Halliday ◆ Resnick ◆ Walker

FUNDAMENTALS OF PHYSICS
SIXTH EDITION

Selected Solutions

Chapter 20

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13. Suppose the gas expands from volume V_i to volume V_f during the isothermal portion of the process. The work it does is

$$W = \int_{V_i}^{V_f} p \, dV = nRT \int_{V_i}^{V_f} \frac{dV}{V} = nRT \ln \frac{V_f}{V_i} \, ,$$

where the ideal gas law $pV = nRT$ was used to replace p with nRT/V. Now $V_i = nRT/p_i$ and $V_f = nRT/p_f$, so $V_f/V_i = p_i/p_f$. Also replace nRT with $p_i V_i$ to obtain

$$W = p_i V_i \ln \frac{p_i}{p_f} \, .$$

Since the initial gauge pressure is 1.03×10^5 Pa, $p_i = 1.03 \times 10^5$ Pa $+ 1.013 \times 10^5$ Pa $= 2.04 \times 10^5$ Pa. The final pressure is atmospheric pressure: $p_f = 1.013 \times 10^5$ Pa. Thus

$$W = (2.04 \times 10^5 \text{ Pa})(0.14 \text{ m}^3) \ln \frac{2.04 \times 10^5 \text{ Pa}}{1.013 \times 10^5 \text{ Pa}} = 2.00 \times 10^4 \text{ J} \, .$$

During the constant pressure portion of the process the work done by the gas is $W = p_f(V_i - V_f)$. The gas starts in a state with pressure p_f, so this is the pressure throughout this portion of the process. We also note that the volume decreases from V_f to V_i. Now $V_f = p_i V_i/p_f$, so

$$\begin{aligned} W &= p_f \left(V_i - \frac{p_i V_i}{p_f} \right) = (p_f - p_i) V_i \\ &= (1.013 \times 10^5 \text{ Pa} - 2.04 \times 10^5 \text{ Pa})(0.14 \text{ m}^3) = -1.44 \times 10^4 \text{ J} \, . \end{aligned}$$

The total work done by the gas over the entire process is $W = 2.00 \times 10^4$ J $- 1.44 \times 10^4$ J $= 5.6 \times 10^3$ J.

27. (a) We use $\epsilon = L_V/N$, where L_V is the heat of vaporization and N is the number of molecules per gram. The molar mass of atomic hydrogen is $1\,\mathrm{g/mol}$ and the molar mass of atomic oxygen is $16\,\mathrm{g/mol}$ so the molar mass of H_2O is $1+1+16 = 18\,\mathrm{g/mol}$. There are $N_A = 6.02{\times}10^{23}$ molecules in a mole so the number of molecules in a gram of water is $(6.02\times10^{23}\,\mathrm{mol}^{-1})/(18\,\mathrm{g/mol}) = 3.34\times10^{22}$ molecules/g. Thus $\epsilon = (539\,\mathrm{cal/g})/(3.34 \times 10^{22}/\mathrm{g}) = 1.61 \times 10^{-20}\,\mathrm{cal}$. This is $(1.61 \times 10^{-20}\,\mathrm{cal})(4.186\,\mathrm{J/cal}) = 6.76 \times 10^{-20}\,\mathrm{J}$.

(b) The average translational kinetic energy is

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

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

39. (a) The rms speed of molecules in a gas is given by $v_{\text{rms}} = \sqrt{3RT/M}$, where T is the temperature and M is the molar mass of the gas. See Eq. 20–34. The speed required for escape from Earth's gravitational pull is $v = \sqrt{2gr_e}$, where g is the acceleration due to gravity at Earth's surface and r_e ($= 6.37 \times 10^6$ m) is the radius of Earth. To derive this expression, take the zero of gravitational potential energy to be at infinity. Then, the gravitational potential energy of a particle with mass m at Earth's surface is $U = -GMm/r_e^2 = -mgr_e$, where $g = GM/r_e^2$ was used. If v is the speed of the particle, then its total energy is $E = -mgr_e + \frac{1}{2}mv^2$. If the particle is just able to travel far away, its kinetic energy must tend toward zero as its distance from Earth becomes large without bound. This means $E = 0$ and $v = \sqrt{2gr_e}$. We equate the expressions for the speeds to obtain $\sqrt{3RT/M} = \sqrt{2gr_e}$. The solution for T is $T = 2gr_e M/3R$. The molar mass of hydrogen is 2.02×10^{-3} kg/mol, so for that gas

