

## CHAPTER 13

1. The number of atoms in a mass
- $m$
- is given by

$$N = m/Mm_{\text{atom}}$$

Because the masses of the two rings are the same, for the ratio we have

$$N_{\text{Au}}/N_{\text{Ag}} = M_{\text{Ag}}/M_{\text{Au}} = 108/197 = \quad 0.548.$$

2. The number of atoms in a mass
- $m$
- is given by

$$N = m/Mm_{\text{atom}} = (3.4 \times 10^{-3} \text{ kg}) / (63.5 \text{ u})(1.66 \times 10^{-27} \text{ kg/u}) = \quad 3.2 \times 10^{22} \text{ atoms}.$$

3. (a)
- $T(^{\circ}\text{C}) = (5/9)[T(^{\circ}\text{F}) - 32] = (5/9)(68^{\circ}\text{F} - 32) = \quad 20^{\circ}\text{C}.$

$$(b) T(^{\circ}\text{F}) = (9/5)T(^{\circ}\text{C}) + 32 = (9/5)(1800^{\circ}\text{C}) + 32 = \quad 3272^{\circ}\text{F}.$$

4. (a)
- $T(^{\circ}\text{F}) = (9/5)T(^{\circ}\text{C}) + 32 = (9/5)(-15^{\circ}\text{C}) + 32 = \quad 5^{\circ}\text{F}.$

$$(b) T(^{\circ}\text{C}) = (5/9)[T(^{\circ}\text{F}) - 32] = (5/9)(-15^{\circ}\text{F} - 32) = \quad -26^{\circ}\text{C}.$$

- 5.
- $T_1(^{\circ}\text{C}) = (5/9)[T_1(^{\circ}\text{F}) - 32] = (5/9)(136^{\circ}\text{F} - 32) = \quad 58^{\circ}\text{C};$

$$T_2(^{\circ}\text{C}) = (5/9)[T_2(^{\circ}\text{F}) - 32] = (5/9)(-129^{\circ}\text{F} - 32) = \quad -89^{\circ}\text{C}.$$

6. Because the temperature and length are linearly related, we have

$$\Delta T / \Delta L = (100.0^{\circ}\text{C} - 0.0^{\circ}\text{C}) / (22.85 \text{ cm} - 10.70 \text{ cm}) = 8.23 \text{ }^{\circ}\text{C}/\text{cm}.$$

$$(a) (T_1 - 0.0^{\circ}\text{C}) / (16.70 \text{ cm} - 10.70 \text{ cm}) = 8.23 \text{ }^{\circ}\text{C}/\text{cm}, \text{ which gives } T_1 = \quad 49.4^{\circ}\text{C}.$$

$$(b) (T_2 - 0.0^{\circ}\text{C}) / (20.50 \text{ cm} - 10.70 \text{ cm}) = 8.23 \text{ }^{\circ}\text{C}/\text{cm}, \text{ which gives } T_2 = \quad 80.7^{\circ}\text{C}.$$

7. Because
- $0^{\circ}$
- in the original scale corresponds to
- $100^{\circ}\text{C}$
- and
- $100^{\circ}$
- corresponds to
- $0^{\circ}\text{C}$
- , the conversion between the two scales is

$$[T(^{\circ}\text{C}) - 0^{\circ}\text{C}] / (100^{\circ}\text{C} - 0^{\circ}\text{C}) = (T - 100^{\circ}) / (0^{\circ} - 100^{\circ}), \text{ or}$$

$$T = 100^{\circ} - T(^{\circ}\text{C}) = 100^{\circ} - 35^{\circ} = \quad 65^{\circ}.$$

8. We set
- $T(^{\circ}\text{F}) = T(^{\circ}\text{C}) = T$
- in the conversion between the temperature scales:

$$T(^{\circ}\text{F}) = (9/5)T(^{\circ}\text{C}) + 32$$

$$T = (9/5)T + 32, \text{ which gives } T = \quad -40^{\circ}\text{F} = -40^{\circ}\text{C}.$$

9. If the slabs are in contact at
- $20^{\circ}\text{C}$
- , at any temperature below this the expansion cracks will increase. Thus the expansion from
- $20^{\circ}\text{C}$
- to
- $50^{\circ}\text{C}$
- must eliminate the cracks. Any higher temperature will cause stress in the concrete. If the cracks have a width
- $\Delta L$
- , we have

$$\Delta L = \alpha L_0 \Delta T = [12 \times 10^{-6} \text{ (}^{\circ}\text{C)}^{-1}](14 \text{ m})(50^{\circ}\text{C} - 20^{\circ}\text{C}) = 5.9 \times 10^{-3} \text{ m} = \quad 0.50 \text{ cm}.$$

10. For the expansion
- $\Delta L$
- , we have

$$\Delta L = \alpha L_0 \Delta T = [0.2 \times 10^{-6} \text{ (}^{\circ}\text{C)}^{-1}](2.0 \text{ m})(5.0^{\circ}\text{C}) = \quad 2.0 \times 10^{-6} \text{ m}.$$

11. The unit for
- $\alpha$
- is
- $(^{\circ}\text{C)}^{-1}$
- . In British units it will be
- $(^{\circ}\text{F)}^{-1}$
- , so we have

$$\alpha_B / \alpha = (F^\circ)^{-1} / (C^\circ)^{-1} = C^\circ / F^\circ = 5/9.$$

12. We can treat the change in diameter as a simple change in length, so we have

$$\Delta L = \alpha L_0 \Delta T;$$

$$1.869 \text{ cm} - 1.871 \text{ cm} = [12 \times 10^{-6} (\text{C}^\circ)^{-1}](1.871 \text{ cm})(T - 20^\circ\text{C}), \text{ which gives } T = -69^\circ\text{C}.$$

13. For the expanded dimensions, we have

$$r' = r(1 + \alpha \Delta T); w' = w(1 + \alpha \Delta T).$$

Thus the change in area is

$$\Delta A = A' - A = r'^2 w' - r^2 w = r^2 w (1 + \alpha \Delta T)^2 - r^2 w = r^2 w [2\alpha \Delta T + (\alpha \Delta T)^2] = r^2 w \alpha \Delta T (2 + \alpha \Delta T).$$

Because  $\alpha \Delta T \ll 2$ , we have

$$\Delta A = 2\alpha r^2 w \Delta T.$$

14. We consider a fixed mass of iron. The change in volume from the temperature change is

$$\Delta V_T = \beta V_0 \Delta T.$$

The change in volume from the pressure change depends on the bulk modulus:

$$\Delta V_P = - (V_0/B) \Delta P.$$

Because the density is mass/volume, for the fractional change in the density we have

$$\begin{aligned} \Delta \rho / \rho_0 &= [(1/V) - (1/V_0)] / (1/V_0) = (V_0 - V) / V \approx (V_0 - V) / V_0 = -\Delta V / V_0 \\ &= -\beta \Delta T + \Delta P / B \\ &= -[35 \times 10^{-6} (\text{C}^\circ)^{-1}](2000^\circ\text{C} - 20^\circ\text{C}) + (5000 \text{ atm})(1.013 \times 10^5 \text{ N/m}^2 \cdot \text{atm}) / (90 \times 10^9 \text{ N/m}^2) \\ &= -0.064 = -6.4\%. \end{aligned}$$

