15. Far above the Earth's surface the gas kinetic temperature is reported to be on the order of 1000 K. However, a person placed in such an environment would freeze to death rather than vaporize. Explain.
16. Why doesn't the Earth's atmosphere leak away? At the top of the atmosphere atoms will occasionally be headed out with a speed exceeding the escape speed. Isn't it just a matter of time?
17. Titan, one of Saturn's many moons, has an atmosphere, but our own Moon does not. What is the explanation?
18. How, if at all, would you expect the composition of the air to change with altitude?
19. Explain why the temperature decreases with height in the lower atmosphere.
20. In large-scale inelastic collisions mechanical energy is lost through internal friction resulting in a rise of temperature owing to increased internal molecular agitation. Is there a loss of mechanical energy to heat in an inelastic collision between molecules?
21. By considering quantities that must be conserved in an elastic collision, show that in general molecules of a gas cannot have the same speeds after a collision as they had before. Is it possible, then, for a gas to consist of molecules that all have the same speed?
22. We often say that we see the steam emerging from the spout of a kettle in which water is boiling. However, steam itself is a colorless gas. What is it that you really see?
23. Why does smoke rise, rather than fall, from a lighted candle?
24. Would a gas whose molecules were true geometric points obey the ideal gas law?
25. Why do molecules not travel in perfectly straight lines between collisions and what effect, easily observable in the laboratory, occurs as a result?
26. Why must the time allowed for diffusion separation be relatively short?
27. Suppose we want to obtain ^{238}U instead of ^{235}U as the end product of a diffusion process. Would we use the same process? If not, explain how the separation process would have to be modified.
28. Considering the diffusion of gases into each other, can you draw an analogy to a large jostling crowd with many "collisions" on a large inclined plane with a slope of a few degrees?
29. Can you describe a centrifugal device for gaseous separation? Is a centrifuge better than a diffusion chamber for separation of gases?
30. Do the pressure and volume of air in a house change when the furnace raises the temperature significantly? If not, is the ideal gas law violated?
31. Would you expect real molecules to be spherically symmetrical? If not, how would the potential energy function of Fig. 12*a* change?
32. Explain why the temperature of a gas drops in an adiabatic expansion.
33. If hot air rises, why is it cooler at the top of a mountain than near sea level?
34. Comment on this statement: "There are two ways to carry out an adiabatic process. One is to do it quickly and the other is to do it in an insulated box."
35. A sealed rubber balloon contains a very light gas. The balloon is released and it rises high into the atmosphere. Describe and explain the thermal and mechanical behavior of the balloon.
36. Although real gases can be liquified, an ideal gas cannot be. Explain.
37. Show that as the volume per mole of a gas increases, the van der Waals equation tends to the equation of state of an ideal gas.
38. *Extensive* quantities have values that depend on what the system's boundaries are, whereas *intensive* quantities are independent of the choice of boundaries. That is, extensive quantities are necessarily defined for a whole system, whereas intensive quantities apply uniformly to any small part of the system. Of the following quantities, determine which are extensive and which are intensive: pressure, volume, temperature, density, mass, internal energy.

PROBLEMS

Section 23-1 Macroscopic Properties of a Gas and the Ideal Gas Law

1. (*a*) Calculate the volume occupied by 1.00 mol of an ideal gas at standard conditions, that is, pressure of 1.00 atm ($= 1.01 \times 10^5$ Pa) and temperature of 0°C ($= 273$ K). (*b*) Show that the number of molecules per cubic centimeter (the Loschmidt number) at standard conditions is 2.68×10^{19}.
2. The best vacuum that can be attained in the laboratory corresponds to a pressure of about 10^{-18} atm, or 1.01×10^{-13} Pa. How many molecules are there per cubic centimeter in such a vacuum at 22°C?
3. A quantity of ideal gas at 12.0°C and a pressure of 108 kPa occupies a volume of 2.47 m^3. (*a*) How many moles of the gas are present? (*b*) If the pressure is now raised to 316 kPa and the temperature is raised to 31.0°C, how much volume will the gas now occupy? Assume no leaks.
4. Oxygen gas having a volume of 1130 cm^3 at 42.0°C and a pressure of 101 kPa expands until its volume is 1530 cm^3 and its pressure is 106 kPa. Find (*a*) the number of moles of oxygen in the system and (*b*) its final temperature.
5. A weather balloon is loosely inflated with helium at a pressure of 1.00 atm ($=76.0$ cm Hg) and a temperature of 22.0°C. The gas volume is 3.47 m^3. At an elevation of 6.50 km, the atmospheric pressure is down to 36.0 cm Hg and the helium has expanded, being under no restraint from the confining bag. At this elevation the gas temperature is −48.0°C. What is the gas volume now?
6. The variation in pressure in the Earth's atmosphere, assumed to be at a uniform temperature, is given by

$p = p_0 e^{-Mgy/RT}$, where M is the molar mass of the air. (See Section 17-3.) Show that $n_V = n_{V0} e^{-Mgy/RT}$, where n_V is the number of molecules per unit volume.

