PHYSICS APPLIED
Diffusion in living organisms

Diffusion is extremely important for living organisms. For example, molecules produced in certain chemical reactions within cells diffuse to other areas where they take part in other reactions.

Gas diffusion is important too. Plants require carbon dioxide for photosynthesis. The CO_2 diffuses into leaves from the outside air through tiny openings (stomata). As CO_2 is utilized by the cells, its concentration drops below that in the air outside, and more diffuses inward. Water vapor and oxygen produced by the cells diffuse outward into the air.

Animals also exchange oxygen and CO_2 with the environment. Oxygen is required for energy-producing reactions and must diffuse into cells. CO_2 is produced as an end product of many metabolic reactions and must diffuse out of cells. But diffusion is slow over longer distances, so only the smallest organisms in the animal world could survive without having developed complex respiratory and circulatory systems. In humans, oxygen is taken into the lungs, where it diffuses short distances across lung tissue and into the blood. Then the blood circulates it to cells throughout the body. The blood also carries CO_2 produced by the cells back to the lungs, where it diffuses outward.

Summary

The atomic theory of matter postulates that all matter is made up of tiny entities called **atoms**, which are typically 10^{-10} m in diameter.

Atomic and **molecular masses** are specified on a scale where ordinary carbon (^{12}C) is arbitrarily given the value 12.0000 u (atomic mass units).

The distinction between solids, liquids, and gases can be attributed to the strength of the attractive forces between the atoms or molecules and to their average speed.

Temperature is a measure of how hot or cold something is. **Thermometers** are used to measure temperature on the **Celsius** (°C), **Fahrenheit** (°F), and **Kelvin** (K) scales. Two standard points on each scale are the freezing point of water (0°C, 32°F, 273.15 K) and the boiling point of water (100°C, 212°F, 373.15 K). A one-kelvin change in temperature equals a change of one Celsius degree or $\frac{9}{5}$ Fahrenheit degrees. Kelvins are related to °C by

$$T(\mathrm{K}) = T(^\circ\mathrm{C}) + 273.15.$$

The change in length, ΔL, of a solid, when its temperature changes by an amount ΔT, is directly proportional to the temperature change and to its original length L_0. That is,

$$\Delta L = \alpha L_0 \, \Delta T, \tag{13–1a}$$

where α is the *coefficient of linear expansion*.

The change in volume of most solids, liquids, and gases is proportional to the temperature change and to the original volume V_0:

$$\Delta V = \beta V_0 \, \Delta T. \tag{13–2}$$

The *coefficient of volume expansion*, β, is approximately equal to 3α for uniform solids.

Water is unusual because, unlike most materials whose volume increases with temperature, its volume actually decreases as the temperature increases in the range from 0°C to 4°C.

The **ideal gas law**, or **equation of state for an ideal gas**, relates the pressure P, volume V, and temperature T (in kelvins) of n moles of gas by

$$PV = nRT, \tag{13–3}$$

where $R = 8.314\,\mathrm{J/mol\cdot K}$ for all gases. Real gases obey the ideal gas law quite accurately if they are not at too high a pressure or near their liquefaction point.

One **mole** of a substance is defined as the number of grams which is numerically equal to the atomic or molecular mass.

Avogadro's number, $N_A = 6.02 \times 10^{23}$, is the number of atoms or molecules in 1 mol of any pure substance.

The ideal gas law can be written in terms of the number of molecules N in the gas as

$$PV = NkT, \tag{13–4}$$

where $k = R/N_A = 1.38 \times 10^{-23}\,\mathrm{J/K}$ is Boltzmann's constant.

According to the **kinetic theory** of gases, which is based on the idea that a gas is made up of molecules that are moving rapidly and randomly, the average kinetic energy of molecules is proportional to the Kelvin temperature T:

$$\overline{\mathrm{KE}} = \tfrac{1}{2}m\overline{v^2} = \tfrac{3}{2}kT, \tag{13–8}$$

where k is Boltzmann's constant. At any moment, there exists a wide distribution of molecular speeds within a gas.