15. The contraction of the glass causes the enclosed volume to decrease as if it were glass. The volume of water that can be added is

$$\begin{aligned} \Delta V &= \Delta V_{\text{glass}} - \Delta V_{\text{water}} = V_0 \beta_{\text{glass}} \Delta T - V_0 \beta_{\text{water}} \Delta T = V_0 (\beta_{\text{glass}} - \beta_{\text{water}}) \Delta T \\ &= (350 \text{ mL}) [27 \times 10^{-6} (\text{C}^\circ)^{-1} - 210 \times 10^{-6} (\text{C}^\circ)^{-1}] (20^\circ\text{C} - 100^\circ\text{C}) = 5.1 \text{ mL}. \end{aligned}$$

16. (a) The expansion of the container causes the enclosed volume to increase as if it were made of the same material as the container. The volume of water that was lost is

$$\begin{aligned} \Delta V &= \Delta V_{\text{water}} - \Delta V_{\text{container}} = V_0 \beta_{\text{water}} \Delta T - V_0 \beta_{\text{container}} \Delta T = V_0 (\beta_{\text{water}} - \beta_{\text{container}}) \Delta T; \\ (0.35 \text{ g}) / (0.98324 \text{ g/mL}) &= (65.50 \text{ mL}) [210 \times 10^{-6} (\text{C}^\circ)^{-1} - \beta_{\text{container}}] (60^\circ\text{C} - 20^\circ\text{C}), \text{ which gives} \\ \beta_{\text{container}} &= 74 \times 10^{-6} (\text{C}^\circ)^{-1}. \end{aligned}$$

- (b) From Table 13-1, **aluminum** is the most likely material.

17. We find the change in volume from

$$\begin{aligned} \Delta V &= V_0 \beta \Delta T = 9^3 r^3 \beta \Delta T \\ &= 9^3 (7.25 \text{ cm})^3 [1 \times 10^{-6} (\text{C}^\circ)^{-1}] (200^\circ\text{C} - 30^\circ\text{C}) = 0.27 \text{ cm}^3. \end{aligned}$$

18. We can treat the change in diameter as a simple change in length, so we have

$$D = D_0(1 + \alpha \Delta T).$$

The two objects must reach the same diameter:

$$D = D_{0\text{brass}}(1 + \alpha_{\text{brass}} \Delta T) = D_{0\text{iron}}(1 + \alpha_{\text{iron}} \Delta T);$$

$$(8.753 \text{ cm}) \{1 + [19 \times 10^{-6} (\text{C}^\circ)^{-1}]\} (T - 20^\circ\text{C}) = (8.743 \text{ cm}) \{1 + [12 \times 10^{-6} (\text{C}^\circ)^{-1}]\} (T - 20^\circ\text{C}),$$

which gives

$$T = -1.4 \times 10^2 \text{ C}^\circ.$$

19. We assume that we can ignore the change in cross sectional area of the tube. The volume change of the fluid is the increased volume in the column:

$$\Delta V = AL\beta\Delta T = A\Delta L, \text{ or } \Delta L = L\beta\Delta T.$$

When we compare this to the expression for linear expansion,

$$\Delta L = L\alpha\Delta T,$$

we see that  $\alpha = \beta$ .

20. (a) We consider a fixed mass of the substance. The change in volume from the temperature change is

$$\Delta V = \beta V_0 \Delta T.$$

Because the density is mass/volume, for the fractional change in the density we have

$$\Delta\rho/\rho = [(1/V) - (1/V_0)]/(1/V_0) = (V_0 - V)/V \approx (V_0 - V)/V_0 = -\Delta V/V_0 = -\beta\Delta T,$$

which we can write

$$\Delta\rho = -\beta\rho\Delta T.$$

- (b) For the lead sphere we have

$$\Delta\rho/\rho = -[87 \times 10^{-6} (\text{C}^\circ)^{-1}](40^\circ\text{C} - 25^\circ\text{C}) = -0.0057 \text{ (0.57\%)}.$$

21. For the expanded dimensions of the rectangular solid, we have

$$L = L_0(1 + \alpha\Delta T); W = W_0(1 + \alpha\Delta T); H = H_0(1 + \alpha\Delta T).$$

Thus the change in volume is

$$\begin{aligned} \Delta V &= V - V_0 = LWH - L_0W_0H_0 \\ &= L_0(1 + \alpha\Delta T)W_0(1 + \alpha\Delta T)H_0(1 + \alpha\Delta T) - L_0W_0H_0 = L_0W_0H_0(1 + \alpha\Delta T)^3 - L_0W_0H_0 \\ &= L_0W_0H_0[3\alpha\Delta T + 3(\alpha\Delta T)^2 + (\alpha\Delta T)^3] = L_0W_0H_0\alpha\Delta T[3 + 3(\alpha\Delta T) + (\alpha\Delta T)^2]. \end{aligned}$$

Because  $\alpha\Delta T \ll 1$ , we have

$$\Delta V = 3\alpha V_0 \Delta T.$$

When we compare this to the expression for volume expansion,

$$\Delta V = \beta V_0 \Delta T,$$

we see that  $\beta = 3\alpha$ .

22. The increase in temperature will cause the length of the brass rod to increase. The period of the pendulum depends on the length,

$$T = 2\pi(L/g)^{1/2},$$

so the period will be greater. This means the pendulum will make fewer swings in a day, so the clock will be slow and the clock will lose time.

We use  $T_C$  for the temperature to distinguish it from the period.

For the length of the brass rod, we have

$$L = L_0(1 + \alpha\Delta T_C).$$

Thus the ratio of periods is

$$T/T_0 = (L/L_0)^{1/2} = (1 + \alpha\Delta T_C)^{1/2}.$$

Because  $\alpha\Delta T_C$  is much less than 1, we have

$$T/T_0 \approx 1 + \frac{1}{2}\alpha\Delta T_C, \text{ or } \Delta T/T_0 = \frac{1}{2}\alpha\Delta T_C.$$

The number of swings in a time  $t$  is  $N = t/T$ . For the same time  $t$ , the change in period will cause a change in the number of swings:

$$\Delta N = (t/T) - (t/T_0) = t(T_0 - T)/TT_0 \approx -t(\Delta T/T_0)/T_0,$$

because  $T \approx T_0$ . The time difference in one year is

$$\begin{aligned} \Delta t &= T_0 \Delta N = -t(\Delta T/T_0) = -t(\frac{1}{2}\alpha\Delta T_C) \\ &= -(1 \text{ yr})(3.16 \times 10^7 \text{ s/yr})(\frac{1}{2})(19 \times 10^{-6} (\text{C}^\circ)^{-1})(25^\circ\text{C} - 17^\circ\text{C}) = -2.4 \times 10^3 \text{ s} = -40 \text{ min}. \end{aligned}$$

23. We find the change in radius from

$$\Delta R = R\alpha\Delta T.$$

Because the bearings are frictionless, angular momentum will be conserved:

$$I_1\omega_1 = I_2\omega_2, \text{ with } I = \frac{1}{2}mR^2 \text{ for a solid cylinder.}$$

For the fractional change in the angular velocity, we have

$$\Delta\omega/\omega = (\omega_2 - \omega_1)/\omega_1 = [(I_1\omega_1/I_2) - \omega_1]/\omega_1 = (I_1 - I_2)/I_2.$$

Because the mass is constant, we have

$$\Delta\omega/\omega = [R^2 - (R + \Delta R)^2]/(R + \Delta R)^2 = -[2R\Delta R + (\Delta R)^2]/(R + \Delta R)^2 \approx -2R\Delta R/R^2 = -2\Delta R/R.$$

From the temperature change, we have

$$\Delta\omega/\omega = -2\alpha\Delta T = -2[25 \times 10^{-6} (\text{C}^\circ)^{-1}](75.0^\circ\text{C} - 20.0^\circ\text{C}) = -2.8 \times 10^{-3} (0.28\%).$$