7. Consider a given mass of ideal gas. Compare curves representing constant pressure, constant volume, and isothermal (constant temperature) processes on (*a*) a pV diagram, (*b*) a pT diagram, and (*c*) a VT diagram. (*d*) How do these curves depend on the mass of gas chosen?

8. Estimate the mass of the Earth's atmosphere. Express your estimate as a fraction of the mass of the Earth. Recall that atmospheric pressure equals 101 kPa.

9. An automobile tire has a volume of 988 in.^{3} and contains air at a gauge pressure of 24.2 lb/in.^{2} when the temperature is $-2.60°$C. Find the gauge pressure of the air in the tire when its temperature rises to 25.6°C and its volume increases to 1020 in.^{3}. (*Hint*: It is not necessary to convert from British to SI units. Why? Use $p_{atm} = 14.7$ lb/in.^{2}.)

10. (*a*) Consider 1.00 mol of an ideal gas at 285 K and 1.00 atm pressure. Imagine that the molecules are for the most part evenly spaced at the centers of identical cubes. Using Avogadro's constant and taking the diameter of a molecule to be 3.00×10^{-8} cm, find the length of an edge of such a cube and calculate the ratio of this length to the diameter of a molecule. The edge length is an estimate of the distance between molecules in the gas. (*b*) Now consider a mole of water having a volume of 18 cm^3. Again imagine the molecules to be evenly spaced at the centers of identical cubes and repeat the calculation in (*a*).

11. An air bubble of 19.4 cm^3 volume is at the bottom of a lake 41.5 m deep where the temperature is 3.80°C. The bubble rises to the surface, which is at a temperature of 22.6°C. Take the temperature of the bubble to be the same as that of the surrounding water and find its volume just before it reaches the surface.

12. An open–closed pipe of length $L = 25.0$ m contains air at atmospheric pressure. It is thrust vertically into a freshwater lake until the water rises halfway up in the pipe, as shown in Fig. 16. What is the depth h of the lower end of the pipe? Assume that the temperature is the same everywhere and does not change.

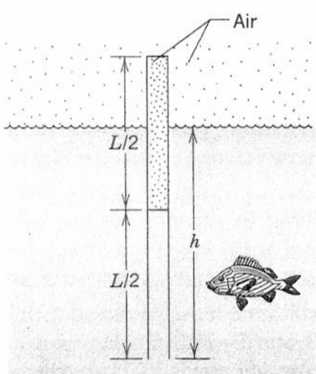

Figure 16 Problem 12.

13. Container A contains an ideal gas at a pressure of 5.0×10^5 Pa and at a temperature of 300 K. It is connected by a thin tube to container B with four times the volume of A; see Fig. 17. B contains the same ideal gas at a pressure of 1.0×10^5 Pa and at a temperature of 400 K. The connecting valve is opened, and equilibrium is achieved at a common pressure while the temperature of each container is kept constant at its initial value. What is the final pressure in the system?

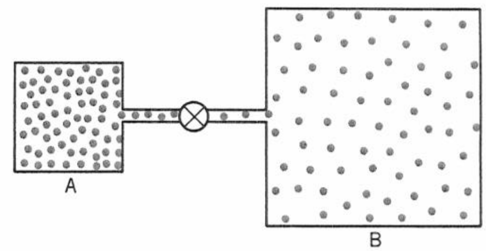

Figure 17 Problem 13.

14. Two vessels of volumes 1.22 L and 3.18 L contain krypton gas and are connected by a thin tube. Initially, the vessels are at the same temperature, 16.0°C, and the same pressure, 1.44 atm. The larger vessel is then heated to 108°C while the smaller one remains at 16.0°C. Calculate the final pressure. (*Hint*: There are no leaks.)

