Exercises

Pressure and Its Measurement

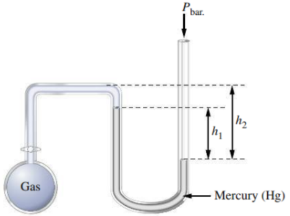
1. Convert each pressure to an equivalent pressure in atmospheres. **(a)** 736 mmHg; **(b)** 0.776 bar; **(c)** 892 Torr; **(d)** 225 kPa.

2. Calculate the height of a mercury column required to produce a pressure **(a)** of 0.984 atm; **(b)** of 928 Torr; **(c)** equal to that of a column of water 142 ft high.

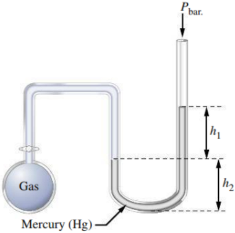
3. Calculate the height of a column of liquid benzene ($d = 0.879\ g/cm^3$), in meters, required to exert a pressure of 0.970 atm.

4. Calculate the height of a column of liquid glycerol ($d = 1.26\ g/cm^3$), in meters, required to exert the same pressure as 3.02 m of $CCl_4(l)$ ($d = 1.59\ g/cm^3$).

5. What is the pressure (in mmHg) of the gas inside the apparatus below if $P_{bar.} = 740$ mmHg, $h_1 = 30$ mm, and $h_2 = 50$ mm?



6. What is the pressure (in mmHg) of the gas inside the apparatus below if $P_{bar.} = 740$ mmHg, $h_1 = 30$ mm, and $h_2 = 40$ mm?



7. At times, a pressure is stated in units of *mass* per unit area rather than *force* per unit area. Express $P = 1$ atm in the unit kg/cm^2.
[*Hint:* How is a mass in kilograms related to a force?]

8. Express $P = 1$ atm in pounds per square inch (psi).
[*Hint:* Refer to Exercise 7.]

The Simple Gas Laws

9. A sample of $O_2(g)$ has a volume of 26.7 L at 762 Torr. What is the new volume if, with the temperature and amount of gas held constant, the pressure is **(a)** lowered to 385 Torr; **(b)** increased to 3.68 atm?

10. An 886 mL sample of Ne(g) is at 752 mmHg and 26 °C. What will be the new volume if, with the pressure and amount of gas held constant, the temperature is **(a)** increased to 98 °C; **(b)** lowered to −20 °C?

11. If 3.0 L of oxygen gas at 177 °C is cooled at constant pressure until the volume becomes 1.50 L, then what is the final temperature?

12. We want to change the volume of a fixed amount of gas from 725 mL to 2.25 L while holding the temperature constant. To what value must we change the pressure if the initial pressure is 105 kPa?

13. A 35.8 L cylinder of Ar(g) is connected to an evacuated 1875 L tank. If the temperature is held constant and the final pressure is 721 mmHg, what must have been the original gas pressure in the cylinder, in atmospheres?

14. A sample of $N_2(g)$ occupies a volume of 42.0 mL under the existing barometric pressure. Increasing the pressure by 85 mmHg reduces the volume to 37.7 mL. What is the prevailing barometric pressure, in millimeters of mercury?

15. A weather balloon filled with He gas has a volume of $2.00 \times 10^3\ m^3$ at ground level, where the atmospheric pressure is 1.000 atm and the temperature 27 °C. After the balloon rises high above Earth to a point where the atmospheric pressure is 0.340 atm, its volume increases to $5.00 \times 10^3\ m^3$. What is the temperature of the atmosphere at this altitude?

16. The photographs show the contraction of an argon-filled balloon when it is cooled by liquid nitrogen. To what

Richard Megna/Fundamental Photographs

approximate fraction of its original volume will the balloon shrink when it is cooled from a room temperature of 22 °C to a final temperature of about −22 °C?

17. What is the mass of argon gas in a 75.0 mL volume at STP?

18. What volume of gaseous chlorine at STP would you need to obtain a 250.0 g sample of gas?

19. A 27.6 mL sample of $PH_3(g)$ (used in the manufacture of flame-retardant chemicals) is obtained at STP.
(a) What is the mass of this sample, in milligrams?
(b) How many molecules of PH_3 are present?

20. A 5.0×10^{17} atom sample of radon gas is obtained.
(a) What is the mass of this sample, in micrograms?
(b) What is the volume of this sample at STP, in microliters?

21. You purchase a bag of potato chips at an ocean beach to take on a picnic in the mountains. At the picnic, you notice that the bag has become inflated, almost to the point of bursting. Use your knowledge of gas behavior to explain this phenomenon.

22. Scuba divers know that they must not ascend quickly from deep underwater because of a condition known as the *bends*, discussed in Chapter 14. Another concern is that they must constantly exhale during their ascent to prevent damage to the lungs and blood vessels. Describe what would happen to the lungs of a diver who inhaled compressed air at a depth of 30 m and held her breath while rising to the surface.

General Gas Equation

23. A sample of gas has a volume of 4.25 L at 25.6 °C and 748 mmHg. What will be the volume of this gas at 26.8 °C and 742 mmHg?

24. A 10.0 g sample of a gas has a volume of 5.25 L at 25 °C and 102 kPa. If 2.5 g of the same gas is added to this *constant* 5.25 L volume and the temperature raised to 62 °C, what is the new gas pressure?

25. A constant-volume vessel contains 12.5 g of a gas at 21 °C. If the pressure of the gas is to remain constant as the temperature is raised to 210 °C, how many grams of gas must be released?

26. A 34.0 L cylinder contains 305 g $O_2(g)$ at 22 °C. How many grams of $O_2(g)$ must be released to reduce the pressure in the cylinder to 1.15 atm if the temperature remains constant?

Ideal Gas Equation

27. What is the volume, in liters, occupied by 89.2 g $CO_2(g)$ at 37 °C and 98.3 kPa?

28. A 12.8 L cylinder contains 35.8 g O_2 at 46 °C. What is the pressure of this gas, in kilopascals?

29. Kr(g) in a 18.5 L cylinder exerts a pressure of 11.2 atm at 28.2 °C. How many grams of gas are present?

30. A 72.8 L constant-volume cylinder containing 7.41 g He is heated until the pressure reaches 3.50 atm. What is the final temperature in degrees Celsius?