24. The compressive strain must compensate for the thermal expansion. From the relation between stress and strain, we have

$$\text{Stress} = E(\text{Strain}) = E\alpha\Delta T.$$

When we use the ultimate strength of concrete, we have

$$20 \times 10^6 \text{ N/m}^2 = (20 \times 10^9 \text{ N/m}^2)[12 \times 10^{-6} (\text{C}^\circ)^{-1}](T - 10.0^\circ\text{C}), \text{ which gives } T = 93^\circ\text{C}.$$

25. The compressive strain must compensate for the thermal expansion. From the relation between stress and strain, we have

$$\text{Stress} = E(\text{Strain}) = E\alpha\Delta T;$$

$$F/A = (70 \times 10^9 \text{ N/m}^2)[25 \times 10^{-6} (\text{C}^\circ)^{-1}](35^\circ\text{C} - 15^\circ\text{C}) = 3.5 \times 10^7 \text{ N/m}^2.$$

26. (a) The tensile strain must compensate for the thermal contraction. From the relation between stress and strain, we have

$$\text{Stress} = E(\text{Strain}) = E\alpha\Delta T;$$

$$F/A = (200 \times 10^9 \text{ N/m}^2)[12 \times 10^{-6} (\text{C}^\circ)^{-1}](-30^\circ\text{C} - 30^\circ\text{C}) = -1.4 \times 10^8 \text{ N/m}^2.$$

(b) **No**, because the ultimate strength of steel is  $500 \times 10^6 \text{ N/m}^2 = 5.0 \times 10^8 \text{ N/m}^2$ .

(c) For concrete we have

$$F/A = (20 \times 10^9 \text{ N/m}^2)[12 \times 10^{-6} (\text{C}^\circ)^{-1}](-30^\circ\text{C} - 30^\circ\text{C}) = -1.4 \times 10^7 \text{ N/m}^2.$$

Because the ultimate tensile strength of concrete is  $2 \times 10^6 \text{ N/m}^2$ , it **will fracture**.

27. (a) As the iron band expands, the inside diameter will increase as if it were iron. We can treat the change in inside diameter as a simple change in length, so we have

$$D = D_0(1 + \alpha\Delta T), \text{ or } D - D_0 = D_0\alpha\Delta T;$$

$$134.122 \text{ cm} - 134.110 \text{ cm} = (134.110 \text{ cm})[12 \times 10^{-6} (\text{C}^\circ)^{-1}](T - 20^\circ\text{C}), \text{ which gives } T = 27^\circ\text{C}.$$

(b) We assume that the barrel is rigid. The tensile strain in the circumference of the band is

$$\Delta D/D_0 = \Delta D/D_0,$$

which is the thermal strain. The tensile strain must compensate for the thermal contraction.

From the relation between stress and strain, we have

$$\text{Stress} = E(\text{Strain}) = E\alpha\Delta T;$$

$$F/(0.089 \text{ m})(0.0065 \text{ m}) = (100 \times 10^9 \text{ N/m}^2)(134.122 \text{ cm} - 134.110 \text{ cm})/(134.110 \text{ cm}),$$

which gives

$$F = 5.2 \times 10^3 \text{ N}.$$

28. (a)
- $T(\text{K}) = T(^{\circ}\text{C}) + 273 = 86^\circ\text{C} + 273 = 359 \text{ K}.$
- 
- (b)
- $T(^{\circ}\text{C}) = (5/9)[T(^{\circ}\text{F}) - 32] = (5/9)(78^\circ\text{F} - 32) = 26^\circ\text{C}.$
- 
- $T(\text{K}) = T(^{\circ}\text{C}) + 273 = 26^\circ\text{C} + 273 = 299 \text{ K}.$
- 
- (c)
- $T(\text{K}) = T(^{\circ}\text{C}) + 273 = -100^\circ\text{C} + 273 = 173 \text{ K}.$

(d)  $T(\text{K}) = T(^{\circ}\text{C}) + 273 = 5500^{\circ}\text{C} + 273 = 5773 \text{ K}.$

29. On the Celsius scale, absolute zero is

$$T(^{\circ}\text{C}) = T(\text{K}) - 273.15 = 0 \text{ K} - 273.15 = -273.15^{\circ}\text{C}.$$

On the Fahrenheit scale, we have

$$T(^{\circ}\text{F}) = (9/5)T(^{\circ}\text{C}) + 32 = (9/5)(-273.15^{\circ}\text{C}) + 32 = -459.7^{\circ}\text{F}.$$

30. (a)
- $T_1(\text{K}) = T_1(^{\circ}\text{C}) + 273 = 4000^{\circ}\text{C} + 273 = 4273 \text{ K};$

$$T_2(\text{K}) = T_2(^{\circ}\text{C}) + 273 = 15 \times 10^6 \text{ }^{\circ}\text{C} + 273 = 15 \times 10^6 \text{ K}.$$

- (b) The difference in each case is 273, so we have

$$\text{Earth: } (273)(100)/(4273) = 6.4\%;$$

$$\text{Sun: } (273)(100)/(15 \times 10^6) = 0.0018\%.$$

31. For the two states of the gas we can write

$$P_1V_1 = nRT_1 \quad \text{and} \quad P_2V_2 = nRT_2, \text{ which can be combined to give}$$

$$(P_2/P_1)(V_2/V_1) = T_2/T_1;$$

$$(4.00 \text{ atm}/1.00 \text{ atm})(V_2/3.00 \text{ m}^3) = (311 \text{ K}/273 \text{ K}), \text{ which gives } V_2 = 0.854 \text{ m}^3.$$

32. If we assume oxygen is an ideal gas, we have

$$PV = nRT = (m/M)RT;$$

$$(1.013 \times 10^5 \text{ Pa})V = [m/(32 \text{ g/mol})(10^3 \text{ kg/g})](8.315 \text{ J/mol} \cdot \text{K})(273 \text{ K}), \text{ which gives}$$

$$m/V = 1.43 \text{ kg/m}^3.$$

33. The volume, temperature, and mass are constant. For the two states of the gas we can write

$$P_1V = n_1RT = (m/M_1)RT, \quad \text{and} \quad P_2V = n_2RT = (m/M_2)RT, \text{ which can be combined to give}$$

$$P_2/P_1 = M_1/M_2;$$

$$P_2/(3.65 \text{ atm}) = (28 \text{ g/mol})/(44 \text{ g/mol}), \text{ which gives } P_2 = 2.32 \text{ atm}.$$