15. Consider a sample of argon gas at 35.0°C and 1.22 atm pressure. Suppose that the radius of a (spherical) argon atom is 0.710×10^{-10} m. Calculate the fraction of the container volume actually occupied by atoms.

16. A mercury-filled manometer with two unequal-length arms of the same cross-sectional area is sealed off with the same pressure p_0 in the two arms, as in Fig. 18. With the temperature constant, an additional 10.0 cm^3 of mercury is admitted through the stopcock at the bottom. The level on the left increases 6.00 cm and that on the right increases 4.00 cm. Find the pressure p_0.

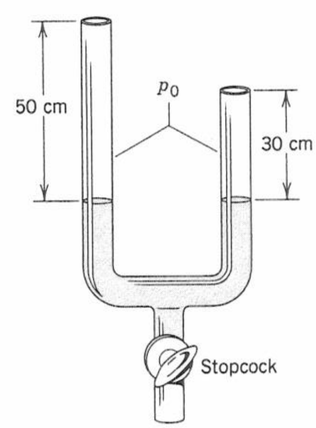

Figure 18 Problem 16.

Section 23-3 Kinetic Calculation of the Pressure

17. The temperature in interstellar space is 2.7 K. Find the root-mean-square speed of hydrogen molecules at this temperature. (See Table 1.)

18. Calculate the root-mean-square speed of ammonia (NH_3) molecules at 56.0°C. An atom of nitrogen has a mass of

2.33×10^{-26} kg and an atom of hydrogen has a mass of 1.67×10^{-27} kg.

19. At 0°C and 1.000 atm pressure the densities of air, oxygen, and nitrogen are, respectively, 1.293 kg/m^3, 1.429 kg/m^3, and 1.250 kg/m^3. Calculate the fraction by mass of nitrogen in the air from these data, assuming only these two gases to be present.

20. The mass of the H_2 molecule is 3.3×10^{-24} g. If 1.6×10^{23} hydrogen molecules per second strike 2.0 cm^2 of wall at an angle of 55° with the normal when moving with a speed of 1.0×10^5 cm/s, what pressure do they exert on the wall?

21. At 44.0°C and 1.23×10^{-2} atm the density of a gas is 1.32×10^{-5} g/cm^3. (*a*) Find v_{rms} for the gas molecules. (*b*) Find the molar mass of the gas and identify it.

22. *Dalton's law* states that when mixtures of gases having no chemical interaction are present together in a vessel, the pressure exerted by each constituent at a given temperature is the same as it would exert if it alone filled the whole vessel, and that the total pressure is equal to the sum of the partial pressures of each gas. Derive this law from kinetic theory, using Eq. 14.

23. A container encloses two ideal gases. Two moles of the first gas are present, with molar mass M_1. Molecules of the second gas have a molar mass $M_2 = 3M_1$, and 0.5 mol of this gas is present. What fraction of the total pressure on the container wall is attributable to the second gas? (*Hint*: See Problem 22.)

Section 23-4 Kinetic Interpretation of the Temperature

24. The Sun is a huge ball of hot ideal gas. The glow surrounding the Sun in the x-ray photo shown in Fig. 19 is the corona— the atmosphere of the Sun. Its temperature and pressure are 2.0×10^6 K and 0.030 Pa. Calculate the rms speed of free electrons in the corona.

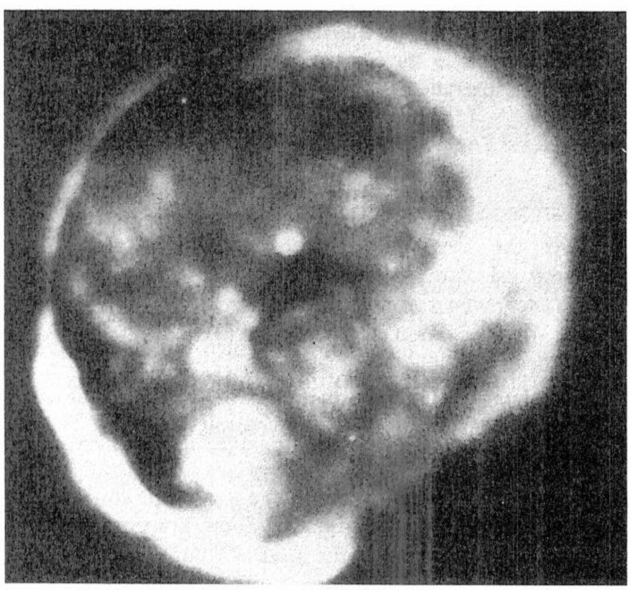

Figure 19 Problem 24.