31. A laboratory high vacuum system is capable of evacuating a vessel to the point that the amount of gas remaining is 5.0×10^9 molecules per cubic meter. What is the residual pressure in pascals?

32. What is the pressure, in pascals, exerted by 1242 g $CO_2(g)$ when confined at −25 °C to a cylindrical tank 25.0 cm in diameter and 1.75 m high?

33. What is the molar volume of an ideal gas at **(a)** 25 °C and 1.00 atm; **(b)** 100 °C and 748 Torr?

34. At what temperature is the molar volume of an ideal gas equal to 22.4 L, if the pressure of the gas is 2.5 atm?

Determining Molar Mass

35. A 0.418 g sample of gas has a volume of 115 mL at 66.3 °C and 99.0 kPa. What is the molar mass of this gas?

36. What is the molar mass of a gas found to have a density of 0.841 g/L at 415 K and 96.7 kPa?

37. What is the molecular formula of a gaseous fluoride of sulfur containing 70.4% F and having a density of approximately 4.5 g/L at 20 °C and 1.0 atm?

38. A 2.650 g sample of a gaseous compound occupies 428 mL at 24.3 °C and 742 mmHg. The compound consists of 15.5% C, 23.0% Cl, and 61.5% F, by mass. What is its molecular formula?

39. A gaseous hydrocarbon weighing 0.231 g occupies a volume of 102 mL at 23 °C and 749 mmHg. What is the molar mass of this compound? What conclusion can you draw about its molecular formula?

40. A 132.10 mL glass vessel weighs 56.1035 g when evacuated and 56.2445 g when filled with the gaseous hydrocarbon acetylene at 749.3 mmHg and 20.02 °C. What is the molar mass of acetylene? What conclusion can you draw about its molecular formula?

Gas Densities

41. A particular application calls for $N_2(g)$ with a density of 1.80 g/L at 32 °C. What must be the pressure of the $N_2(g)$ in millimeters of mercury? What is the molar volume under these conditions?

42. Monochloroethylene gas is used to make polyvinylchloride (PVC). It has a density of 2.56 g/L at 22.8 °C and 101 kPa. What is the molar mass of monochloroethylene? What is the molar volume under these conditions?

43. In order for a gas-filled balloon to rise in air, the density of the gas in the balloon must be less than that of air.
(a) Consider air to have a molar mass of 28.96 g/mol; determine the density of air at 25 °C and 1.00 atm, in g/L.
(b) Show by calculation that a balloon filled with carbon dioxide at 25 °C and 1 atm could not be expected to rise in air at 25 °C.

44. Refer to Exercise 43, and determine the minimum temperature to which the balloon described in part (b) would have to be heated before it could begin to rise in air. (Ignore the mass of the balloon itself.)

45. The density of phosphorus vapor is 2.64 g/L at 310 °C and 1.03 bar. What is the molecular formula of the phosphorus under these conditions?

46. A particular gaseous hydrocarbon that is 82.7% C and 17.3% H by mass has a density of 2.33 g/L at 23 °C and 746 mmHg. What is the molecular formula of this hydrocarbon?

Gases in Chemical Reactions

47. What volume of $O_2(g)$ is consumed in the combustion of 75.6 L $C_3H_8(g)$ if both gases are measured at STP?

48. How many liters of $H_2(g)$ at STP are produced per gram of Al(s) consumed in the following reaction?

$$2\,Al(s) + 6\,HCl(aq) \longrightarrow 2\,AlCl_3(aq) + 3\,H_2(g)$$

49. A particular coal sample contains 3.28% S by mass. When the coal is burned, the sulfur is converted to $SO_2(g)$. What volume of $SO_2(g)$, measured at 23 °C and 738 mmHg, is produced by burning 1.2×10^6 kg of this coal?

50. One method of removing $CO_2(g)$ from a spacecraft is to allow the CO_2 to react with LiOH. How many liters of $CO_2(g)$ at 25.9 °C and 1.00 bar can be removed per kilogram of LiOH consumed?

$$2\,LiOH(s) + CO_2(g) \longrightarrow Li_2CO_3(s) + H_2O(l)$$

51. A 3.57 g sample of a $KCl-KClO_3$ mixture is decomposed by heating and produces 119 mL $O_2(g)$, measured at 22.4 °C and 98.3 kPa. What is the mass percent of $KClO_3$ in the mixture?

$$2\,KClO_3(s) \longrightarrow 2\,KCl(s) + 3\,O_2(g)$$

52. Hydrogen peroxide, H_2O_2, is used to disinfect contact lenses. How many milliliters of $O_2(g)$ at 22 °C and 1.00 bar can be liberated from 10.0 mL of an aqueous solution containing 3.00% H_2O_2 by mass? The density of the aqueous solution of H_2O_2 is 1.01 g/mL.

$$2\,H_2O_2(aq) \longrightarrow 2\,H_2O(l) + O_2(g)$$

53. Calculate the volume of $H_2(g)$, measured at 26 °C and 751 Torr, required to react with 28.5 L CO(g), measured at 0 °C and 760 Torr, in this reaction.

$$3\,CO(g) + 7\,H_2(g) \longrightarrow C_3H_8(g) + 3\,H_2O(l)$$

54. The Haber process is the principal method for fixing nitrogen (converting N_2 to nitrogen compounds).

$$N_2(g) + 3\,H_2(g) \longrightarrow 2\,NH_3(g)$$

Assume that the reactant gases are completely converted to $NH_3(g)$ and that the gases behave ideally.
(a) What volume of $NH_3(g)$ can be produced from 152 L $N_2(g)$ and 313 L of $H_2(g)$ if the gases are measured at 315 °C and 5.25 atm?
(b) What volume of $NH_3(g)$, measured at 25 °C and 727 mmHg, can be produced from 152 L $N_2(g)$ and 313 L $H_2(g)$, measured at 315 °C and 5.25 atm?

Mixtures of Gases

55. What is the volume, in liters, occupied by a mixture of 15.2 g Ne(g) and 34.8 g Ar(g) at 7.24 bar pressure and 26.7 °C?

56. A balloon filled with $H_2(g)$ at 0.0 °C and 1.00 atm has a volume of 2.24 L. What is the final gas volume if 0.10 mol He(g) is added to the balloon and the temperature is then raised to 100 °C while the pressure and amount of gas are held constant?