34. (a) For the ideal gas we have

$$PV = nRT = (m/M)RT;$$

$$(1.013 \times 10^5 \text{ Pa})V = [(18.5 \text{ kg})(10^3 \text{ g/kg})/(28 \text{ g/mol})](8.314 \text{ J/mol} \cdot \text{K})(273 \text{ K}),$$

$$\text{which gives } V = 14.8 \text{ m}^3.$$

- (b) With the additional mass in the same volume, we have

$$PV = nRT = (m/M)RT;$$

$$P(14.8 \text{ m}^3) = [(18.5 \text{ kg} + 15.0 \text{ kg})(10^3 \text{ g/kg})/(28 \text{ g/mol})](8.314 \text{ J/mol} \cdot \text{K})(273 \text{ K}),$$

$$\text{which gives } P = 1.83 \times 10^5 \text{ Pa} = 1.81 \text{ atm}.$$

35. (a) For the ideal gas we have

$$PV = nRT;$$

$$(1.000 \text{ atm} + 0.350 \text{ atm})(1.013 \times 10^5 \text{ Pa/atm})V = (25.50 \text{ mol})(8.314 \text{ J/mol} \cdot \text{K})(283 \text{ K}),$$

$$\text{which gives } V = 0.439 \text{ m}^3.$$

- (b) For the two states of the gas we can write

$$P_1V_1 = nRT_1 \quad \text{and} \quad P_2V_2 = nRT_2, \text{ which can be combined to give}$$

$$(P_2/P_1)(V_2/V_1) = T_2/T_1;$$

$$[(1.00 \text{ atm} + 1.00 \text{ atm})/(1.00 \text{ atm} + 0.350 \text{ atm})](1/2) = (T_2/283 \text{ K}),$$

$$\text{which gives } T_2 = 210 \text{ K} = -63^{\circ}\text{C}.$$





36. If we assume argon is an ideal gas, we have

$$PV = nRT = (m/M)RT;$$

$$P(50.0 \times 10^{-3} \text{ m}^3) = [(105.0 \text{ kg})(10^3 \text{ g/kg})/(40 \text{ g/mol})](8.314 \text{ J/mol} \cdot \text{K})(293 \text{ K}),$$

which gives  $P = 1.28 \times 10^8 \text{ Pa} = 1.26 \times 10^3 \text{ atm}$ .

37. The volume and pressure are constant. For the fractional change in the number of moles, we can write

$$\Delta n/n = [(PV/RT_2) - (PV/RT_1)]/(PV/RT_1) = (T_1 - T_2)/T_2$$

$$= (288 \text{ K} - 311 \text{ K})/(311 \text{ K}) = -0.074 \text{ (7.4\%)}$$

38. For the two states of the gas we can write

$$P_1 V_1 = nRT_1 \text{ and } P_2 V_2 = nRT_2, \text{ which can be combined to give}$$

$$(P_2/P_1)(V_2/V_1) = T_2/T_1;$$

$$(P_2/1.00 \text{ atm})(48.8 \text{ L}/55.0 \text{ L}) = (323.2 \text{ K}/291.2 \text{ K}), \text{ which gives } P_2 = 3.06 \text{ atm}.$$

39. If we assume water vapor is an ideal gas, we have

$$PV = nRT = (m/M)RT;$$

$$(1.013 \times 10^5 \text{ Pa})V = [m/(18 \text{ g/mol})(10^3 \text{ kg/g})](8.315 \text{ J/mol} \cdot \text{K})(373 \text{ K}), \text{ which gives}$$

$$m/V = 0.588 \text{ kg/m}^3.$$

This is less than the listed value of  $0.598 \text{ kg/m}^3$ . We expect a difference because the tendency of steam to form droplets indicates an attractive force, so **water vapor is not an ideal gas**.

40. For the two states of the gas we can write

$$P_1 V_1 = nRT_1 \text{ and } P_2 V_2 = nRT_2, \text{ which can be combined to give}$$

$$(P_2/P_1)(V_2/V_1) = T_2/T_1;$$

$$(0.70 \text{ atm}/1.00 \text{ atm})(V_2/V_1) = (278.2 \text{ K}/293.2 \text{ K}), \text{ which gives } V_2/V_1 = 1.4 \times.$$

41. The pressure at the bottom of the lake is

$$P_{\text{bottom}} = P_{\text{top}} + \rho gh = 1.013 \times 10^5 \text{ Pa} + (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(43.5 \text{ m}) = 5.28 \times 10^5 \text{ Pa}.$$

For the two states of the gas we can write

$$P_{\text{bottom}} V_{\text{bottom}} = nRT_{\text{bottom}}, \text{ and } P_{\text{top}} V_{\text{top}} = nRT_{\text{top}}, \text{ which can be combined to give}$$

$$(P_{\text{bottom}}/P_{\text{top}})(V_{\text{bottom}}/V_{\text{top}}) = T_{\text{bottom}}/T_{\text{top}};$$

$$(5.28 \times 10^5 \text{ Pa}/1.013 \times 10^5 \text{ Pa})(1.00 \text{ cm}^3/V_{\text{top}}) = (278.7 \text{ K}/294.2 \text{ K}), \text{ which gives } V_{\text{top}} = 5.50 \text{ cm}^3.$$

42. If we write the ideal gas law as
- $PV = NkT$
- , we have

$$N/V = P/kT = (1.013 \times 10^5 \text{ Pa})/(1.38 \times 10^{-23} \text{ J/K})(273 \text{ K}) = 2.69 \times 10^{25} \text{ molecules/m}^3.$$

43. We find the number of moles from

$$n = \rho V/M = (1.000 \text{ g/cm}^3)(1.000 \times 10^3 \text{ cm}^3)/(18 \text{ g/mol}) = 55.6 \text{ mol}.$$

For the number of molecules we have

$$N = nN_A = (55.6 \text{ mol})(6.02 \times 10^{23} \text{ molecules/mol}) = 3.34 \times 10^{25} \text{ molecules}.$$

44. (a) We find the number of moles from

$$n = \rho V/M = \rho + 4R^2 d/M$$

$$= (1000 \text{ kg/m}^3)3^1(6.4 \times 10^6 \text{ m})^2(3 \times 10^3 \text{ m})(10^3 \text{ g/kg})/(18 \text{ g/mol}) = 6 \times 10^{22} \text{ mol}.$$

(b) For the number of molecules we have

$$N = nN_A = (6 \times 10^{22} \text{ mol})(6.02 \times 10^{23} \text{ molecules/mol}) = 4 \times 10^{46} \text{ molecules.}$$

45. The volume and mass are constant. For the two states of the gas we can write

$$P_1 V_1 = nRT_1, \text{ and } P_2 V_2 = nRT_2, \text{ which can be combined to give}$$

$$P_2/P_1 = T_2/T_1;$$

$$(P_2/1.00 \text{ atm}) = (455 \text{ K}/293 \text{ K}), \text{ which gives } P_2 = 1.55 \text{ atm.}$$

We find the length of a side of the box from

$$V = L^3;$$

$$3.9 \times 10^{-2} \text{ m}^3 = L^3, \text{ which gives } L = 0.339 \text{ m.}$$

The net force is the same on each side of the box. Because there is atmospheric pressure outside the box, the net force is

$$F = A \Delta P = L^2(P_2 - P_1) = (0.339 \text{ m})^2(1.55 \text{ atm} - 1.00 \text{ atm})(1.013 \times 10^5 \text{ Pa/atm}) = 6.4 \times 10^3 \text{ N.}$$

Note that we have assumed no change in dimensions from the increased pressure.

46. We find the number of moles in one breath from

$$PV = nRT;$$

$$(1.013 \times 10^5 \text{ Pa})(2.0 \times 10^{-3} \text{ m}^3) = n(8.315 \text{ J/mol} \cdot \text{K})(300 \text{ K}), \text{ which gives } n = 8.02 \times 10^{-2} \text{ mol.}$$

For the number of molecules in one breath we have

$$N = nN_A = (8.02 \times 10^{-2} \text{ mol})(6.02 \times 10^{23} \text{ molecules/mol}) = 4.83 \times 10^{22} \text{ molecules.}$$

We assume that all of the molecules from the last breath that Einstein took are uniformly spread throughout the atmosphere, so the fraction that are in one breath is given by  $V/V_{\text{atmosphere}}$ . We find the number now in one breath from

$$N'/N = V/V_{\text{atmosphere}} = V/4^1 R^2 h;$$

$$N'/(4.83 \times 10^{22} \text{ molecules}) = (2.0 \times 10^{-3} \text{ m}^3)/4^1(6.4 \times 10^6 \text{ m})^2(10 \times 10^3 \text{ m}),$$

which gives  $N' = 20 \text{ molecules}$ .