25. (*a*) Calculate the average value in electron-volts of the translational kinetic energy of the particles of an ideal gas at 0°C and at 100°C. (*b*) Find the translational kinetic energy per mole of an ideal gas at these temperatures, in joules.

26. At what temperature is the average translational kinetic energy of a molecule in an ideal gas equal to 1.00 eV?

27. Oxygen (O_2) gas at 15°C and 1.0 atm pressure is confined to a cubical box 25 cm on a side. Calculate the ratio of the change in gravitational potential energy of a mole of oxygen molecules falling the height of the box to the total translational kinetic energy of the molecules.

28. Gold has a molar (atomic) mass of 197 g/mol. Consider a 2.56-g sample of pure gold vapor. (*a*) Calculate the number of moles of gold present. (*b*) How many atoms of gold are present?

29. Find the average translational kinetic energy of individual nitrogen molecules at 1600 K (*a*) in joules and (*b*) in electron-volts.

30. (*a*) Find the number of molecules in 1.00 m^3 of air at 20.0°C and at a pressure of 1.00 atm. (*b*) What is the mass of this volume of air? Assume that 75% of the molecules are nitrogen (N_2) and 25% are oxygen (O_2).

31. Consider a gas at temperature T occupying a volume V to consist of a mixture of atoms, namely, N_a atoms of mass m_a each having an rms speed v_a, and N_b atoms of mass m_b each having an rms speed v_b. (*a*) Give an expression for the total pressure exerted by the gas. (*b*) Suppose now that $N_a = N_b$ and that the different atoms combine at constant volume to form molecules of mass $m_a + m_b$. Once the temperature returns to its original value, what would be the ratio of the pressure after combination to the pressure before?

32. A steel tank contains 315 g of ammonia gas (NH_3) at an absolute pressure of 1.35×10^6 Pa and temperature 77.0°C. (*a*) What is the volume of the tank? (*b*) The tank is checked later when the temperature has dropped to 22.0°C and the absolute pressure has fallen to 8.68×10^5 Pa. How many grams of gas leaked out of the tank?

33. (*a*) Compute the temperatures at which the rms speed is equal to the speed of escape from the surface of the Earth for molecular hydrogen and for molecular oxygen. (*b*) Do the same for the Moon, assuming the gravitational acceleration on its surface to be $0.16g$. (*c*) The temperature high in the Earth's upper atmosphere is about 1000 K. Would you expect to find much hydrogen there? Much oxygen?

34. At what temperature do the atoms of helium gas have the same rms speed as the molecules of hydrogen gas at 26.0°C?

35. The envelope and basket of a hot-air balloon have a combined mass of 249 kg, and the envelope has a capacity of 2180 m^3. When fully inflated, what should be the temperature of the enclosed air to give the balloon a lifting capacity of 272 kg (in addition to its own mass)? Assume that the surrounding air, at 18.0°C, has a density of 1.22 kg/m^3.

Section 23-5 Work Done on an Ideal Gas

36. A sample of gas expands from 1.0 to 5.0 m^3 while its pressure decreases from 15 to 5.0 Pa. How much work is done on the gas if its pressure changes with volume according to each of the three processes shown in the pV diagram in Fig. 20?

37. Suppose that a sample of gas expands from 2.0 to 8.0 m^3 along the diagonal path in the pV diagram shown in Fig. 21. It is then compressed back to 2.0 m^3 along either path 1 or

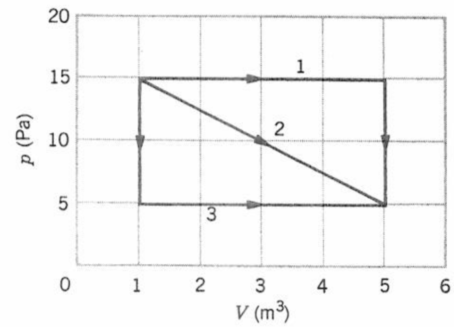

Figure 20 Problem 36.

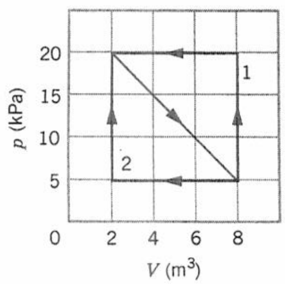

Figure 21 Problem 37.

path 2. Compute the net work done on the gas for the complete cycle in each case.