57. A gas cylinder of 53.7 L volume contains $N_2(g)$ at a pressure of 28.2 atm and 26 °C. How many grams of Ne(g) must we add to this same cylinder to raise the total pressure to 75.0 atm?

58. A 2.35 L container of $H_2(g)$ at 762 mmHg and 24 °C is connected to a 3.17 L container of He(g) at 728 mmHg and 24 °C. After mixing, what is the total gas pressure, in millimeters of mercury, with the temperature remaining at 24 °C?

59. Which actions would you take to establish a pressure of 2.00 atm in a 2.24 L cylinder containing 1.60 g $O_2(g)$ at 0 °C? **(a)** add 1.60 g O_2; **(b)** release 0.80 g O_2; **(c)** add 2.00 g He; **(d)** add 0.60 g He.

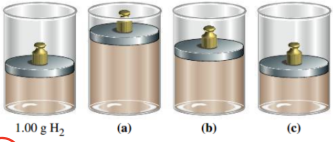
60. A mixture of 4.0 g $H_2(g)$ and 10.0 g He(g) in a 5.2 L flask is maintained at 0 °C.
(a) What is the total pressure in the container?
(b) What is the partial pressure of each gas?

61. A 2.00 L container is filled with Ar(g) at 752 mmHg and 35 °C. A 0.728 g sample of C_6H_6 vapor is then added.
(a) What is the total pressure in the container?
(b) What is the partial pressure of Ar and of C_6H_6?

62. The chemical composition of air that is exhaled (expired) is different from ordinary air. A typical analysis of expired air at 37 °C and 1.00 atm, expressed as percent by volume, is 74.2% N_2, 15.2% O_2, 3.8% CO_2, 5.9% H_2O, and 0.9% Ar. The composition of ordinary air is given in Practice Example 6-12B.
(a) What is the ratio of the partial pressure of $CO_2(g)$ in expired air to that in ordinary air?
(b) Would you expect the density of expired air to be greater or less than that of ordinary air at the same temperature and pressure? Explain.

(c) Confirm your expectation by calculating the densities of ordinary air and expired air at 37 °C and 1.00 atm.

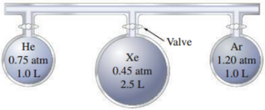
63. In the drawing below, 1.00 g $H_2(g)$ is maintained at 1 atm pressure in a cylinder closed off by a freely moving piston. Which sketch, **(a)**, **(b)**, or **(c)**, best represents the mixture obtained when 1.00 g He(g) is added? Explain.



64. In the drawing above, 1.00 g $H_2(g)$ at 300 K is maintained at 1 atm pressure in a cylinder closed off by a freely moving piston. Which sketch, **(a)**, **(b)**, or **(c)**, best represents the mixture obtained when 0.50 g $H_2(g)$ is added and the temperature is reduced to 275 K? Explain your answer.

65. A 4.0 L sample of O_2 gas has a pressure of 1.0 bar. A 2.0 L sample of N_2 gas has a pressure of 2.0 bar. If these two samples are mixed and then compressed in a 2.0 L vessel, what is the final pressure of the mixture? Assume that the temperature remains unchanged.

66. The following figure shows the contents and pressures of three vessels of gas that are joined by a connecting tube.



After the valves on the vessels are opened, the final pressure is measured and found to be 0.675 atm. What is the total volume of the connecting tube? Assume that the temperature remains constant.

Collecting Gases over Liquids

67. A 1.65 g sample of Al reacts with excess HCl, and the liberated H_2 is collected over water at 25 °C at a barometric pressure of 744 mmHg. What volume of gaseous mixture, in liters, is collected?

$$2\,Al(s) + 6\,HCl(aq) \longrightarrow 2\,AlCl_3(aq) + 3\,H_2(g)$$

68. An 89.3 mL sample of wet $O_2(g)$ is collected over water at 21.3 °C at a barometric pressure of 756 mmHg (vapor pressure of water at 21.3 °C = 19 mmHg). **(a)** What is the partial pressure of $O_2(g)$ in the sample collected, in millimeters of mercury? **(b)** What is the volume percent O_2 in the gas collected? **(c)** How many grams of O_2 are present in the sample?

69. A sample of $O_2(g)$ is collected over water at 24 °C. The volume of gas is 1.16 L. In a subsequent experiment, it is determined that the mass of O_2 present is 1.46 g. What must have been the barometric pressure at the time the gas was collected? (The vapor pressure of water at 24 °C is 22.4 Torr.)

70. A 1.072 g sample of He(g) is found to occupy a volume of 8.446 L when collected over hexane at 25.0 °C and 738.6 mmHg barometric pressure. Use these data to determine the vapor pressure of hexane at 25.0 °C.

71. At elevated temperatures, solid sodium chlorate ($NaClO_3$) decomposes to produce sodium chloride, NaCl, and O_2 gas. A 0.8765 g sample of impure sodium chlorate was heated until the production of oxygen ceased. The oxygen gas was collected over water and occupied a volume of 57.2 mL at 23.0 °C and 734 Torr. Calculate the mass percentage of $NaClO_3$ in the original sample. Assume that none of the impurities produce oxygen on heating. The vapor pressure of water is 21.07 Torr at 23.0 °C.

72. When solid $KClO_3$ is heated strongly, it decomposes to form solid potassium chloride, KCl, and O_2 gas. A 0.415 g sample of impure $KClO_3$ is heated strongly and the O_2 gas produced by the decomposition is collected over water. When the wet O_2 gas is cooled back to 26 °C, the total volume is 229 mL and the total pressure is 323 Torr. What is the mass percentage of $KClO_3$ in the original sample? Assume that none of the impurities produce oxygen on heating. The vapor pressure of water is 25.22 Torr at 26 °C.

Kinetic–Molecular Theory

73. Calculate u_{rms}, in meters per second, for $Cl_2(g)$ molecules at 30 °C.

74. The u_{rms} of H_2 molecules at 273 K is 1.84×10^3 m/s. At what temperature is u_{rms} for H_2 twice this value?

75. Refer to Example 6-14. What must be the molecular mass of a gas if its molecules are to have a root-mean-square speed at 25 °C equal to the speed of the M-16 rifle bullet?

76. Refer to Example 6-14. Noble gases (group 18) exist as atoms, not molecules (they are monatomic). Cite one noble gas whose u_{rms} at 25 °C is higher than the speed of the rifle bullet and one whose u_{rms} is lower.