[*The behavior of real gases at high pressure, and/or near their liquefaction point, deviates from the ideal gas law, due to molecular size and the attractive forces between molecules. Below the **critical temperature**, a gas can change to a liquid if sufficient pressure is applied; but if the temperature is higher than the critical temperature, no amount of pressure will cause a liquid surface to form. The **triple point** of a substance is that unique temperature and pressure at which all three phases—solid, liquid, and gas—can coexist in equilibrium.]

[***Evaporation** of a liquid is the result of the fastest moving molecules escaping from the surface. **Saturated vapor pressure** refers to the pressure of the vapor above a liquid when the two phases are in equilibrium. The vapor pressure of a substance at its boiling point is equal to atmospheric pressure. **Relative humidity** of air at a given place is the ratio of the partial pressure of water vapor in the air to the saturated vapor pressure at that temperature; it is usually expressed as a percentage.]

[***Diffusion** is the process whereby molecules of a substance move (on average) from one area to another because of a difference in that substance's concentration.]

Questions

1. Which has more atoms: 1 kg of iron or 1 kg of aluminum? See the Periodic Table or Appendix B.

2. Name several properties of materials that could be exploited to make a thermometer.

3. Which is larger, 1 C° or 1 F°?

*4. If system A is in thermal equilibrium with system B, but B is not in thermal equilibrium with system C, what can you say about the temperatures of A, B, and C?

5. A flat bimetallic strip consists of aluminum riveted to a strip of iron. When heated, the strip will bend. Which metal will be on the outside of the curve? [*Hint*: See Table 13–1.] Why?

6. In the relation $\Delta L = \alpha L_0 \Delta T$, should L_0 be the initial length, the final length, or does it matter? Explain.

7. The units for the coefficient of linear expansion α are $(\mathrm{C}°)^{-1}$, and there is no mention of a length unit such as meters. Would the expansion coefficient change if we used feet or millimeters instead of meters? Explain.

8. Figure 13–27 shows a diagram of a simple *thermostat* used to control a furnace (or other heating or cooling system). The bimetallic strip consists of two strips of different metals bonded together. The electric switch is a glass vessel containing liquid mercury that conducts electricity when it can flow to touch both contact wires. Explain how this device controls the furnace and how it can be set at different temperatures.

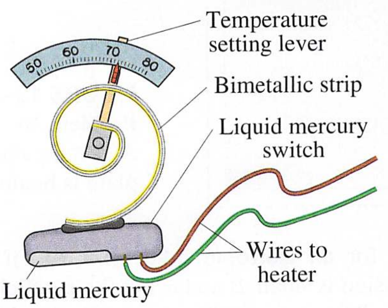

FIGURE 13–27 A thermostat (Question 8).

9. Long steam pipes that are fixed at the ends often have a section in the shape of a U. Why?

10. A flat, uniform cylinder of lead floats in mercury at 0°C. Will the lead float higher or lower when the temperature is raised? Explain.

11. When a cold mercury-in-glass thermometer is first placed in a hot tub of water, the mercury initially descends a bit and then rises. Explain.

12. A glass container may break if one part of it is heated or cooled more rapidly than adjacent parts. Explain.

13. The principal virtue of Pyrex glass is that its coefficient of linear expansion is much smaller than that for ordinary glass (Table 13–1). Explain why this gives rise to the increased heat resistance of Pyrex.

14. Will a grandfather clock, accurate at 20°C, run fast or slow on a hot day (30°C)? Explain. The clock uses a pendulum supported on a long, thin brass rod.

15. Freezing a can of soda will cause its bottom and top to bulge so badly the can will not stand up. What has happened?

16. When a gas is rapidly compressed (say, by pushing down a piston), its temperature increases. When a gas expands against a piston, it cools. Explain these changes in temperature using the kinetic theory, in particular noting what happens to the momentum of molecules when they strike the moving piston.