47. The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = 8kT, \text{ which gives}$$

$$v_{\text{rms}} = (3kT/m)^{1/2} = [3(1.38 \times 10^{-23} \text{ J/K})(6000 \text{ K})/(4 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})]^{1/2} = 6.1 \times 10^3 \text{ m/s.}$$

48. (a) The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = 8kT = 8(1.38 \times 10^{-23} \text{ J/K})(273 \text{ K}) = 5.65 \times 10^{-21} \text{ J.}$$

(b) For the total translational kinetic energy we have

$$\text{KE} = N(\frac{1}{2}mv_{\text{rms}}^2) = 8nN_A kT$$

$$= 8(1.00 \text{ mol})(6.02 \times 10^{23} \text{ molecules/mol})(1.38 \times 10^{-23} \text{ J/K})(293 \text{ K}) = 3.65 \times 10^3 \text{ J.}$$

49. We find the rms speed from

$$v_{\text{rms}} = [(v^2)/N]^{1/2} = [(6^2 + 2^2 + 4^2 + 6^2 + 0^2 + 4^2 + 1^2 + 8^2 + 5^2 + 3^2 + 7^2 + 8^2)/12]^{1/2} = 5.2.$$

Note that this is greater than the average speed of 4.5.

50. The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = 8kT.$$

We form the ratio at the two temperatures:

$$(v_{\text{rms}2}/v_{\text{rms}1})^2 = T_2/T_1;$$

$$(2)^2 = T_2/273 \text{ K, which gives } T_2 = 1092 \text{ K} = 819^\circ\text{C.}$$

51. The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = 8kT.$$

We form the ratio at the two temperatures:

$$(v_{\text{rms}2}/v_{\text{rms}1})^2 = T_2/T_1;$$

$$(1.020)^2 = T_2/293.2 \text{ K, which gives } T_2 = 304.9 \text{ K} = 31.7^\circ\text{C}.$$

52. The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = 8kT.$$

We form the ratio at the two temperatures, and use the ideal gas law:

$$(v_{\text{rms}2}/v_{\text{rms}1})^2 = T_2/T_1 = P_2V_2/P_1V_1 = P_2/P_1;$$

$$(v_{\text{rms}2}/v_{\text{rms}1})^2 = 2, \text{ which gives } v_{\text{rms}2}/v_{\text{rms}1} = \sqrt{2}.$$

53. The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = 8kT.$$

We form the ratio at the two temperatures, and use the ideal gas law:

$$(m_2/m_1)(v_{\text{rms}2}/v_{\text{rms}1})^2 = T_2/T_1 = 1, \text{ so we have}$$

$$(v_{\text{rms}2}/v_{\text{rms}1})^2 = (m_1/m_2), \text{ or } v_{\text{rms}2}/v_{\text{rms}1} = (m_1/m_2)^{1/2}.$$

54. (a) We find the rms speed from

$$v_{\text{rms}} = (3kT/m)^{1/2} = [3(1.38 \times 10^{-23} \text{ J/K})(310 \text{ K})/(89 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})]^{1/2} = 2.9 \times 10^2 \text{ m/s}.$$

- (b) For the protein we have

$$v_{\text{rms}} = (3kT/m)^{1/2} = [3(1.38 \times 10^{-23} \text{ J/K})(310 \text{ K})/(50,000 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})]^{1/2} \\ = 12 \text{ m/s}.$$

55. The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = 8kT, \text{ or } kT/m = \frac{1}{2}v_{\text{rms}}^2.$$

With  $M$  the mass of the gas and  $m$  the mass of a molecule, we write the ideal gas law as

$$PV = NkT = (M/m)kT, \text{ or}$$

$$P = (M/V)(kT/m) = \rho(\frac{1}{2}v_{\text{rms}}^2) = \frac{1}{2}\rho v_{\text{rms}}^2.$$

56. The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = 8kT.$$

We form the ratio for the two masses:

$$(m_{235}/m_{238})(v_{\text{rms}235}/v_{\text{rms}238})^2 = T_2/T_1 = 1, \text{ so we have}$$

$$(v_{\text{rms}235}/v_{\text{rms}238})^2 = (m_{238}/m_{235}), \text{ or}$$

$$v_{\text{rms}235}/v_{\text{rms}238} = (m_{238}/m_{235})^{1/2} = \{[6(19 \text{ u}) + 238 \text{ u}]/[6(19 \text{ u}) + 235 \text{ u}]\}^{1/2} = 1.00429.$$

57. (a) From Figure 13–23 we see that at atmospheric pressure
- $\text{CO}_2$
- can exist as a solid or vapor.

- (b) From Figure 13–23 we see that
- $\text{CO}_2$
- may be a liquid when

$$5.11 \text{ atm} < P < 73 \text{ atm, and } -56.6^\circ\text{C} < T < 31^\circ\text{C}.$$

58. From Figure 13–23 we see that
- $\text{CO}_2$
- is a vapor at 30 atm and
- $30^\circ\text{C}$
- .



59. (a) From Figure 13–22 we see that the phase is **vapor**.  
 (b) From Figure 13–22 we see that the phase is **solid**.

60. The saturated vapor pressure at 25°C is 23.8 torr.

At 50% humidity the partial vapor pressure is

$$P = 0.50P_s = 0.50(23.8 \text{ torr}) = 11.9 \text{ torr}.$$

This corresponds to a saturated vapor pressure between 10°C and 15°C. We assume a linear change between values listed in Table 13–4 and use the values at 10°C and 15°C to find the dew point;

$$T = 10^\circ\text{C} + [(15^\circ\text{C} - 10^\circ\text{C})(11.9 \text{ torr} - 9.21 \text{ torr}) / (12.8 \text{ torr} - 9.21 \text{ torr})] = \mathbf{14^\circ\text{C}}.$$

61. Water boils when the saturated vapor pressure equals the air pressure. From Table 13–4 we see that the saturated vapor pressure at 90°C is

$$7.01 \times 10^4 \text{ Pa} = \mathbf{0.69 \text{ atm}}.$$

62. Water boils when the saturated vapor pressure equals the air pressure. From Table 13–4 we see that 0.85 atm =  $8.6 \times 10^4$  Pa lies between 90°C and 100°C. We use the values at 90°C and 100°C to find the temperature;

$$T = 90^\circ\text{C} + [(100^\circ\text{C} - 90^\circ\text{C})(8.6 \times 10^4 \text{ Pa} - 7.0 \times 10^4 \text{ Pa}) / (10.1 \times 10^4 \text{ Pa} - 7.0 \times 10^4 \text{ Pa})] = \mathbf{95^\circ\text{C}}.$$

63. We find the saturated vapor pressure from

$$P = (\text{RH})P_s;$$

$$530 \text{ Pa} = 0.40P_s, \text{ which gives } P_s = 1325 \text{ Pa}.$$

This saturated vapor pressure corresponds to a temperature between 10°C and 15°C. We use the values at 10°C and 15°C to find the dew point;

$$T = 10^\circ\text{C} + [(15^\circ\text{C} - 10^\circ\text{C})(1.325 \times 10^3 \text{ Pa} - 1.23 \times 10^3 \text{ Pa}) / (1.71 \times 10^3 \text{ Pa} - 1.23 \times 10^3 \text{ Pa})] = \mathbf{11^\circ\text{C}}.$$