77. At what temperature will u_{rms} for Ne(g) be the same as u_{rms} for He at 300 K?

78. Determine u_m, $\bar{u}$, and u_{rms} for a group of ten automobiles clocked by radar at speeds of 38, 44, 45, 48, 50, 55, 55, 57, 58, and 60 mi/h, respectively.

79. Calculate the average kinetic energy, $\overline{E_k}$, for $O_2(g)$ at 298 K and 1.00 atm.

80. Calculate the total kinetic energy, in joules, of 155 g $N_2(g)$ at 25 °C and 1.00 atm. [*Hint*: First calculate the average kinetic energy, $\overline{E_k}$.]

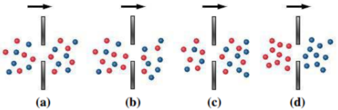
Diffusion and Effusion of Gases

81. If 0.00484 mol $N_2O(g)$ effuses through an orifice in a certain period of time, how much $NO_2(g)$ would effuse in the same time under the same conditions?

82. A sample of $N_2(g)$ effuses through a tiny hole in 38 s. What must be the molar mass of a gas that requires 64 s to effuse under identical conditions?

83. What are the ratios of the diffusion rates for the pairs of gases **(a)** N_2 and O_2; **(b)** H_2O and D_2O (D = deuterium, i.e., ^2_1H); **(c)** $^{14}CO_2$ and $^{12}CO_2$; **(d)** $^{235}UF_6$ and $^{238}UF_6$?

84. Which of the following visualizations best represents the distribution of O_2 and SO_2 molecules near an orifice some time after effusion occurs in the direction indicated by the arrows? The initial condition was one of equal numbers of O_2 molecules (●) and SO_2 molecules (●) on the left side of the orifice. Explain.



85. It takes 22 hours for a neon-filled balloon to shrink to half its original volume at STP. If the same balloon had been filled with helium, then how long would it have taken for the balloon to shrink to half its original volume at STP?

86. The molar mass of radon gas was first estimated by comparing its diffusion rate with that of mercury vapor, Hg(g). What is the molar mass of radon if mercury vapor diffuses 1.082 times as fast as radon gas? Assume that Graham's law holds for diffusion.

Nonideal Gases

87. Refer to Example 6-17. Recalculate the pressure of $Cl_2(g)$ by using both the ideal gas equation and the van der Waals equation at the temperatures **(a)** 100 °C; **(b)** 200 °C; **(c)** 400 °C. From the results, confirm the statement that a gas tends to be more ideal at high temperatures than at low temperatures.

88. Use both the ideal gas equation and the van der Waals equation to calculate the pressure exerted by 1.50 mol of $SO_2(g)$ when it is confined at 298 K to a volume of **(a)** 100.0 L; **(b)** 50.0 L; **(c)** 20.0 L; **(d)** 10.0 L. Under which of these conditions is the pressure calculated with the ideal gas equation within a few percent of that calculated with the van der Waals equation? Use values of a and b from Table 6.5.

89. Use the value of the van der Waals constant b for He(g), given in Table 6.5, to estimate the radius, r, of a single helium atom. Give your answer in picometers. [*Hint*: The volume of a sphere of radius r is $4\pi r^3/3$.]

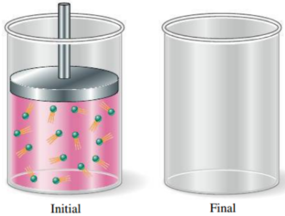
90. **(a)** Use the value of the van der Waals constant b for $CH_4(g)$, given in Table 6.5, to estimate the radius of the CH_4 molecule. (See Exercise 89.) How does your estimate of the radius compare with the value r = 228 pm, obtained experimentally from an analysis of the structure of solid methane? **(b)** The density of $CH_4(g)$ is 66.02 g mL^{-1} at 100 bar and 325 K. What is the value of the compressibility factor at this temperature and pressure?

Integrative and Advanced Exercises

91. Explain why it is necessary to include the density of Hg(l) and the value of the acceleration due to gravity, g, in a precise definition of a millimeter of mercury (page 196).

92. Assume the following initial conditions for the graphs labeled A, B, and C in Figure 6-7. (A) 10.0 mL at 400 K; (B) 20.0 mL at 400 K; (C) 40.0 mL at 400 K. Use Charles's law to calculate the volume of each gas at 0, −100, −200, −250, and −270 °C. Show that the volume of each gas becomes zero at −273.15 °C.

93. Consider the diagram to the right. The "initial" sketch illustrates, both at the macroscopic and molecular levels, an initial condition: 1 mol of a gas at 273 K and 1.00 bar. With as much detail as possible, illustrate the final condition after each of the following changes.
(a) The pressure is changed to 250 mmHg while standard temperature is maintained.
(b) The temperature is changed to 140 K while standard pressure is maintained.
(c) The pressure is changed to 0.5 bar while the temperature is changed to 550 K.
(d) An additional 0.5 mol of gas is introduced into the cylinder, the temperature is changed to 135 °C, and the pressure is changed to 2.25 bar.



94. Two evacuated bulbs of equal volume are connected by a tube of negligible volume. One of the bulbs is placed in a constant-temperature bath at 225 K and the other bulb is placed in a constant-temperature bath at 350 K. Exactly 1 mol of an ideal gas is injected into the system. Calculate the final number of moles of gas in each bulb.

95. A compound is 85.6% carbon by mass. The rest is hydrogen. When 10.0 g of the compound is evaporated at 50.0 °C, the vapor occupies 6.30 L at 1.00 atm pressure. What is the molecular formula of the compound?

96. A 0.7178 g sample of a hydrocarbon occupies a volume of 390.7 mL at 65.0 °C and 99.2 kPa. When the sample is burned in excess oxygen, 2.4267 g CO_2 and 0.4967 g H_2O are obtained. What is the molecular formula of the hydrocarbon? Write a plausible structural formula for the molecule.

97. A 3.05 g sample of $NH_4NO_3(s)$ is introduced into an evacuated 2.18 L flask and then heated to 250 °C. What is the total gas pressure, in atmospheres, in the flask at 250 °C when the NH_4NO_3 has completely decomposed?

$$NH_4NO_3(s) \longrightarrow N_2O(g) + 2\,H_2O(g)$$

98. Ammonium nitrite, NH_4NO_2, decomposes according to the chemical equation below.

$$NH_4NO_2(s) \longrightarrow N_2(g) + 2\,H_2O(g)$$

What is the total volume of products obtained when 128 g NH_4NO_2 decomposes at 819 °C and 101 kPa?