17. Will the buoyant force on an aluminum sphere submerged in water increase or decrease if the temperature is increased from 20°C to 40°C? Explain.

18. Explain in words how Charles's law follows from kinetic theory and the relation between average kinetic energy and the absolute temperature.

19. Explain in words how Gay-Lussac's law follows from kinetic theory.

20. As you go higher in the Earth's atmosphere, the ratio of N_2 molecules to O_2 molecules increases. Why?

*21. Escape velocity for the Earth refers to the minimum speed an object must have to leave the Earth and never return. The escape velocity for the Moon is about one-fifth what it is for the Earth due to the Moon's smaller mass. Explain why the Moon has practically no atmosphere.

*22. Alcohol evaporates more quickly than water at room temperature. What can you infer about the molecular properties of one relative to the other?

*23. Explain why a hot humid day is far more uncomfortable than a hot dry day at the same temperature.

*24. Is it possible to boil water at room temperature (20°C) without heating it? Explain.

*25. Consider two days when the air temperature is the same but the humidity is different. Which is more dense, the dry air or the humid air at the same T? Explain.

*26. Explain why it is dangerous to open the radiator cap of an overheated automobile engine.

*27. Why does exhaled air appear as a little white cloud in the winter (Fig. 13–28)?

FIGURE 13–28 Question 27.

Problems

13–1 Atomic Theory

1. (I) How many atoms are there in a 3.4-gram copper penny?
2. (I) How does the number of atoms in a 26.5-gram gold ring compare to the number in a silver ring of the same mass?

13–2 Temperature and Thermometers

3. (I) (*a*) "Room temperature" is often taken to be 68°F. What is this on the Celsius scale? (*b*) The temperature of the filament in a lightbulb is about 1800°C. What is this on the Fahrenheit scale?
4. (I) Among the highest and lowest temperatures recorded are 136°F in the Libyan desert and −129°F in Antarctica. What are these temperatures on the Celsius scale?
5. (I) (*a*) 15° below zero on the Celsius scale is what Fahrenheit temperature? (*b*) 15° below zero on the Fahrenheit scale is what Celsius temperature?
6. (II) In an alcohol-in-glass thermometer, the alcohol column has length 11.82 cm at 0.0°C and length 22.85 cm at 100.0°C. What is the temperature if the column has length (*a*) 16.70 cm, and (*b*) 20.50 cm?

13–4 Thermal Expansion

7. (I) A concrete highway is built of slabs 12 m long (20°C). How wide should the expansion cracks between the slabs be (at 20°C) to prevent buckling if the range of temperature is −30°C to +50°C?
8. (I) Super Invar™, an alloy of iron and nickel, is a strong material with a very low coefficient of linear expansion $[0.2 \times 10^{-6}\,(\mathrm{C}°)^{-1}]$. A 2.0-m-long tabletop made of this alloy is used for sensitive laser measurements where extremely high tolerances are required. How much will this table expand along its length if the temperature increases 5.0 C°? Compare to tabletops made of steel.
9. (I) The Eiffel Tower (Fig. 13–29) is built of wrought iron approximately 300 m tall. Estimate how much its height changes between July (average temperature of 25°C) and January (average temperature of 2°C). Ignore the angles of the iron beams, and treat the tower as a vertical beam.

FIGURE 13–29 Problem 9. The Eiffel Tower in Paris.