64. Water boils when the saturated vapor pressure equals the air pressure. From Table 13–4 we see that the saturated vapor pressure at 120°C is

$$1.99 \times 10^4 \text{ Pa} = \mathbf{1.96 \text{ atm}}.$$

65. From Table 13–4 we see that the saturated vapor pressure at 25°C is  $3.17 \times 10^3$  Pa. Water can evaporate until the saturated vapor pressure is reached. The initial pressure is (relative humidity)(saturated vapor pressure). Because the volume and temperature are constant, we use the ideal gas law to find the number of moles that can evaporate:

$$\Delta n = \Delta P(V/RT) = (1 - \text{RH})P_s V/RT$$

$$= (1 - 0.80)(3.17 \times 10^3 \text{ Pa})(680 \text{ m}^3) / (8.315 \text{ J/mol} \cdot \text{K})(298 \text{ K}) = 174 \text{ mol}.$$

We find the mass from

$$m = M \Delta n = (18 \text{ g/mol})(174 \text{ mol}) = 3.1 \times 10^3 \text{ g} = \mathbf{3.1 \text{ kg}}.$$

66. From Table 13–4 we see that the saturated vapor pressure at 20°C is  $2.33 \times 10^3$  Pa. The vapor pressure is (relative humidity)(saturated vapor pressure). Because the volume and temperature are constant, we use the ideal gas law to find the number of moles that must be removed:

$$\Delta n = \Delta P(V/RT) = (\text{RH}_2 - \text{RH}_1)P_s V/RT$$

$$= (0.30 - 0.95)(2.33 \times 10^3 \text{ Pa})(95 \text{ m}^2)(2.8 \text{ m}) / (8.315 \text{ J/mol} \cdot \text{K})(293 \text{ K}) = -165 \text{ mol}.$$

We find the mass from

$$m = M \Delta n = (18 \text{ g/mol})(165 \text{ mol}) = 3.0 \times 10^3 \text{ g} = \mathbf{3.0 \text{ kg}}.$$



67. Because there is only steam in the autoclave, the saturated vapor pressure is the gauge pressure plus atmospheric pressure:

$$1.0 \text{ atm} + 1.0 \text{ atm} = 2.0 \text{ atm} = 2.03 \times 10^5 \text{ Pa.}$$

From Table 13-4 we see this saturated vapor pressure occurs at  $120^\circ\text{C}$ .

68. Because the outside air is at the dew point, its vapor pressure is the saturated vapor pressure at  $5^\circ\text{C}$ , which is 872 Pa. We consider a constant mass of gas, that is a fixed number of moles, that moves from outside to inside. Because the pressure is constant, we have

$$V_2/T_2 = V_1/T_1.$$

The vapor pressure inside is

$$P_2 = nRT_2/V_2 = nRT_1/V_1 = P_1 = 872 \text{ Pa.}$$

The saturated vapor pressure at  $25^\circ\text{C}$  is 3170 Pa, so the relative humidity is

$$(872 \text{ Pa})/(3170 \text{ Pa}) = 0.28 = 28\%.$$

69. Because the air at the wet-bulb thermometer is at the dew point, the partial vapor pressure at  $30^\circ\text{C}$  is the saturated vapor pressure at  $10^\circ\text{C}$ , which is 1230 Pa. The saturated vapor pressure at  $30^\circ\text{C}$  is 4240 Pa, so the relative humidity is

$$(1230 \text{ Pa})/(4240 \text{ Pa}) = 0.29 = 29\%.$$

70. From the result of Example 13-19, we have

$$t = \left(\frac{\bar{C}}{\Delta C}\right) \frac{(\Delta x)^2}{D} = \frac{1}{2} \frac{(2.0 \text{ m})^2}{4.0 \times 10^{-5} \text{ m}^2/\text{s}} = 5.0 \times 10^4 / \text{s} = 14 \text{ h.}$$

Our experience is that the odor is detected much sooner than this, which means that convection is much more important than diffusion.

71. From the result of Example 13-19, we have

$$t = \left(\frac{\bar{C}}{\Delta C}\right) \frac{(\Delta x)^2}{D} = \frac{(1.0 \text{ mol}/\text{m}^3 + 0.40 \text{ mol}/\text{m}^3)/2}{(1.0 \text{ mol}/\text{m}^3 - 0.40 \text{ mol}/\text{m}^3)} \frac{(15 \times 10^{-6} \text{ m})^2}{95 \times 10^{-11} \text{ m}^2/\text{s}} = 0.28 \text{ s.}$$

The diffusion speed is

$$v = \Delta x/t = (15 \times 10^{-6} \text{ m})/(0.28 \text{ s}) = 5.4 \times 10^{-5} \text{ m/s.}$$

We find the rms speed from

$$v_{\text{rms}} = (3kT/m)^{1/2} = [3(1.38 \times 10^{-23} \text{ J/K})(293 \text{ K})/(75 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})]^{1/2} = 3.1 \times 10^2 \text{ m/s.}$$

72. (a) From the ideal gas law, we have

$$C_0 = n/V = P/RT = (0.21)(1.013 \times 10^5 \text{ Pa})/(8.315 \text{ J/mol} \cdot \text{K})(293 \text{ K}) = 8.7 \text{ mol}/\text{m}^3.$$

- (b) The concentration change is

$$\Delta C = C_0 - !C_0 = !C_0 = !(8.7 \text{ mol}/\text{m}^3) = 4.35 \text{ mol}/\text{m}^3.$$

We find the diffusion rate from

$$J = DA \Delta C/\Delta x = (1 \times 10^{-5} \text{ m}^2/\text{s})(2 \times 10^{-9} \text{ m}^2)(4.35 \text{ mol}/\text{m}^3)/(2 \times 10^{-3} \text{ m}) = 4 \times 10^{-11} \text{ mol/s.}$$

- (c) For the average concentration we have

$$C_{\text{av}} = !(C_0 + !C_0) = +C_0 = 6.53 \text{ mol}/\text{m}^3.$$

We find the average time from

$$t = N/J = C_{\text{av}}V/J = (6.53 \text{ mol}/\text{m}^3)(2 \times 10^{-9} \text{ m}^2)(2 \times 10^{-3} \text{ m})/(4 \times 10^{-11} \text{ mol/s}) = 0.6 \text{ s.}$$



73. (a) If we consider a cross-sectional area through which diffusion is taking place, the diffusion rate will be proportional to have frequently a molecule, during its random motion, will strike the area. This frequency is proportional to its average speed, for which we can use the rms speed. The temperature is related to the average kinetic energy of a molecule:

$$\frac{1}{2}mv_{\text{rms}}^2 = \frac{3}{2}kT, \text{ or } v_{\text{rms}}^2 \propto 1/m.$$

Thus we have

$$J \propto v_{\text{rms}} \propto 1/\sqrt{m}.$$

- (b) The molecular mass is proportional to the molecular weight, so the molecule with the lighter mass, which is **nitrogen**, will diffuse faster.  
For the ratio of diffusion rates, we have

$$J_{\text{N}}/J_{\text{O}} = (m_{\text{O}}/m_{\text{N}})^{1/2} = (M_{\text{O}}/M_{\text{N}})^{1/2} = (32/28)^{1/2} = 1.069, \text{ or } \mathbf{6.9\%}.$$

74. (a) The tape will expand, so the numbers will be beyond the true length, so it will read **low**.  
(b) The percentage error will be

$$(\Delta L/L)(100) = (L\alpha \Delta T/L)(100) = (\alpha \Delta T)(100) = [12 \times 10^{-6} (\text{C}^\circ)^{-1}](34^\circ\text{C} - 20^\circ\text{C})(100) = \mathbf{0.017\%}.$$