99. A mixture of 1.00 g H_2 and 8.60 g O_2 is introduced into a 1.500 L flask at 25 °C. When the mixture is ignited, an explosive reaction occurs in which water is the only product. What is the total gas pressure when the flask is returned to 25 °C? (The vapor pressure of water at 25 °C is 23.8 mmHg.)

100. In the reaction of $CO_2(g)$ and solid sodium peroxide (Na_2O_2), solid sodium carbonate (Na_2CO_3) and oxygen gas are formed. This reaction is used in submarines and space vehicles to remove expired $CO_2(g)$ and to generate some of the $O_2(g)$ required for breathing. Assume that the volume of gases exchanged in the lungs equals 4.0 L/min, the CO_2 content of expired air is 3.8% CO_2 by volume, and the gases are at 25 °C and 735 mmHg. If the $CO_2(g)$ and $O_2(g)$ in the above reaction are measured at the same temperature and pressure, **(a)** how many milliliters of $O_2(g)$ are produced per minute and **(b)** at what rate is the $Na_2O_2(s)$ consumed, in grams per hour?

101. What is the partial pressure of $Cl_2(g)$, in millimeters of mercury, at 0.00 °C and 1.00 atm in a gaseous mixture that consists of 46.5% N_2, 12.7% Ne, and 40.8% Cl_2, by mass?

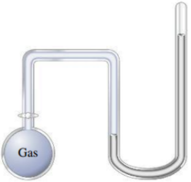
102. A gaseous mixture of He and O_2 has a density of 0.518 g/L at 25 °C and 721 mmHg. What is the mass percent He in the mixture?

103. When working with a mixture of gases, it is sometimes convenient to use an *apparent molar mass* (a weighted-average molar mass). Think in terms of replacing the mixture with a hypothetical single gas. What is the apparent molar mass of air, given that air is 78.08% N_2, 20.95% O_2, 0.93% Ar, and 0.036% CO_2, by volume?

104. A mixture of $N_2O(g)$ and $O_2(g)$ can be used as an anesthetic. In a particular mixture, the partial pressures of N_2O and O_2 are 612 Torr and 154 Torr, respectively. Calculate **(a)** the mass percentage of N_2O in this mixture, and **(b)** the apparent molar mass of this anesthetic. [*Hint*: For part (b), refer to Exercise 103.]

105. Gas cylinder A has a volume of 48.2 L and contains $N_2(g)$ at 8.35 atm at 25 °C. Gas cylinder B, of unknown volume, contains He(g) at 9.50 atm and 25 °C. When the two cylinders are connected and the gases mixed, the pressure in each cylinder becomes 8.71 atm. What is the volume of cylinder B?

106. The accompanying sketch is that of a closed-end manometer. Describe how the gas pressure is measured. Why is a measurement of $P_{bar.}$ not necessary when using this manometer? Explain why the closed-end manometer is more suitable for measuring low pressures and the open-end manometer more suitable for measuring pressures nearer atmospheric pressure.



107. Producer gas is a type of fuel gas made by passing air or steam through a bed of hot coal or coke. A typical producer gas has the following composition in percent by volume: 8.0% CO_2, 23.2% CO, 17.7% H_2, 1.1% CH_4, and 50.0% N_2.
(a) What is the density of this gas at 23 °C and 763 mmHg, in grams per liter?
(b) What is the partial pressure of CO in this mixture at 0.00 °C and 1 atm?
(c) What volume of air, measured at 23 °C and 741 Torr, is required for the complete combustion of 1.00×10^3 L of this producer gas, also measured at 23 °C and 741 Torr?
[*Hint:* Which three of the constituent gases are combustible?]

108. What volume of air, measured at 298 K and 101 kPa, is required to burn 2.00 kg C_8H_{18}? Air is approximately 78.1% N_2 and 20.9% O_2, by volume. Other gases make up the remaining 1.0%.

109. A mixture of $H_2(g)$ and $O_2(g)$ is prepared by electrolyzing 1.32 g water, and the mixture of gases is collected over water at 30 °C and 748 mmHg. The volume of "wet" gas obtained is 2.90 L. What must be the vapor pressure of water at 30 °C?

$$2\,H_2O(l) \xrightarrow{\text{electrolysis}} 2\,H_2(g) + O_2(g)$$

110. Aluminum (Al) and iron (Fe) each react with hydrochloric acid solution (HCl) to produce a chloride salt and hydrogen gas, $H_2(g)$. A 0.1924 g sample of a mixture of Al and Fe is treated with excess HCl solution. A volume of 159 mL of H_2 gas is collected over water at 19.0 °C and 841 Torr. What is the percent (by mass) of Fe in the mixture? The vapor pressure of water at 19.0 °C is 16.5 Torr.

111. A 0.168 L sample of $O_2(g)$ is collected over water at 26 °C and a barometric pressure of 737 mmHg. In the gas that is collected, what is the percent water vapor **(a)** by volume; **(b)** by number of molecules; **(c)** by mass? (Vapor pressure of water at 26 °C = 25.2 mmHg.)

112. A breathing mixture is prepared in which He is substituted for N_2. The gas is 79% He and 21% O_2, by volume. **(a)** What is the density of this mixture in grams per liter at 25 °C and 1.00 atm? **(b)** At what pressure would the He–O_2 mixture have the same density as that of air at 25 °C and 1.00 atm? See Exercise 103 for the composition of air.

113. Chlorine dioxide, ClO_2, is sometimes used as a chlorinating agent for water treatment. It can be prepared from the reaction below:

$$Cl_2(g) + 4\,NaClO(aq) \longrightarrow 4\,NaCl(aq) + 2\,ClO_2(g)$$

In an experiment, 1.0 L $Cl_2(g)$, measured at 10.0 °C and 4.66 atm, is dissolved in 0.750 L of 2.00 M NaClO(aq). If 25.9 g of pure ClO_2 is obtained, then what is the percent yield for this experiment?