$$T = \frac{2(9.8\,\text{m/s}^2)(6.37 \times 10^6\,\text{m})(2.02 \times 10^{-3}\,\text{kg/mol})}{3(8.31\,\text{J/mol} \cdot \text{K})} = 1.0 \times 10^4 \text{ K} .$$

(b) The molar mass of oxygen is 32.0×10^{-3} kg/mol, so for that gas

$$T = \frac{2(9.8\,\text{m/s}^2)(6.37 \times 10^6\,\text{m})(32.0 \times 10^{-3}\,\text{kg/mol})}{3(8.31\,\text{J/mol} \cdot \text{K})} = 1.6 \times 10^5 \text{ K} .$$

(c) Now, $T = 2g_m r_m M/3R$, where r_m ($= 1.74 \times 10^6$ m) is the radius of the Moon and g_m ($= 0.16g$) is the acceleration due to gravity at the Moon's surface. For hydrogen

$$T = \frac{2(0.16)(9.8\,\text{m/s}^2)(1.74 \times 10^6\,\text{m})(2.02 \times 10^{-3}\,\text{kg/mol})}{3(8.31\,\text{J/mol} \cdot \text{K})} = 4.4 \times 10^2\,\text{K} .$$

For oxygen

$$T = \frac{2(0.16)(9.8\,\text{m/s}^2)(1.74 \times 10^6\,\text{m})(32.0 \times 10^{-3}\,\text{kg/mol})}{3(8.31\,\text{J/mol} \cdot \text{K})} = 7.0 \times 10^3 \text{ K} .$$

(d) The temperature high in Earth's atmosphere is great enough for a significant number of hydrogen atoms in the tail of the Maxwellian distribution to escape. As a result the atmosphere is depleted of hydrogen. On the other hand, very few oxygen atoms escape.

53. (a) Since the process is at constant pressure energy transferred as heat to the gas is given by $Q = nC_p \Delta T$, where n is the number of moles in the gas, C_p is the molar specific heat at constant pressure, and ΔT is the increase in temperature. For a diatomic ideal gas $C_p = \frac{7}{2}R$. Thus

$$Q = \frac{7}{2}nR\,\Delta T = \frac{7}{2}(4.00\,\text{mol})(8.31\,\text{J/mol}\cdot\text{K})(60.0\,\text{K}) = 6.98 \times 10^3 \text{ J} \ .$$

(b) The change in the internal energy is given by $\Delta E_{\text{int}} = nC_V\,\Delta T$, where C_V is the specific heat at constant volume. For a diatomic ideal gas $C_V = \frac{5}{2}R$, so

$$\Delta E_{\text{int}} = \frac{5}{2}nR\,\Delta T = \frac{5}{2}(4.00\,\text{mol})(8.31\,\text{J/mol}\cdot\text{K})(60.0\,\text{K}) = 4.99 \times 10^3 \text{ J} \ .$$

(c) According to the first law of thermodynamics, $\Delta E_{\text{int}} = Q - W$, so

$$W = Q - \Delta E_{\text{int}} = 6.98 \times 10^3 \text{ J} - 4.99 \times 10^3 \text{ J} = 1.99 \times 10^3 \text{ J} \ .$$

(d) The change in the total translational kinetic energy is

$$\Delta K = \frac{3}{2}nR\,\Delta T = \frac{3}{2}(4.00\,\text{mol})(8.31\,\text{J/mol}\cdot\text{K})(60.0\,\text{K}) = 2.99 \times 10^3 \text{ J} \ .$$