

Chapter 19

10. Using Eq. 19-14, we note that since it is an isothermal process (involving an ideal gas) then $Q = W = nRT \ln(V_f/V_i)$ applies at any point on the graph. An easy one to read is $Q = 1000 \text{ J}$ and $V_f = 0.30 \text{ m}^3$, and we can also infer from the graph that $V_i = 0.20 \text{ m}^3$. We are told that $n = 0.825 \text{ mol}$, so the above relation immediately yields $T = 360 \text{ K}$.

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

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

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 $T = 273 \text{ K}$.

$$M = \frac{\rho RT}{p} = \frac{(0.0124 \text{ kg/m}^3)(8.31 \text{ J/mol} \cdot \text{K})(273 \text{ K})}{1.01 \times 10^3 \text{ Pa}} = 0.0279 \text{ kg/mol} = 27.9 \text{ g/mol}.$$

(c) From Table 19.1, we identify the gas to be N_2 .

25. (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 $(1.0 + 1.0 + 16) = 18 \text{ g/mol}$. There are $N_A = 6.02 \times 10^{23}$ molecules in a mole so the number of molecules in a gram of water is $(6.02 \times 10^{23} \text{ mol}^{-1})/(18 \text{ g/mol}) = 3.34 \times 10^{22} \text{ molecules/g}$. 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 $(6.76 \times 10^{-20} \text{ J})/(6.32 \times 10^{-21} \text{ J}) = 10.7$.

45. Argon is a monatomic gas, so $f = 3$ in Eq. 19-51, which provides

$$C_V = \frac{3}{2}R = \frac{3}{2}(8.31 \text{ J/mol} \cdot \text{K}) \left(\frac{1 \text{ cal}}{4.186 \text{ J}} \right) = 2.98 \frac{\text{cal}}{\text{mol} \cdot \text{C}^\circ}$$

where we have converted Joules to calories, and taken advantage of the fact that a Celsius degree is equivalent to a unit change on the Kelvin scale. Since (for a given substance) M is effectively a conversion factor between grams and moles, we see that c_V (see units specified in the problem statement) is related to C_V by $C_V = c_V M$ where $M = mN_A$, and m is the mass of a single atom (see Eq. 19-4).

(a) From the above discussion, we obtain

$$m = \frac{M}{N_A} = \frac{C_V / c_V}{N_A} = \frac{2.98/0.075}{6.02 \times 10^{23}} = 6.6 \times 10^{-23} \text{ g}.$$

(b) The molar mass is found to be $M = C_V/c_V = 2.98/0.075 = 39.7 \text{ g/mol}$ which should be rounded to 40 since the given value of c_V is specified to only two significant figures.

59. 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, ΔT is the temperature change, and n is the number of moles.

The process 1 \rightarrow 2 takes place at constant volume.

(a) The heat added is

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

(b) 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

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

(c) The work W done by the gas is zero.

The process $2 \rightarrow 3$ is adiabatic.

(d) The heat added is zero.

(e) The change in the internal energy is

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

(f) 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.

(g) The heat added is

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

(h) The change in the internal energy is

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

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

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

(j) For the entire process the heat added is

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

(k) The change in the internal energy is

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

(l) The work done by the gas is

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

(m) We first find the initial volume. Use the ideal gas law $p_1V_1 = nRT_1$ to obtain

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

(n) Since $1 \rightarrow 2$ is a constant volume process $V_2 = V_1 = 2.46 \times 10^{-2} \text{ m}^3$. The pressure for state 2 is

$$p_2 = \frac{nRT_2}{V_2} = \frac{(1.00 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})(600 \text{ K})}{2.46 \times 10^{-2} \text{ m}^3} = 2.02 \times 10^5 \text{ Pa}.$$

This is approximately equal to 2.00 atm.

(o) $3 \rightarrow 1$ is a constant pressure process. The volume for state 3 is

$$V_3 = \frac{nRT_3}{p_3} = \frac{(1.00 \text{ mol})(8.31 \text{ J/mol} \cdot \text{K})(455 \text{ K})}{1.013 \times 10^5 \text{ Pa}} = 3.73 \times 10^{-2} \text{ m}^3.$$

(p) The pressure for state 3 is the same as the pressure for state 1: $p_3 = p_1 = 1.013 \times 10^5 \text{ Pa}$ (1.00 atm)