Chapter 19

5. With $V = 1.0 \times 10^{-6}$ m^3, $p = 1.01 \times 10^{-13}$ Pa, and $T = 293$ K, the ideal gas law gives

$$n = \frac{pV}{RT} = \frac{\left(1.01\times 10^{-13}\ \text{Pa}\right)\left(1.0\times 10^{-6}\ \text{m}^3\right)}{\left(8.31\ \text{J/mol}\cdot\text{K}\right)\left(293\ \text{K}\right)} = 4.1\times 10^{-23}\,\text{mole.}$$

Consequently, Eq. 19-2 yields $N = nN_A = 25$ molecules. We can express this as a ratio (with V now written as 1 cm^3) $N/V = 25$ molecules/cm^3.

9. Since (standard) air pressure is 101 kPa, then the initial (absolute) pressure of the air is $p_i = 266$ kPa. Setting up the gas law in ratio form (where $n_i = n_f$ and thus cancels out), we have

$$\frac{p_f V_f}{p_i V_i} = \frac{T_f}{T_i}$$

which yields

$$p_f = p_i\left(\frac{V_i}{V_f}\right)\left(\frac{T_f}{T_i}\right) = \left(266\,\text{kPa}\right)\left(\frac{1.64\times 10^{-2}\ \text{m}^3}{1.67\times 10^{-2}\ \text{m}^3}\right)\left(\frac{300\,\text{K}}{273\,\text{K}}\right) = 287\ \text{kPa}\ .$$

Expressed as a gauge pressure, we subtract 101 kPa and obtain 186 kPa.

16. We assume that the pressure of the air in the bubble is essentially the same as the pressure in the surrounding water. If d is the depth of the lake and ρ is the density of water, then the pressure at the bottom of the lake is $p_1 = p_0 + \rho g d$, where p_0 is atmospheric pressure. Since $p_1V_1 = nRT_1$, the number of moles of gas in the bubble is

$$n = p_1V_1/RT_1 = (p_0 + \rho g d)V_1/RT_1,$$

where V_1 is the volume of the bubble at the bottom of the lake and T_1 is the temperature there. At the surface of the lake the pressure is p_0 and the volume of the bubble is $V_2 = nRT_2/p_0$. We substitute for n to obtain

$$\begin{aligned} V_2 &= \frac{T_2}{T_1}\,\frac{p_0 + \rho g d}{p_0}\,V_1 \\ &= \left(\frac{293\,\text{K}}{277\,\text{K}}\right)\left(\frac{1.013\times 10^5\ \text{Pa} + \left(0.998\times 10^3\ \text{kg/m}^3\right)\left(9.8\,\text{m/s}^2\right)\left(40\,\text{m}\right)}{1.013\times 10^5\ \text{Pa}}\right)\left(20\,\text{cm}^3\right) \\ &= 1.0\times 10^2\ \text{cm}^3. \end{aligned}$$

27. (a) We use $\varepsilon = L_V/N$, where L_V is the heat of vaporization and N is the number of molecules per gram. The molar mass of atomic hydrogen is 1 g/mol and the molar mass of atomic oxygen is 16 g/mol, so the molar mass of H_2O is (1.0 + 1.0 + 16) = 18 g/mol. There are $N_A = 6.02 \times 10^{23}$ molecules in a mole, so the number of molecules in a gram of water is $(6.02 \times 10^{23}\ \text{mol}^{-1})/(18\ \text{g/mol}) = 3.34 \times 10^{22}$ molecules/g. Thus

$$\varepsilon = (539\ \text{cal/g})/(3.34 \times 10^{22}/\text{g}) = 1.61 \times 10^{-20}\ \text{cal} = 6.76 \times 10^{-20}\ \text{J}.$$

(b) The average translational kinetic energy is

$$K_{\text{avg}} = \frac{3}{2}kT = \frac{3}{2}(1.38 \times 10^{-23}\ \text{J/K})[(32.0 + 273.15)\ \text{K}] = 6.32 \times 10^{-21}\ \text{J}.$$

The ratio $\varepsilon/K_{\text{avg}}$ is $(6.76 \times 10^{-20}\ \text{J})/(6.32 \times 10^{-21}\ \text{J}) = 10.7$.