114. The amount of ozone, O_3, in a mixture of gases can be determined by passing the mixture through a solution of excess potassium iodide, KI. Ozone reacts with the iodide ion as follows:

$$O_3(g) + 3\,I^-(aq) + H_2O(l) \longrightarrow O_2(g) + I_3^-(aq) + 2\,OH^-(aq)$$

The amount of I_3^- produced is determined by titrating with thiosulfate ion, $S_2O_3^{2-}$:

$$I_3^-(aq) + 2\,S_2O_3^{2-}(aq) \longrightarrow 3\,I^-(aq) + S_4O_6^{2-}(aq)$$

A mixture of gases occupies a volume of 53.2 L at 18 °C and 0.993 atm. The mixture is passed slowly through a solution containing an excess of KI to ensure that all the ozone reacts. The resulting solution requires 26.2 mL of 0.1359 M $Na_2S_2O_3$ to titrate to the end point. Calculate the mole fraction of ozone in the original mixture.

115. A 0.1052 g sample of $H_2O(l)$ in an 8.050 L sample of dry air at 30.1 °C evaporates completely. To what temperature must the air be cooled to give a relative humidity of 80.0%? Vapor pressures of water: 20 °C, 17.54 mmHg; 19 °C, 16.49 mmHg; 18 °C, 15.48 mmHg; 17 °C, 14.54 mmHg; 16 °C, 13.63 mmHg; 15 °C, 12.79 mmHg. [*Hint*: Go to Focus On feature for Chapter 6 on the MasteringChemistry site, www.masteringchemistry.com, for a discussion of relative humidity.]

116. An alternative to Figure 6-6 is to plot P against $1/V$. The resulting graph is a straight line passing through the origin. Use Boyle's data from Feature Problem 125 to draw such a straight-line graph. What factors would affect the *slope* of this straight line? Explain.

117. We have noted that atmospheric pressure depends on altitude. Atmospheric pressure as a function of altitude can be calculated with an equation known as the barometric formula:

$$P = P_0 \times 10^{-Mgh/2.303RT}$$

In this equation, P and P_0 can be in any pressure units, for example, Torr. P_0 is the pressure at sea level, generally taken to be 1.00 atm or its equivalent. The units in the exponential term must be SI units, however. Use the barometric formula to
(a) estimate the barometric pressure at the top of Mt. Whitney in California (altitude: 14,494 ft; assume a temperature of 10 °C);
(b) show that barometric pressure decreases by one-thirtieth in value for every 900-ft increase in altitude.

118. Consider a sample of $O_2(g)$ at 298 K and 1.0 atm. Calculate **(a)** u_{rms} and **(b)** the fraction of molecules that have speed equal to u_{rms}.

119. A nitrogen molecule (N_2) having the average kinetic energy at 300 K is released from Earth's surface to travel upward. If the molecule could move upward without colliding with other molecules, then how high would it go before coming to rest? Give your answer in kilometers. [*Hint*: When the molecule comes to rest, the potential energy of the molecule will be mgh, where m is the molecular mass in kilograms, $g = 9.81\ m\,s^{-2}$ is the acceleration due to gravity, and h is the height, in meters, above Earth's surface.]

120. For $H_2(g)$ at 0 °C and 1 atm, calculate the percentage of molecules that have speed **(a)** $0\ m\,s^{-1}$; **(b)** $500\ m\,s^{-1}$; **(c)** $1000\ m\,s^{-1}$; **(d)** $1500\ m\,s^{-1}$; **(e)** $2000\ m\,s^{-1}$; **(f)** $2500\ m\,s^{-1}$; **(g)** $3500\ m\,s^{-1}$. Graph your results to obtain your own version of Figure 6-15.

121. If the van der Waals equation is solved for volume, a cubic equation is obtained.
(a) Derive the equation below by rearranging equation (6.26).

$$V^3 - n\left(\frac{RT + bP}{P}\right)V^2 + \left(\frac{n^2a}{P}\right)V - \frac{n^3ab}{P} = 0$$

(b) What is the volume, in liters, occupied by 185 g $CO_2(g)$ at a pressure of 12.5 atm and 286 K? For $CO_2(g)$, $a = 3.61\ atm\,L^2\,mol^{-2}$ and $b = 0.0429\ L\,mol^{-1}$. [*Hint*: Use the ideal gas equation to obtain an estimate of the volume. Then refine your estimate, either by trial and error, or using the method of successive approximations. See Appendix A, pages A5–A6, for a description of the method of successive approximations.]

122. According to the *CRC Handbook of Chemistry and Physics* (95th ed.), the molar volume of $O_2(g)$ is $0.2168\ L\,mol^{-1}$ at 280 K and 10 MPa. (Note: 1 MPa = 1×10^6 Pa.)
(a) Use the van der Waals equation to calculate the pressure of one mole of $O_2(g)$ at 280 K if the volume is 0.2168 L. What is the % error in the calculated pressure? The van der Waals constants are $a = 1.382\ bar\,L^2\,mol^{-2}$ and $b = 0.0319\ L\,mol^{-1}$.
(b) Use the ideal gas equation to calculate the volume of one mole of $O_2(g)$ at 280 K and 10 MPa. What is the % error in the calculated volume?

123. A particular equation of state for $O_2(g)$ has the form

$$P\overline{V} = RT\left(1 + \frac{B}{\overline{V}} + \frac{C}{\overline{V}^2}\right)$$

where $\overline{V}$ is the molar volume, $B = -21.89\ cm^3/mol$ and $C = 1230\ cm^6/mol^2$.

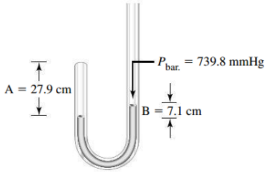
(a) Use the equation to calculate the pressure exerted by 1 mol $O_2(g)$ confined to a volume of $500\ cm^3$ at 273 K.

(b) Is the result calculated in part (a) consistent with that suggested for $O_2(g)$ by Figure 6-21? Explain.

124. A 0.156 g sample of a magnesium–aluminum alloy dissolves completely in an excess of HCl(aq). The liberated $H_2(g)$ is collected over water at 5 °C when the barometric pressure is 752 Torr. After the gas is collected, the water and gas gradually warm to the prevailing room temperature of 23 °C. The pressure of the collected gas is again equalized against the barometric pressure of 752 Torr, and its volume is found to be 202 mL. What is the percent composition of the magnesium–aluminum alloy? (Vapor pressure of water: 6.54 mmHg at 5 °C and 21.07 mmHg at 23 °C).