10. (II) To make a secure fit, rivets that are larger than the rivet hole are often used and the rivet is cooled (usually in dry ice) before it is placed in the hole. A steel rivet 1.871 cm in diameter is to be placed in a hole 1.869 cm in diameter at 20°C. To what temperature must the rivet be cooled if it is to fit in the hole?
11. (II) The density of water at 4°C is $1.00 \times 10^3\ \mathrm{kg/m^3}$. What is water's density at 94°C?
12. (II) A quartz sphere is 8.75 cm in diameter. What will be its change in volume if it is heated from 30°C to 200°C?
13. (II) An ordinary glass is filled to the brim with 350.0 mL of water at 100.0°C. If the temperature decreased to 20.0°C, how much water could be added to the glass?
14. (II) It is observed that 55.50 mL of water at 20°C completely fills a container to the brim. When the container and the water are heated to 60°C, 0.35 g of water is lost. (*a*) What is the coefficient of volume expansion of the container? (*b*) What is the most likely material of the container? The density of water at 60°C is 0.98324 g/mL.
15. (II) (*a*) A brass plug is to be placed in a ring made of iron. At 20°C, the diameter of the plug is 8.753 cm and that of the inside of the ring is 8.743 cm. They must both be brought to what common temperature in order to fit? (*b*) What if the plug were iron and the ring brass?
16. (II) If a fluid is contained in a long, narrow vessel so it can expand in essentially one direction only, show that the effective coefficient of linear expansion α is approximately equal to the coefficient of volume expansion β.
17. (II) (*a*) Show that the change in the density ρ of a substance, when the temperature changes by ΔT, is given by $\Delta\rho = -\beta\rho\,\Delta T$. (*b*) What is the fractional change in density of a lead sphere whose temperature decreases from 25°C to −40°C?
18. (II) A uniform rectangular plate of length l and width w has coefficient of linear expansion α. Show that, if we neglect very small quantities, the change in area of the plate due to a temperature change ΔT is $\Delta A = 2\alpha l w\,\Delta T$. See Fig. 13–30.

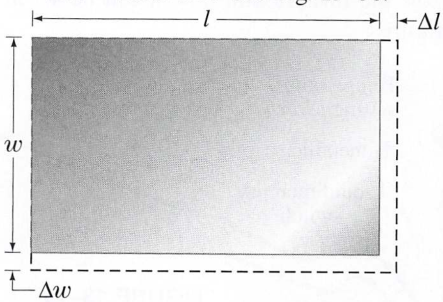

FIGURE 13–30 Problem 18. A rectangular plate is heated.

19. (III) Show that for an isotropic solid, $\beta = 3\alpha$, if the amount of expansion is small. β and α are the coefficients of volume and linear expansion, respectively. [*Hint*: Consider a cubical solid, and neglect very small quantities. See also Problem 18 and Fig. 13–30.]
20. (III) The pendulum in a grandfather clock is made of brass and keeps perfect time at 17°C. How much time is gained or lost in a year if the clock is kept at 25°C? (Assume the frequency dependence on length for a simple pendulum applies.)
21. (III) (*a*) The tube of a mercury thermometer has an inside diameter of 0.140 mm. The bulb has a volume of 0.255 cm³. How far will the thread of mercury move when the temperature changes from 11.5°C to 33.0°C? Take into account expansion of the Pyrex glass. (*b*) Determine a formula for the change in length of the mercury column in terms of relevant variables. Ignore tube volume compared to bulb volume.
22. (III) A 23.4-kg solid aluminum cylindrical wheel of radius 0.41 m is rotating about its axle on frictionless bearings with angular velocity $\omega = 32.8\ \mathrm{rad/s}$. If its temperature is now raised from 20.0°C to 75.0°C, what is the fractional change in ω?

* 13–5 Thermal Stresses

* **23.** (II) An aluminum bar has the desired length when at 15°C. How much stress is required to keep it at this length if the temperature increases to 35°C?

* **24.** (II) (*a*) A horizontal steel I-beam of cross-sectional area $0.041\ m^2$ is rigidly connected to two vertical steel girders. If the beam was installed when the temperature was 30°C, what stress is developed in the beam when the temperature drops to −30°C? (*b*) Is the ultimate strength of the steel exceeded? (*c*) What stress is developed if the beam is concrete and has a cross-sectional area of $0.13\ m^2$? Will it fracture?