35. (a) The average speed is

$$v_{\text{avg}} = \frac{1}{N}\sum_{i=1}^{N} v_i = \frac{1}{10}[4(200\ \text{m/s}) + 2(500\ \text{m/s}) + 4(600\ \text{m/s})] = 420\ \text{m/s}.$$

(b) The rms speed is

$$v_{\text{rms}} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} v_i^2} = \sqrt{\frac{1}{10}[4(200\ \text{m/s})^2 + 2(500\ \text{m/s})^2 + 4(600\ \text{m/s})^2]} = 458\ \text{m/s}$$

(c) Yes, $v_{\text{rms}} > v_{\text{avg}}$.

38. (a) From the graph we see that $v_p = 400$ m/s. Using the fact that $M = 28$ g/mol = 0.028 kg/mol for nitrogen (N_2) gas, Eq. 19-35 can then be used to determine the absolute temperature. We obtain $T = \frac{1}{2}Mv_p^2/R = 2.7\times10^2$ K.

(b) Comparing with Eq. 19-34, we conclude $v_{\text{rms}} = \sqrt{3/2}\, v_p = 4.9\times10^2$ m/s.

47. (a) The work is zero in this process since volume is kept fixed.

(b) Since $C_V = \frac{3}{2}R$ for an ideal monatomic gas, then Eq. 19-39 gives $Q = +374$ J.

(c) $\Delta E_{\text{int}} = Q - W = +374$ J.

(d) Two moles are equivalent to $N = 12 \times 10^{23}$ particles. Dividing the result of part (c) by N gives the average translational kinetic energy change per atom: 3.11×10^{-22} J.

59. Since ΔE_{int} does not depend on the type of process,

$$\left(\Delta E_{\text{int}}\right)_{\text{path 2}} = \left(\Delta E_{\text{int}}\right)_{\text{path 1}}.$$

Also, since (for an ideal gas) it only depends on the temperature variable (so $\Delta E_{\text{int}} = 0$ for isotherms), then

$$\left(\Delta E_{\text{int}}\right)_{\text{path1}} = \sum \left(\Delta E_{\text{int}}\right)_{\text{adiabat}}.$$

Finally, since $Q = 0$ for adiabatic processes, then (for path 1)

$$\begin{aligned}\left(\Delta E_{\text{int}}\right)_{\text{adiabatic expansion}} &= -W = -40\ \text{J}\\ \left(\Delta E_{\text{int}}\right)_{\text{adiabatic compression}} &= -W = -(-25)\ \text{J} = 25\ \text{J}.\end{aligned}$$

Therefore, $\left(\Delta E_{\text{int}}\right)_{\text{path 2}} = -40\ \text{J} + 25\ \text{J} = -15\ \text{J}$.

69. Let ρ_c be the density of the cool air surrounding the balloon and ρ_h be the density of the hot air inside the balloon. The magnitude of the buoyant force on the balloon is $F_b = \rho_c g V$, where V is the volume of the envelope. The force of gravity is $Fg = W + \rho_h g V$, where W is the combined weight of the basket and the envelope. Thus, the net upward force is

$$F_{\text{net}} = F_b - F_g = \rho_c g V - W - \rho_h g V.$$

With $F_{\text{net}} = 2.67 \times 10^3$ N, $W = 2.45 \times 10^3$ N, $V = 2.18 \times 10^3$ m^3, $\rho_c g = 11.9$ N/m^3, we obtain

$$\rho_h g = \frac{\rho_c g V - W - F_{\text{net}}}{V} = \frac{(11.9\ \text{N/m}^3)(2.18\times10^3\ \text{m}^3) - 2.45\times10^3\ \text{N} - 2.67\times10^3\ \text{N}}{2.18\times10^3\ \text{m}^3}$$
$$= 9.55\ \text{N/m}^3.$$