Feature Problems

125. Shown below is a diagram of Boyle's original apparatus. At the start of the experiment, the length of the



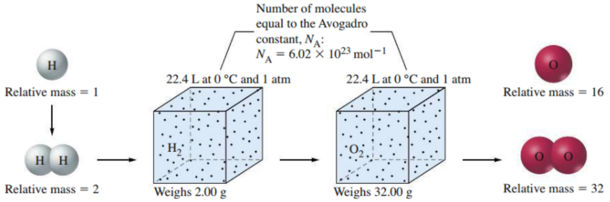
air column (A) on the left was 30.5 cm and the heights of mercury in the arms of the tube were equal. When mercury was added to the right arm of the tube, a difference in mercury levels (B) was produced, and the entrapped air on the left was compressed into a shorter length of the tube (smaller volume) as shown in the illustration for A = 27.9 cm and B = 7.1 cm. Boyle's values of A and B, in centimeters, are listed as follows:

A:	30.5	27.9	25.4	22.9	20.3
B:	0.0	7.1	15.7	25.7	38.3
A:	17.8	15.2	12.7	10.2	7.6
B:	53.8	75.4	105.6	147.6	224.6

Barometric pressure at the time of the experiment was 739.8 mmHg. Assuming that the length of the air column (A) is proportional to the volume of air, show that these data conform reasonably well to Boyle's law.

126. In 1860, Stanislao Cannizzaro showed how Avogadro's hypothesis could be used to establish the atomic masses of elements in gaseous compounds. Cannizzaro took the atomic mass of hydrogen to be exactly one and assumed that hydrogen exists as H_2 molecules (molecular mass = 2). Next, he determined the volume of $H_2(g)$ at 0.00 °C and 1.00 atm that has a mass of exactly 2 g. This volume is 22.4 L. Then he assumed that 22.4 L of any other gas would have the same number of molecules as in 22.4 L of $H_2(g)$. (Here is where Avogadro's hypothesis entered in.) Finally, he reasoned that the ratio of the mass of 22.4 L of any other gas to the mass of 22.4 L of $H_2(g)$ should be the same as the ratio of their molecular masses. The sketch below illustrates Cannizzaro's reasoning in establishing the atomic weight of oxygen as 16. The gases in the table all contain the element X. Their molecular masses were determined by Cannizzaro's method. Use the percent composition data to deduce the atomic mass of X, the number of atoms of X in each of the gas molecules, and the identity of X.

Compound	Molecular Mass, u	Mass Percent X, %
Nitryl fluoride	65.01	49.4
Nitrosyl fluoride	49.01	32.7
Thionyl fluoride	86.07	18.6
Sulfuryl fluoride	102.07	31.4



127. In research that required the careful measurement of gas densities, John Rayleigh, a physicist, found that the density of $O_2(g)$ had the same value whether the gas was obtained from air or derived from one of its compounds. The situation with $N_2(g)$ was different, however. The density of $N_2(g)$ had the same value when the $N_2(g)$ was derived from any of various compounds, but a *different* value if the $N_2(g)$ was extracted from air. In 1894, Rayleigh enlisted the aid of William Ramsay, a chemist, to solve this apparent mystery; in the course of their work they discovered the noble gases.
(a) Why do you suppose that the $N_2(g)$ extracted from liquid air did *not* have the same density as $N_2(g)$ obtained from its compounds?
(b) Which gas do you suppose had the greater density: $N_2(g)$ extracted from air or $N_2(g)$ prepared from nitrogen compounds? Explain.
(c) The way in which Ramsay proved that nitrogen gas extracted from air was itself a mixture of gases involved allowing this nitrogen to react with magnesium metal to form magnesium nitride. Explain the significance of this experiment.
(d) Calculate the *percent difference* in the densities at 0.00 °C and 1.00 atm of Rayleigh's $N_2(g)$ extracted from air and $N_2(g)$ derived from nitrogen compounds. [The volume percentages of the major components of air are 78.084% N_2, 20.946% O_2, 0.934% Ar, and 0.0379% CO_2.]

128. The equation $d/P = M/RT$, which can be derived from equation (6.14), suggests that the ratio of the density (d) to pressure (P) of a gas at constant temperature should be a constant. The gas density data at the end of this question were obtained for $O_2(g)$ at various pressures at 273.15 K.
(a) Calculate values of d/P, and with a graph or by other means determine the ideal value of the term d/P for $O_2(g)$ at 273.15 K.
[*Hint:* The ideal value is that associated with a perfect (ideal) gas.]
(b) Use the value of d/P from part (a) to calculate a precise value for the atomic mass of oxygen, and compare this value with that listed on the inside front cover.

P, mmHg:	760.00	570.00	380.00	190.00
d, g/L:	1.428962	1.071485	0.714154	0.356985

129. A sounding balloon is a rubber bag filled with $H_2(g)$ and carrying a set of instruments (the payload). Because this combination of bag, gas, and payload has a smaller mass than a corresponding volume of air, the balloon rises. As the balloon rises, it expands. From the table below, estimate the maximum height to which a spherical balloon can rise given the mass of balloon, 1200 g; payload, 1700 g: quantity of $H_2(g)$ in balloon, 120 ft^3 at 0.00 °C and 1.00 atm; diameter of balloon at maximum height, 25 ft. Air pressure and temperature as functions of altitude are:

Altitude, km	Pressure, mbar	Temperature, K
0	1.0×10^3	288
5	5.4×10^2	256
10	2.7×10^2	223
20	5.5×10^1	217
30	1.2×10^1	230
40	2.9×10^0	250
50	8.1×10^{-1}	250
60	2.3×10^{-1}	256

Self-Assessment Exercises

130. In your own words, define or explain each term or symbol. **(a)** atm; **(b)** STP; **(c)** R; **(d)** partial pressure; **(e)** u_{rms}.

131. Briefly describe each concept or process: **(a)** absolute zero of temperature; **(b)** collection of a gas over water; **(c)** effusion of a gas; **(d)** law of combining volumes.

132. Explain the important distinctions between **(a)** barometer and manometer; **(b)** Celsius and Kelvin temperature; **(c)** ideal gas equation and general gas equation; **(d)** ideal gas and real gas.