* **25.** (III) A barrel of diameter 134.122 cm at 20°C is to be enclosed by an iron band. The circular band has an inside diameter of 134.110 cm at 20°C. It is 7.4 cm wide and 0.65 cm thick. (*a*) To what temperature must the band be heated so that it will fit over the barrel? (*b*) What will be the tension in the band when it cools to 20°C?

13–6 Gas Laws; Absolute Temperature

26. (I) What are the following temperatures on the Kelvin scale: (*a*) 86°C, (*b*) 78°F, (*c*) −100°C, (*d*) 5500°C, (*e*) −459°F?

27. (I) Absolute zero is what temperature on the Fahrenheit scale?

28. (II) Typical temperatures in the interior of the Earth and Sun are about 4000°C and 15×10^6 °C, respectively. (*a*) What are these temperatures in kelvins? (*b*) What percent error is made in each case if a person forgets to change °C to K?

13–7 and 13–8 Ideal Gas Law

29. (I) If $3.00\ m^3$ of a gas initially at STP is placed under a pressure of 3.20 atm, the temperature of the gas rises to 38.0°C. What is the volume?

30. (I) In an internal combustion engine, air at atmospheric pressure and a temperature of about 20°C is compressed in the cylinder by a piston to $\frac{1}{9}$ of its original volume (compression ratio = 9.0). Estimate the temperature of the compressed air, assuming the pressure reaches 40 atm.

31. (II) Calculate the density of oxygen at STP using the ideal gas law.

32. (II) A storage tank contains 21.6 kg of nitrogen (N_2) at an absolute pressure of 3.65 atm. What will the pressure be if the nitrogen is replaced by an equal mass of CO_2?

33. (II) A storage tank at STP contains 18.5 kg of nitrogen (N_2). (*a*) What is the volume of the tank? (*b*) What is the pressure if an additional 15.0 kg of nitrogen is added without changing the temperature?

34. (II) If 18.75 mol of helium gas is at 10.0°C and a gauge pressure of 0.350 atm, (*a*) calculate the volume of the helium gas under these conditions. (*b*) Calculate the temperature if the gas is compressed to precisely half the volume at a gauge pressure of 1.00 atm.

35. (II) What is the pressure inside a 35.0-L container holding 105.0 kg of argon gas at 385 K?

36. (II) A tank contains 26.0 kg of O_2 gas at a gauge pressure of 8.70 atm. If the oxygen is replaced by helium, how many kilograms of the latter will be needed to produce a gauge pressure of 7.00 atm?

37. (II) A hot-air balloon achieves its buoyant lift by heating the air inside the balloon, which makes it less dense than the air outside. Suppose the volume of a balloon is $1800\ m^3$ and the required lift is 2700 N (rough estimate of the weight of the equipment and passenger). Calculate the temperature of the air inside the balloon which will produce the required lift. Assume that the outside air temperature is 0°C and that air is an ideal gas under these conditions. What factors limit the maximum altitude attainable by this method for a given load? (Neglect variables like wind.)

38. (II) A tire is filled with air at 15°C to a gauge pressure of 220 kPa. If the tire reaches a temperature of 38°C, what fraction of the original air must be removed if the original pressure of 220 kPa is to be maintained?

39. (II) If 61.5 L of oxygen at 18.0°C and an absolute pressure of 2.45 atm are compressed to 48.8 L and at the same time the temperature is raised to 50.0°C, what will the new pressure be?

40. (III) A helium-filled balloon escapes a child's hand at sea level and 20.0°C. When it reaches an altitude of 3000 m, where the temperature is 5.0°C and the pressure is only 0.70 atm, how will its volume compare to that at sea level?

13–9 Ideal Gas Law in Terms of Molecules; Avogadro's Number

41. (I) Calculate the number of molecules/m^3 in an ideal gas at STP.

42. (I) How many moles of water are there in 1.000 L? How many molecules?

43. (II) Estimate the number of (*a*) moles, and (*b*) molecules of water in all the Earth's oceans. Assume water covers 75% of the Earth to an average depth of 3 km.