75. Because we neglect the glass expansion, when the 300 mL cools to room temperature, the change in volume of the water will be

$$\Delta V = \beta V_0 \Delta T = [210 \times 10^{-6} (\text{C}^\circ)^{-1}](300 \text{ mL})(20^\circ\text{C} - 80^\circ\text{C}) = \mathbf{-3.8 \text{ mL (1.3\%)}}.$$

76. For the two conditions of the gas in the cylinder, we can write

$$P_1V = n_1RT, \text{ and } P_2V = n_2RT, \text{ which can be combined to give}$$

$$P_2/P_1 = n_2/n_1;$$

$$(5 \text{ atm}/28 \text{ atm}) = n_2/n_1, \text{ which gives } n_2/n_1 = \mathbf{0.18}.$$

77. The ideal gas law is

$$PV = nRT = (m/M)RT,$$

where  $m$  is the mass and  $M$  is the molecular weight. We write this as

$$P = (m/V)RT/M = \rho RT/M.$$

78. We use the ideal gas law:

$$PV = NkT;$$

$$(1.013 \times 10^5 \text{ Pa})(5 \text{ m})(3 \text{ m})(2.5 \text{ m}) = N(1.38 \times 10^{-23} \text{ J/K})(293 \text{ K}),$$

which gives  $N = \mathbf{9.4 \times 10^{26} \text{ molecules}}$ .

We find the number of moles from

$$n = N/N_A = (9.4 \times 10^{26} \text{ molecules})/(6.02 \times 10^{23} \text{ molecules/mol}) = \mathbf{1.6 \times 10^3 \text{ mol}}.$$

79. We use the ideal gas law:

$$PV = NkT, \text{ or}$$

$$N/V = P/kT = (1 \times 10^{-12} \text{ N/m}^2)/(1.38 \times 10^{-23} \text{ J/K})(273 \text{ K})(10^6 \text{ cm}^3/\text{m}^3) = \mathbf{3 \times 10^2 \text{ molecules/cm}^3}.$$

80. The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = \frac{3}{2}kT, \text{ which gives}$$

$$v_{\text{rms}} = (3kT/m)^{1/2} = [3(1.38 \times 10^{-23} \text{ J/K})(2.7 \text{ K})/(1 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})]^{1/2} = \mathbf{2.6 \times 10^2 \text{ m/s}}.$$

We find the pressure from

$$PV = NkT, \text{ or}$$

$$P = (N/V)/kT = (1 \text{ atom/cm}^3)(10^6 \text{ cm}^3/\text{m}^3)/(1.38 \times 10^{-23} \text{ J/K})(2.7 \text{ K}) = 4 \times 10^{-17} \text{ N/m}^2.$$

81. The pressure at a depth  $h$  is

$$P = P_0 + \rho gh = 1.013 \times 10^5 \text{ Pa} + (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(10 \text{ m}) = 1.99 \times 10^5 \text{ Pa}.$$

For the two states of the gas we can write

$$PV = nRT, \text{ and } P_0V_0 = nRT, \text{ which can be combined to give}$$

$$P/P_0 = V_0/V;$$

$$(1.99 \times 10^5 \text{ Pa}/1.013 \times 10^5 \text{ Pa}) = (V_0/5.5 \text{ L}), \text{ which gives } V_0 = \mathbf{11 \text{ L}}.$$

This doubling of the volume is definitely **not advisable**.

82. (a) The volume of each gas is  $V_{\text{tank}}$ . We use the ideal gas law:

$$PV_0 = N_0kT;$$

$$(10 \text{ atm} + 1 \text{ atm})(1.013 \times 10^5 \text{ Pa/atm})(3500 \text{ cm}^3)/(10^6 \text{ cm}^3/\text{m}^3) = N_0(1.38 \times 10^{-23} \text{ J/K})(293 \text{ K}),$$

which gives  $N_0 = 4.8 \times 10^{23} \text{ molecules} = N_{\text{He}}$ , because the mass is not in the ideal gas law.

(b) The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = \frac{3}{2}kT.$$

Because the gases are at the same temperature, the ratio of average kinetic energies is **1**.

(c) We see that

$$(v_{\text{rmsHe}}/v_{\text{rmsO}})^2 = m_{\text{O}}/m_{\text{He}} = (32 \text{ u})/(4 \text{ u}), \text{ which gives } v_{\text{rmsHe}}/v_{\text{rmsO}} = \mathbf{2.8}.$$

83. The rms speed is the speed of the nitrogen molecules, so we have

$$\frac{1}{2}mv_{\text{rms}}^2 = \frac{3}{2}kT;$$

$$(28 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})[(40,000 \text{ km/h})/(3.6 \text{ ks/h})]^2 = 3(1.38 \times 10^{-23} \text{ J/K})T,$$

which gives  $T = \mathbf{1.4 \times 10^5 \text{ K}}$ .

84. For the two conditions of the gas in the cylinder, we can write

$$P_1V = nRT_1, \text{ and } P_2V = nRT_2, \text{ which can be combined to give}$$

$$P_2/P_1 = T_2/T_1;$$

$$P_2/P_1 = (633 \text{ K}/393 \text{ K}) = \mathbf{1.61}.$$

The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = \frac{3}{2}kT.$$

We form the ratio for the two temperatures:

$$(v_{\text{rms2}}/v_{\text{rms1}})^2 = T_2/T_1 = (633 \text{ K}/393 \text{ K}), \text{ which gives } v_{\text{rms2}}/v_{\text{rms1}} = \mathbf{1.27}.$$

85. (a) The ideal gas law is

$$PV = nRT = (m/M)RT;$$

$$(1.013 \times 10^5 \text{ Pa})(770 \text{ m}^3) = [m/(29 \text{ g/mol})](8.315 \text{ J/mol} \cdot \text{K})(293 \text{ K}),$$

which gives  $m = 9.2 \times 10^5 \text{ g} = \mathbf{9.2 \times 10^2 \text{ kg}}$ .

(b) At the lower temperature we have

$$(1.013 \times 10^5 \text{ Pa})(770 \text{ m}^3) = [m/(29 \text{ g/mol})](8.315 \text{ J/mol} \cdot \text{K})(263 \text{ K}),$$

which gives  $m = 1.03 \times 10^6 \text{ g} = 10.3 \times 10^2 \text{ kg}$ .

Thus the mass that has entered the house is  $10.3 \times 10^2 \text{ kg} - 9.2 \times 10^2 \text{ kg} = \mathbf{1.1 \times 10^2 \text{ kg}}$ .

86. (a) The ideal gas law is

$$PV = nRT.$$

At constant pressure we have

$$P \Delta V = nR \Delta T, \text{ or}$$

$$\Delta V/V = \Delta T/T.$$

The thermal expansion is  $\Delta V/V = \beta \Delta T$ , so we see that  $\beta = 1/T$ .