133. Which exerts the greatest pressure, **(a)** a 75.0 cm column of Hg(l) (d = 13.6 g/mL); **(b)** a column of air 10 mi high; **(c)** a 5.0 m column of $CCl_4(l)$ (d = 1.59 g/mL); **(d)** 10.0 g $H_2(g)$ at STP?

134. For a fixed amount of gas at a fixed pressure, changing the temperature from 100.0 °C to 200 K causes the gas volume to **(a)** double; **(b)** increase, but not to twice its original value; **(c)** decrease; **(d)** stay the same.

135. Two gases were mixed into a 5.000 L container at 291.0 K. Gas A was originally confined in 14.20 L at 1.081 bar and 303.1 K. Gas B was originally confined in 1.251 L at 26.77 bar and 327.5 K. **(a)** What is the final total pressure in the 5.000 L container? **(b)** What is the partial pressure of gas A? **(c)** What is the partial pressure of gas B?

136. A fragile glass vessel will break if the internal pressure equals or exceeds 2.0 bar. If the vessel is sealed at 0 °C and 1.0 bar, then at what temperature will the vessel break? Assume that the vessel does not expand when heated.

137. Which of the following choices represents the molar volume of an ideal gas at 25 °C and 1.5 atm?
(a) (298 × 1.5/273) × 22.4 L;
(b) 22.4 L;
(c) (273 × 1.5/298) × 22.4 L;
(d) [298/(273 × 1.5)] × 22.4 L;
(e) [273/(298 × 1.5)] × 22.4 L.

138. The gas with the greatest density at STP is **(a)** N_2O; **(b)** Kr; **(c)** SO_3; **(d)** Cl_2.

139. Precisely 1 mol of helium and 1 mol of neon are mixed in a container. **(a)** Which gas has the greater average molecular speed? **(b)** Which type of molecule strikes the wall of the container more frequently? **(c)** Which gas exerts the larger pressure?

140. If the Kelvin temperature of a gas doubles, then which of the following also doubles? **(a)** the average molecular speed; **(b)** the speed of every molecule; **(c)** the kinetic energy of every molecule; **(d)** the average kinetic energy of the molecules; **(e)** none of these.

141. The postulates of the kinetic molecular theory of gases include all those that follow *except* **(a)** no forces exist between molecules; **(b)** molecules are point masses; **(c)** molecules are repelled by the wall of the container; **(d)** molecules are in constant random motion; **(e)** all are postulates.

142. Consider the statements (a) to (e) below. Assume that $H_2(g)$ and $O_2(g)$ behave ideally. State whether each of the following statements is true or false. For each false statement, explain how you would change it to make it a true statement.

(a) Under the same conditions of temperature and pressure, the average kinetic energy of O_2 molecules is less than that of H_2 molecules.

(b) Under the same conditions of temperature and pressure, H_2 molecules move faster, on average, than O_2 molecules.

(c) The volume of 1.00 mol of $H_2(g)$ at 25.0 °C, 1.00 atm is 22.4 L.

(d) The volume of 2.0 g $H_2(g)$ is equal to the volume of 32.0 g $O_2(g)$, at the same temperature and pressure.

(e) In a mixture of H_2 and O_2 gases, with partial pressures P_{H_2} and P_{O_2}, respectively, the total pressure is the larger of P_{H_2} and P_{O_2}.

143. A sample of $O_2(g)$ is collected over water at 23 °C and a barometric pressure of 751 Torr. The vapor pressure of water at 23 °C is 21 mmHg. The partial pressure of $O_2(g)$ in the sample collected is **(a)** 21 mmHg; **(b)** 751 Torr; **(c)** 0.96 atm; **(d)** 1.02 atm.

144. At 0 °C and 0.500 atm, 4.48 L of gaseous NH_3 **(a)** contains 6.02×10^{22} molecules; **(b)** has a mass of 17.0 g; **(c)** contains 0.200 mol NH_3; **(d)** has a mass of 3.40 g.

145. To establish a pressure of 2.00 atm in a 2.24 L cylinder containing 1.60 g $O_2(g)$ at 0 °C, **(a)** add 1.60 g O_2; **(b)** add 0.60 g He(g); **(c)** add 2.00 g He(g); **(d)** release 0.80 g $O_2(g)$.

146. Carbon monoxide, CO, and hydrogen react according to the equation below.

$$3\,CO(g) + 7\,H_2(g) \longrightarrow C_3H_8(g) + 3\,H_2O(g)$$

What volume of which reactant gas remains if 12.0 L CO(g) and 25.0 L $H_2(g)$ are allowed to react? Assume that the volumes of both gases are measured at the same temperature and pressure.

147. A mixture of 5.0×10^{-5} mol $H_2(g)$ and 5.0×10^{-5} mol $SO_2(g)$ is placed in a 10.0 L container at 25 °C. The container has a pinhole leak. After a period of time, the partial pressure of $H_2(g)$ in the container **(a)** is less than that of the $SO_2(g)$; **(b)** is equal to that of the $SO_2(g)$; **(c)** exceeds that of the $SO_2(g)$; **(d)** is the same as in the original mixture.

148. Under which conditions is Cl_2 most likely to behave like an ideal gas? Explain. **(a)** 100 °C and 10.0 atm; **(b)** 0 °C and 0.50 atm; **(c)** 200 °C and 0.50 atm; **(d)** 400 °C and 10.0 atm.

149. Without referring to Table 6.5, state which species in each of the following pairs has the greater value for the van der Waals constant *a*, and which one has the greater value for the van der Waals constant *b*. **(a)** He or Ne; **(b)** CH_4 or C_3H_8; **(c)** H_2 or Cl_2.

150. Explain why the height of the mercury column in a barometer is independent of the diameter of the barometer tube.

151. A gaseous hydrocarbon that is 82.7% C and 17.3% H by mass has a density of 2.35 g/L at 25 °C and 752 Torr. What is the molecular formula of this hydrocarbon?

152. Draw a box to represent a sample of air containing N_2 molecules (represented as squares) and O_2 molecules (represented as circles) in their correct proportions. How many squares and circles would you need to draw to also represent the $CO_2(g)$ in air through a single mark? What else should you add to the box for this more complete representation of air? [*Hint:* See Exercise 103.]

153. Appendix E describes a useful study aid known as concept mapping. Using the method presented in Appendix E, construct a concept map illustrating the different concepts to show the relationships among all the gas laws described in this chapter.