44. (II) A cubic box of volume $5.1 \times 10^{-2}\ m^3$ is filled with air at atmospheric pressure at 20°C. The box is closed and heated to 180°C. What is the net force on each side of the box?

45. (III) Estimate how many molecules of air are in each 2.0-L breath you inhale that were also in the last breath Galileo took. [*Hint*: Assume the atmosphere is about 10 km high and of constant density.]

13–10 Molecular Interpretation of Temperature

46. (I) (*a*) What is the average translational kinetic energy of an oxygen molecule at STP? (*b*) What is the total translational kinetic energy of 2.0 mol of O_2 molecules at 20°C?

47. (I) Calculate the rms speed of helium atoms near the surface of the Sun at a temperature of about 6000 K.

48. (I) By what factor will the rms speed of gas molecules increase if the temperature is increased from 0°C to 100°C?

49. (I) A gas is at 20°C. To what temperature must it be raised to double the rms speed of its molecules?

50. (I) Twelve molecules have the following speeds, given in units of km/s: 6, 2, 4, 6, 0, 4, 1, 8, 5, 3, 7, and 8. Calculate the rms speed.

51. (II) The rms speed of molecules in a gas at 20.0°C is to be increased by 1.0%. To what temperature must it be raised?

52. (II) If the pressure of a gas is doubled while its volume is held constant, by what factor does v_{rms} change?

53. (II) Show that the rms speed of molecules in a gas is given by $v_{rms} = \sqrt{3P/\rho}$, where P is the pressure in the gas, and ρ is the gas density.

54. (II) Show that for a mixture of two gases at the same temperature, the ratio of their rms speeds is equal to the inverse ratio of the square roots of their molecular masses.

55. (II) What is the rms speed of nitrogen molecules contained in an 8.5-m^3 volume at 2.1 atm if the total amount of nitrogen is 1300 mol?

56. (II) Calculate (*a*) the rms speed of an oxygen molecule at 0°C and (*b*) determine how many times per second it would move back and forth across a 7.0-m-long room on the average, assuming it made very few collisions with other molecules.

57. (II) What is the average distance between nitrogen molecules at STP?

58. (II) (*a*) Estimate the rms speed of an amino acid whose molecular mass is 89 u in a living cell at 37°C. (*b*) What would be the rms speed of a protein of molecular mass 50,000 u at 37°C?

59. (II) Show that the pressure P of a gas can be written $P = \frac{1}{3}\rho v^2$, where ρ is the density of the gas and v is the rms speed of the molecules.

60. (III) The two isotopes of uranium, ^{235}U and ^{238}U (the superscripts refer to their atomic mass), can be separated by a gas-diffusion process by combining them with fluorine to make the gaseous compound UF_6. Calculate the ratio of the rms speeds of these molecules for the two isotopes, at constant T.

* 13–12 Real Gases; Phase Changes

* 61. (I) (*a*) At atmospheric pressure, in what phases can CO_2 exist? (*b*) For what range of pressures and temperatures can CO_2 be a liquid? Refer to Fig. 13–21.

* 62. (I) Water is in which phase when the pressure is 0.01 atm and the temperature is (*a*) 90°C, (*b*) −20°C?

* 13–13 Vapor Pressure; Humidity

* 63. (I) What is the dew point (approximately) if the humidity is 50% on a day when the temperature is 25°C?

* 64. (I) What is the air pressure at a place where water boils at 90°C?

* 65. (I) If the air pressure at a particular place in the mountains is 0.72 atm, estimate the temperature at which water boils.

* 66. (I) What is the temperature on a day when the partial pressure of water is 530 Pa and the relative humidity is 40%?

* 67. (I) What is the partial pressure of water on a day when the temperature is 25°C and the relative humidity is 35%?

* 68. (I) What is the approximate pressure inside a pressure cooker if the water is boiling at a temperature of 120°C? Assume no air escaped during the heating process, which started at 20°C.

* 69. (II) If the humidity in a room of volume 680 m^3 at 25°C is 80%, what mass of water can still evaporate from an open pan?