The ideal gas law gives $p/RT = n/V$. Multiplying both sides by the "molar weight" Mg then leads to

$$\frac{pMg}{RT} = \frac{nMg}{V} = \rho_h g.$$

With $p = 1.01\times10^5$ Pa and $M = 0.028$ kg/m^3, we find the temperature to be

$$T=\frac{pMg}{R\rho_h g}=\frac{(1.01\times10^5\ \text{Pa})(0.028\ \text{kg/mol})(9.8\ \text{m/s}^2)}{(8.31\ \text{J/mol}\cdot\text{K})(9.55\ \text{N/m}^3)}=349\ \text{K}\,.$$

As can be seen from the results above, increasing the temperature of the gas inside the balloon increases the value of F_{net}, that is, the lifting capacity.

83. (a) The final pressure is

$$p_f=\frac{p_iV_i}{V_f}=\frac{(32\,\text{atm})(1.0\,\text{L})}{4.0\,\text{L}}=8.0\,\text{atm}.$$

(b) For the isothermal process, the final temperature of the gas is $T_f = T_i = 300$ K.

(c) The work done is

$$W=nRT_i\ln\left(\frac{V_f}{V_i}\right)=p_iV_i\ln\left(\frac{V_f}{V_i}\right)=(32\,\text{atm})(1.01\times10^5\ \text{Pa/atm})(1.0\times10^{-3}\ \text{m}^3)\ln\left(\frac{4.0\,\text{L}}{1.0\,\text{L}}\right)$$
$$=4.4\times10^3\ \text{J}.$$

For the adiabatic process, $p_iV_i^{\gamma}=p_fV_f^{\gamma}$. Thus,

(d) The final pressure is

$$p_f=p_i\left(\frac{V_i}{V_f}\right)^{\gamma}=(32\,\text{atm})\left(\frac{1.0\,\text{L}}{4.0\,\text{L}}\right)^{5/3}=3.2\,\text{atm}.$$

(e) The final temperature is

$$T_f=\frac{p_fV_fT_i}{p_iV_i}=\frac{(3.2\,\text{atm})(4.0\,\text{L})(300\,\text{K})}{(32\,\text{atm})(1.0\,\text{L})}=120\,\text{K}\ .$$

(f) The work done is

$$W=Q-\Delta E_{\text{int}}=-\Delta E_{\text{int}}=-\frac{3}{2}nR\Delta T=-\frac{3}{2}\left(p_fV_f-p_iV_i\right)$$
$$=-\frac{3}{2}\left[(3.2\,\text{atm})(4.0\,\text{L})-(32\,\text{atm})(1.0\,\text{L})\right]\left(1.01\times10^5\ \text{Pa/atm}\right)\left(10^{-3}\ \text{m}^3/\text{L}\right)$$
$$=2.9\times10^3\ \text{J}\,.$$

(g) If the gas is diatomic, then $\gamma = 1.4$, and the final pressure is

$$p_f = p_i\left(\frac{V_i}{V_f}\right)^{\gamma} = (32\,\text{atm})\left(\frac{1.0\,\text{L}}{4.0\,\text{L}}\right)^{1.4} = 4.6\,\text{atm}\,.$$

(h) The final temperature is

$$T_f = \frac{p_f V_f T_i}{p_i V_i} = \frac{(4.6\,\text{atm})(4.0\,\text{L})(300\,\text{K})}{(32\,\text{atm})(1.0\,\text{L})} = 170\,\text{K}\,.$$

(i) The work done is

$$\begin{aligned} W &= Q - \Delta E_{\text{int}} = -\frac{5}{2}nR\Delta T = -\frac{5}{2}\left(p_f V_f - p_i V_i\right) \\ &= -\frac{5}{2}\left[(4.6\,\text{atm})(4.0\,\text{L}) - (32\,\text{atm})(1.0\,\text{L})\right]\left(1.01\times10^{5}\,\text{Pa/atm}\right)\left(10^{-3}\,\text{m}^3/\text{L}\right) \\ &= 3.4\times10^{3}\,\text{J}. \end{aligned}$$