has the greatest number of particles per unit volume and therefore has the greatest pressure. The pressures of samples **(a)** and **(b)** at a given temperature are identical. Even though the particles in **(b)** are more massive than those in **(a)**, they have the same average kinetic energy at a given temperature. The particles in **(b)** move more slowly than those in **(a)** and therefore exert the same pressure as the particles in **(a)**.

Cc 10.7 **(b)** Because the total number of gas molecules decreases, the total pressure—the sum of all the partial pressures—must also decrease.

Cc 10.8 $\mathrm{A} < \mathrm{B} < \mathrm{C}$. Curve A is the lowest temperature curve because it deviates the most from ideality. The tendency for the intermolecular forces in carbon dioxide to lower the pressure (relative to that of an ideal gas) is greatest at low temperature (because the molecules are moving more slowly and are therefore less able to overcome the intermolecular forces). As a result, the curve that dips the lowest must correspond to the lowest temperature.