* 70. (III) Air that is at its dew point of 5°C is drawn into a building where it is heated to 25°C. What will be the relative humidity at this temperature? Assume constant pressure of 1.0 atm. Take into account the expansion of the air.

* 13–14 Diffusion

* 71. (II) Estimate the time needed for a glycine molecule (see Table 13–4) to diffuse a distance of 15 μm in water at 20°C if its concentration varies over that distance from 1.00 mol/m^3 to 0.40 mol/m^3. Compare this "speed" to its rms (thermal) speed. The molecular mass of glycine is about 75 u.

* 72. (II) Oxygen diffuses from the surface of insects to the interior through tiny tubes called tracheae. An average trachea is about 2 mm long and has cross-sectional area of $2 \times 10^{-9}\,m^2$. Assuming the concentration of oxygen inside is half what it is outside in the atmosphere, (*a*) show that the concentration of oxygen in the air (assume 21% is oxygen) at 20°C is about 8.7 mol/m^3, then (*b*) calculate the diffusion rate J, and (*c*) estimate the average time for a molecule to diffuse in. Assume the diffusion constant is $1 \times 10^{-5}\,m^2/s$.

General Problems

73. A precise steel tape measure has been calibrated at 20°C. At 34°C, (*a*) will it read high or low, and (*b*) what will be the percentage error?

74. A Pyrex measuring cup was calibrated at normal room temperature. How much error will be made in a recipe calling for 300 mL of cool water, if the water and the cup are hot, at 80°C, instead of at 20°C? Neglect the glass expansion.

75. The gauge pressure in a helium gas cylinder is initially 28 atm. After many balloons have been blown up, the gauge pressure has decreased to 5 atm. What fraction of the original gas remains in the cylinder?

76. Estimate the number of air molecules in a room of length 6.5 m, width 3.1 m, and height 2.5 m. Assume the temperature is 22°C. How many moles does that correspond to?

77. In outer space the density of matter is about one atom per cm^3, mainly hydrogen atoms, and the temperature is about 2.7 K. Calculate the rms speed of these hydrogen atoms, and the pressure (in atmospheres).

78. The lowest pressure attainable using the best available vacuum techniques is about $10^{-12}\,N/m^2$. At such a pressure, how many molecules are there per cm^3 at 0°C?

79. If a scuba diver fills his lungs to full capacity of 5.5 L when 10 m below the surface, to what volume would his lungs expand if he quickly rose to the surface? Is this advisable?

80. A space vehicle returning from the Moon enters Earth's atmosphere at a speed of about 40,000 km/h. Molecules (assume nitrogen) striking the nose of the vehicle with this speed correspond to what temperature? (Because of this high temperature, the nose of a space vehicle must be made of special materials; indeed, part of it does vaporize, and this is seen as a bright blaze upon reentry.)

81. The temperature of an ideal gas is increased from 110°C to 360°C while the volume and the number of moles stay constant. By what factor does the pressure change? By what factor does v_{rms} change?

82. A house has a volume of $770\ m^3$. (*a*) What is the total mass of air inside the house at 20°C? (*b*) If the temperature drops to −10°C, what mass of air enters or leaves the house?

83. From the known value of atmospheric pressure at the surface of the Earth, estimate the total number of air molecules in the Earth's atmosphere.

84. What is the rms speed of nitrogen molecules contained in a 7.6-m^3 volume at 4.2 atm if the total amount of nitrogen is 1800 mol?

85. A standard cylinder of oxygen used in a hospital has gauge pressure = 2000 psi (13,800 kPa) and volume = 16 L ($0.016\ m^3$) at $T = 295$ K. How long will the cylinder last if the flow rate, measured at atmospheric pressure, is constant at 2.4 L/min?

86. An iron cube floats in a bowl of liquid mercury at 0°C. (*a*) If the temperature is raised to 25°C, will the cube float higher or lower in the mercury? (*b*) By what percent will the fraction of volume submerged change?