38. The speed of sound in different gases at the same temperature depends on the molar mass of the gas. Show that $v_1/v_2 = \sqrt{M_2/M_1}$ (constant T), where v_1 is the speed of sound in the gas of molar mass M_1 and v_2 is the speed of sound in the gas of molar mass M_2.

39. Air at 0.00°C and 1.00 atm pressure has a density of 1.291×10^{-3} g/cm³, and the speed of sound is 331 m/s at that temperature. Compute (*a*) the value of γ of air and (*b*) the effective molar mass of air.

40. Air that occupies 0.142 m³ at 103 kPa gauge pressure is expanded isothermally to zero gauge pressure and then cooled at constant pressure until it reaches its initial volume. Compute the work done on the gas.

41. Calculate the work done by an external agent in compressing 1.12 mol of oxygen from a volume of 22.4 L and 1.32 atm pressure to 15.3 L at the same temperature.

42. Use the result of Sample Problem 6 to show that the speed of sound in air increases about 0.59 m/s for each Celsius degree rise in temperature near 20°C.

43. Gas occupies a volume of 4.33 L at a pressure of 1.17 atm and a temperature of 310 K. It is compressed adiabatically to a volume of 1.06 L. Determine (*a*) the final pressure and (*b*) the final temperature, assuming the gas to be an ideal gas for which $\gamma = 1.40$. (*c*) How much work was done on the gas?

44. (*a*) One liter of gas with $\gamma = 1.32$ is at 273 K and 1.00 atm pressure. It is suddenly (adiabatically) compressed to half its original volume. Find its final pressure and temperature. (*b*) The gas is now cooled back to 273 K at constant pressure. Find the final volume. (*c*) Find the total work done on the gas.

45. The gas in a cloud chamber at a temperature of 292 K undergoes a rapid expansion. Assuming the process is adiabatic, calculate the final temperature if $\gamma = 1.40$ and the volume expansion ratio is 1.28.

46. An air compressor takes air at 18.0°C and 1.00 atm pressure and delivers compressed air at 2.30 atm pressure. The compressor operates at 230 W of useful power. Assume that the compressor operates adiabatically. (*a*) Find the temperature of the compressed air. (*b*) How much compressed air, in liters, is delivered each second?

47. A thin tube, sealed at both ends, is 1.00 m long. It lies horizontally, the middle 10.0 cm containing mercury and the two equal ends containing air at standard atmospheric pressure. If the tube is now turned to a vertical position, by what amount will the mercury be displaced? Assume that the process is (*a*) isothermal and (*b*) adiabatic. (For air, $\gamma = 1.40$.) Which assumption is more reasonable?

Section 23-6 The Internal Energy of an Ideal Gas

48. Calculate the internal energy of 1 mole of an ideal gas at 25.0°C.

49. Calculate the total rotational kinetic energy of all the molecules in 1 mole of air at 25.0°C.

50. A cosmic-ray particle with energy 1.34 TeV is stopped in a detecting tube that contains 0.120 mol of neon gas. Once this energy is distributed among all the atoms, by how much is the temperature of the neon increased?

51. An ideal gas experiences an adiabatic compression from $p = 122$ kPa, $V = 10.7$ m³, $T = -23.0$°C to $p = 1450$ kPa, $V = 1.36$ m³. (*a*) Calculate the value of γ. (*b*) Find the final temperature. (*c*) How many moles of gas are present? (*d*) What is the total translational kinetic energy per mole before and after the compression? (*e*) Calculate the ratio of the rms speed before to that after the compression.

Section 23-8 The Van der Waals Equation of State

52. Van der Waals b for oxygen is 32 cm³/mol. Compute the diameter of an O_2 molecule.

53. Using the values of a and b for CO_2 found in Sample Problem 8, calculate the pressure at 16.0°C of 2.55 mol of CO_2 gas occupying a volume of 14.2 L. Assume (*a*) that the van der Waals equation is correct, then (*b*) that CO_2 behaves as an ideal gas.

54. Calculate the work done on n moles of a van der Waals gas in an isothermal expansion from volume V_i to V_f.

55. Show that $V_{cr} = 3nb$.

56. The constants a and b in the van der Waals equation are different for different substances. Show, however, that if we take V_{cr}, p_{cr}, and T_{cr} as the units of volume, pressure, and temperature, the van der Waals equation becomes identical for all substances.