At 293 K we have

$$\beta = 1/293 \text{ K} = 3.41 \times 10^{-3} (\text{C}^\circ)^{-1}, \text{ which agrees with the value of } 3400 \times 10^{-6} (\text{C}^\circ)^{-1} \text{ in Table 13-1.}$$

- (b) At constant temperature, when the pressure is changed we can write

$$P_1 V_1 = nRT = P_2 V_2, \text{ or } P_2 = P_1 V_1/V_2.$$

For the small fractional change in pressure, we have

$$\Delta P/P = (P_2 - P_1)/P_1 = [(P_1 V_1/V_2) - P_1]/P_1 = (V_1 - V_2)/V_2 = -\Delta V/V.$$

From the definition of the bulk modulus, we have

$$B = -\Delta P/(\Delta V/V) = -\Delta P/(-\Delta P/P) = P.$$

87. The pressure on a small area of the surface can be considered to be due to the weight of the air column above the area:

$$P = Mg/A.$$

When we consider the total surface of the Earth, we have

$$\begin{aligned} M_{\text{total}} &= PA_{\text{total}}/g = P4\pi R^2/g \\ &= (1.013 \times 10^5 \text{ Pa})4\pi(6.37 \times 10^6 \text{ m})^2/(9.80 \text{ m/s}^2) = 5.27 \times 10^{18} \text{ kg.} \end{aligned}$$

If we use the average mass of an air molecule, we find the number of molecules from

$$N = M_{\text{total}}/m = (5.27 \times 10^{18} \text{ kg})/(28.8 \text{ u})(1.66 \times 10^{-27} \text{ kg}) = 1.1 \times 10^{44} \text{ molecules.}$$

88. We use the ideal gas law to find the temperature:

$$PV = nRT;$$

$$(4.2 \text{ atm})(1.013 \times 10^5 \text{ Pa/atm})(7.6 \text{ m}^3) = (1800 \text{ mol})(8.315 \text{ J/mol} \cdot \text{K})T,$$

which gives  $T = 216 \text{ K}$ .

The average kinetic energy depends on the temperature:

$$\frac{1}{2}mv_{\text{rms}}^2 = 8kT, \text{ which gives}$$

$$v_{\text{rms}} = (3kT/m)^{1/2} = [3(1.38 \times 10^{-23} \text{ J/K})(216 \text{ K})/(28 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})]^{1/2} = 437 \text{ m/s.}$$

89. (a) The volume of the bulb is so much greater than the volume of mercury in the tube that we can ignore any changes in the tube dimensions. The additional length of the mercury column in the tube will be due to the increased expansion of the mercury in the bulb compared to the expansion of the glass bulb. The volume of mercury that adds to the length in the tube is

$$\begin{aligned} \Delta V &= \Delta V_{\text{mercury}} - \Delta V_{\text{glass}} = V_0 \beta_{\text{mercury}} \Delta T - V_0 \beta_{\text{glass}} \Delta T = V_0 (\beta_{\text{mercury}} - \beta_{\text{glass}}) \Delta T \\ &= (0.255 \text{ cm}^3)[180 \times 10^{-6} (\text{C}^\circ)^{-1} - 9 \times 10^{-6} (\text{C}^\circ)^{-1}](33.0^\circ\text{C} - 11.5^\circ\text{C}) = 9.43 \times 10^{-4} \text{ cm}^3. \end{aligned}$$

We find the additional length from

$$L = \Delta V/A_{\text{tube}} = \Delta V/(d^2 = 4(9.43 \times 10^{-4} \text{ cm}^3)/1(0.0140 \text{ cm})^2 = 6.09 \text{ cm.}$$

- (b) If we combine the two expressions from part (a), we get

$$L(d^2 = \Delta V = V_0(\beta_{\text{mercury}} - \beta_{\text{glass}})\Delta T, \text{ which gives } L = 4V_0(\beta_{\text{mercury}} - \beta_{\text{glass}})\Delta T/d^2.$$

90. We find the molecular density from the ideal gas law:

$$PV = NkT, \text{ or}$$

$$N/V = P/kT = (1.013 \times 10^5 \text{ Pa}) / (1.38 \times 10^{-23} \text{ J/K})(273 \text{ K})(10^6 \text{ cm}^3/\text{m}^3) = 2.79 \times 10^{19} \text{ molecules/cm}^3.$$

If we assume that each molecule occupies a cube of side  $a$ , we can find  $a$ , which is the average distance between molecules, from the volume occupied by a molecule:

$$V/N = a^3;$$

$$1/(2.79 \times 10^{19} \text{ molecules/cm}^3) = a^3, \text{ which gives } a = 3.3 \times 10^{-7} \text{ cm.}$$

91. We find the total number of molecules from the total number of moles of water plus others:

$$N = \{[(0.70)/(18 \text{ g/mol})] + [(0.30)/(10^5 \text{ g/mol})]\}(2.0 \times 10^{-12} \text{ kg})(6.02 \times 10^{23} \text{ molecules/mol}) \\ = 4.7 \times 10^{10} \text{ molecules.}$$

Because each molecule has an average kinetic energy of  $8kT$ , the total translational kinetic energy is

$$\text{KE} = 8NkT = 8(4.7 \times 10^{10} \text{ molecules})(1.38 \times 10^{-23} \text{ J/K})(310 \text{ K}) = 3.0 \times 10^{-10} \text{ J.}$$

92. (a) If  $V_{\text{0Fe}}$  is the volume of the iron and  $V_{\text{0Hg}}$  is the volume of mercury that is displaced, the fraction of the volume of the iron that is submerged is

$$f = V_{\text{0Hg}}/V_{\text{0Fe}}.$$

Each volume will increase as the temperature is raised, so the new fraction will be

$$f' = V_{\text{0Hg}}(1 + \beta_{\text{Hg}} \Delta T) / V_{\text{0Fe}}(1 + \beta_{\text{Fe}} \Delta T) = f(1 + \beta_{\text{Hg}} \Delta T) / (1 + \beta_{\text{Fe}} \Delta T).$$

Because  $\beta \Delta T \ll 1$ , we use the approximation

$$1/(1 + \beta_{\text{Fe}} \Delta T) \approx 1 - \beta_{\text{Fe}} \Delta T, \text{ so we have}$$

$$f' = f(1 + \beta_{\text{Hg}} \Delta T)(1 - \beta_{\text{Fe}} \Delta T) = f[1 + \beta_{\text{Hg}} \Delta T - \beta_{\text{Fe}} \Delta T - \beta_{\text{Hg}}\beta_{\text{Fe}}(\Delta T)^2], \text{ or}$$

$$(f' - f)/f = \beta_{\text{Hg}} \Delta T - \beta_{\text{Fe}} \Delta T - \beta_{\text{Hg}}\beta_{\text{Fe}}(\Delta T)^2.$$

The last term is the product of two small numbers, so it can be neglected and we have

$$\Delta f/f = \beta_{\text{Hg}} \Delta T - \beta_{\text{Fe}} \Delta T = (\beta_{\text{Hg}} - \beta_{\text{Fe}})\Delta T.$$

Because  $\beta_{\text{Hg}} > \beta_{\text{Fe}}$ , the fraction that is submerged will increase, so the cube will float **lower**.

(b) For the percent change in the fraction submerged, we have

$$(\Delta f/f)(100) = (\beta_{\text{Hg}} - \beta_{\text{Fe}})(\Delta T)(100) \\ = [180 \times 10^{-6} (\text{C}^\circ)^{-1} - 35 \times 10^{-6} (\text{C}^\circ)^{-1}](25^\circ\text{C} - 0^\circ\text{C})(100) = 0.36\%.$$

93. We treat the circumference of the band as a length, which will expand according to

$$2^1 R = 2^1 R_0(1 + \alpha \Delta T), \text{ or}$$

$$R - R_0 = R_0 \alpha \Delta T = (6.37 \times 10^6 \text{ m})[12 \times 10^{-6} (\text{C}^\circ)^{-1}](30^\circ\text{C} - 20^\circ\text{C}) = 7.6 \times 10^2 \text{ m.}$$