87. The density of gasoline at 0°C is $0.68 \times 10^3\ kg/m^3$. What is the density on a hot day, when the temperature is 38°C? What is the percentage change?

88. If a steel band were to fit snugly around the Earth's equator at 25°C, but then was heated to 45°C, how high above the Earth would the band be (assume equal everywhere)?

89. A brass lid screws tightly onto a glass jar at 20°C. To help open the jar, it can be placed into a bath of hot water. After this treatment, the temperatures of the lid and the jar are both 60°C. The inside diameter of the lid is 8.0 cm at 20°C. Find the size of the gap (difference in radius) that develops by this procedure.

90. The first length standard, adopted in the 18th century, was a platinum bar with two very fine marks separated by what was defined to be exactly 1 m. If this standard bar was to be accurate to within ± 1.0 μm, how carefully would the trustees have needed to control the temperature? The coefficient of linear expansion for platinum is $9 \times 10^{-6}\ C°^{-1}$.

91. A scuba tank, when fully charged, has a pressure of 195 atm at 20°C. The volume of the tank is 11.3 L. (*a*) What would the volume of the air be at 1.00 atm and at the same temperature? (*b*) Before entering the water, a person consumes 2.0 L of air in each breath, and breathes 12 times a minute. At this rate, how long would the tank last? (*c*) At a depth of 20.0 m of sea water and temperature of 10°C, how long would the same tank last assuming the breathing rate does not change?

92. The escape speed from the Earth is 1.12×10^4 m/s, so a gas molecule travelling away from Earth near the outer boundary of the Earth's atmosphere would, at this speed, be able to escape from the Earth's gravitational field. At what temperature is the average speed of (*a*) oxygen molecules, and (*b*) helium atoms equal to 1.12×10^4 m/s? (*c*) Can you see why our atmosphere contains oxygen but not helium?

93. A 1.0-kg trash-can lid is suspended against gravity by tennis balls thrown vertically upward at it. How many tennis balls per second must rebound from the lid elastically, assuming they have a mass of 0.060 kg and are thrown at 12 m/s?

94. A scuba diver releases a 3.00-cm-diameter (spherical) bubble of air from a depth of 14.0 m in a lake. Assume the temperature is constant at 298 K, and the air behaves as a perfect gas. How large is the bubble when it reaches the surface?

* 95. Calculate the total water vapor pressure in the air on the following two days: (*a*) a hot summer day, with the temperature 30°C and the relative humidity at 40%; (*b*) a cold winter day, with the temperature 5°C and the relative humidity at 80%.

* 96. A sauna has $7.0\ m^3$ of air volume, and the temperature is 90°C. The air is perfectly dry. How much water (in kg) should be evaporated if we want to increase the relative humidity from 0% to 10%? (See Table 13–3.)

* 97. Estimate the percent difference in the density of iron at STP, and when it is a solid deep in the Earth where the temperature is 2000°C and under 5000 atm of pressure. Assume the bulk modulus ($90 \times 10^9\ N/m^2$) and the coefficient of volume expansion do not vary with temperature and are the same as at STP.

* 98. (*a*) Use the ideal gas law to show that, for an ideal gas at constant pressure, the coefficient of volume expansion is equal to $\beta = 1/T$, where T is the temperature in kelvins. Compare to Table 13–1 for gases at $T = 293$ K. (*b*) Show that the bulk modulus (Section 9–5) for an ideal gas held at constant temperature is $B = P$, where P is the pressure.

* 99. In humid climates, people constantly *dehumidify* their cellars to prevent rot and mildew. If the cellar in a house (kept at 20°C) has $95\ m^2$ of floor space and a ceiling height of 2.8 m, what is the mass of water that must be removed from it to drop the humidity from 95% to a more reasonable 30%?

Answers to Exercises

A: −40°C = −40°F.
B: 24.0 L.
C: Less.
D: 3.5×10^{-9} m/s.