

9. (a) With  $T = 283 \text{ K}$ , we obtain

$$n = \frac{pV}{RT} = \frac{(100 \times 10^3 \text{ Pa}) (2.50 \text{ m}^3)}{(8.31 \frac{\text{J}}{\text{mol}\cdot\text{K}}) (283 \text{ K})} = 106 \text{ mol} .$$

(b) We can use the answer to part (a) with the new values of pressure and temperature, and solve the ideal gas law for the new volume, or we could set up the gas law in ratio form as in Sample Problem 20-1 (where  $n_i = n_f$  and thus cancels out):

$$\frac{p_f V_f}{p_i V_i} = \frac{T_f}{T_i} \implies V_f = (2.50 \text{ m}^3) \left( \frac{100 \text{ kPa}}{300 \text{ kPa}} \right) \left( \frac{303 \text{ K}}{283 \text{ K}} \right)$$

which yields a final volume of  $V_f = 0.892 \text{ m}^3$ .

24. We can express the ideal gas law in terms of density using  $n = M_{\text{sam}}/M$ :

$$pV = \frac{M_{\text{sam}}RT}{M} \implies \rho = \frac{pM}{RT} .$$

We can also use this to write the rms speed formula in terms of density:

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3(pM/\rho)}{M}} = \sqrt{\frac{3p}{\rho}} .$$

- (a) We convert to SI units:  $\rho = 1.24 \times 10^{-2} \text{ kg/m}^3$  and  $p = 1.01 \times 10^3 \text{ Pa}$ . The rms speed is  $\sqrt{3(1010)/0.0124} = 494 \text{ m/s}$ .
- (b) We find  $M$  from  $\rho = pM/RT$  with  $T = 273 \text{ K}$ .

$$M = \frac{\rho RT}{p} = \frac{(0.0124 \text{ kg/m}^3) (8.31 \frac{\text{J}}{\text{molK}}) (273 \text{ K})}{1.01 \times 10^3 \text{ Pa}}$$

This yields  $M = 0.028 \text{ kg/mol}$ , which converts to  $28 \text{ g/mol}$ .

26. (a) Eq. 20-24 gives

$$K_{\text{avg}} = \frac{3}{2} \left( 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}} \right) (273 \text{ K}) = 5.65 \times 10^{-21} \text{ J} .$$

(b) Similarly, for  $T = 373 \text{ K}$ , the average translational kinetic energy is  $K_{\text{avg}} = 7.72 \times 10^{-21} \text{ J}$ .

(c) The unit mole may be thought of as a (large) collection:  $6.02 \times 10^{23}$  molecules of ideal gas, in this case. Each molecule has energy specified in part (a), so the large collection has a total kinetic energy equal to

$$K_{\text{mole}} = N_{\text{A}} K_{\text{avg}} = (6.02 \times 10^{23}) (5.65 \times 10^{-21} \text{ J}) = 3.40 \times 10^3 \text{ J} .$$

(d) Similarly, the result from part (b) leads to

$$K_{\text{mole}} = (6.02 \times 10^{23}) (7.72 \times 10^{-21} \text{ J}) = 4.65 \times 10^3 \text{ J} .$$

61. In the following  $C_V = \frac{3}{2}R$  is the molar specific heat at constant volume,  $C_p = \frac{5}{2}R$  is the molar specific heat at constant pressure,  $\Delta T$  is the temperature change, and  $n$  is the number of moles.

(a) The process 1  $\rightarrow$  2 takes place at constant volume. The heat added is

$$\begin{aligned} Q &= nC_V \Delta T = \frac{3}{2}nR \Delta T \\ &= \frac{3}{2}(1.00 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})(600 \text{ K} - 300 \text{ K}) = 3.74 \times 10^3 \text{ J} . \end{aligned}$$

Since the process takes place at constant volume the work  $W$  done by the gas is zero, and the first law of thermodynamics tells us that the change in the internal energy is

$$\Delta E_{\text{int}} = Q = 3.74 \times 10^3 \text{ J} .$$

The process 2  $\rightarrow$  3 is adiabatic. The heat added is zero. The change in the internal energy is

$$\begin{aligned} \Delta E_{\text{int}} &= nC_V \Delta T = \frac{3}{2}nR \Delta T \\ &= \frac{3}{2}(1.00 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})(455 \text{ K} - 600 \text{ K}) = -1.81 \times 10^3 \text{ J} . \end{aligned}$$

According to the first law of thermodynamics the work done by the gas is

$$W = Q - \Delta E_{\text{int}} = +1.81 \times 10^3 \text{ J} .$$

The process 3  $\rightarrow$  1 takes place at constant pressure. The heat added is

$$\begin{aligned} Q &= nC_p \Delta T = \frac{5}{2}nR \Delta T \\ &= \frac{5}{2}(1.00 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})(300 \text{ K} - 455 \text{ K}) = -3.22 \times 10^3 \text{ J} . \end{aligned}$$

The change in the internal energy is

$$\begin{aligned} \Delta E_{\text{int}} &= nC_V \Delta T = \frac{3}{2}nR \Delta T \\ &= \frac{3}{2}(1.00 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})(300 \text{ K} - 455 \text{ K}) = -1.93 \times 10^3 \text{ J} . \end{aligned}$$

According to the first law of thermodynamics the work done by the gas is

$$W = Q - \Delta E_{\text{int}} = -3.22 \times 10^3 \text{ J} + 1.93 \times 10^3 \text{ J} = -1.29 \times 10^3 \text{ J} .$$

For the entire process the heat added is

$$Q = 3.74 \times 10^3 \text{ J} + 0 - 3.22 \times 10^3 \text{ J} = 520 \text{ J} ,$$

the change in the internal energy is

$$\Delta E_{\text{int}} = 3.74 \times 10^3 \text{ J} - 1.81 \times 10^3 \text{ J} - 1.93 \times 10^3 \text{ J} = 0 ,$$

and the work done by the gas is

$$W = 0 + 1.81 \times 10^3 \text{ J} - 1.29 \times 10^3 \text{ J} = 520 \text{ J} .$$

(b) We first find the initial volume. Use the ideal gas law  $p_1 V_1 = nRT_1$  to obtain

$$V_1 = \frac{nRT_1}{p_1} = \frac{(1.00 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})(300 \text{ K})}{(1.013 \times 10^5 \text{ Pa})} = 2.46 \times 10^{-2} \text{ m}^3 .$$