1. (6 points) The mass density of an ideal gas was found to be 1.97 kg m\(^{-3}\) at 350 K and 38 kPa. What is the molar mass of the compound?

\[
\begin{align*}
1 & \text{ if } V = 1.00 \text{ m}^3 \\
\eta & = \frac{pV}{RT} = \frac{(38000 \text{ Pa})(1.00 \text{ m}^3)}{(8.314 \text{ J/mol} \cdot \text{K})(350 \text{ K})} = 13.1 \\
M & = \frac{m}{\eta} = \frac{1.97 \times 10^{-3} \text{ g}}{13.1 \text{ mol}} = 1.51 \text{ g/mol}
\end{align*}
\]

2. (6 points) At an altitude of 20 km the temperature is 217 K and the pressure is 0.050 atm. What is the mean free path of \(N_2\) molecules under these conditions? (\(\sigma = .43 \text{ nm}^2\))

\[
\lambda = \frac{\sqrt{\frac{\pi \sigma}{2}}}{\sqrt{\frac{2}{\rho}} \cdot \sqrt{(1.38 \times 10^{-23} \text{ J/mol} \cdot \text{K})(217 \text{ K})}}
\]

\[
= 1.37 \times 10^{-6} \text{ m}
\]

3. At 400 K and 20 atm, the compression factor of a gas is 0.82.

a. (4 points) Calculate the volume occupied by .056 mol of the gas under these conditions.

\[
Z = \frac{PV}{\rho} = \frac{RT \frac{Z}{\rho}}{\rho} = \frac{(.08206)(400)(.82)}{20} = 1.35 \text{ L}
\]

\[
V = nV_m = (.056)(1.35) = 0.75 \text{ L}
\]

b. (4 points) Calculate an approximate value of the second virial coefficient \(B\) at 400 K.

\[
Z \approx 1 + \frac{B}{V_m}
\]

\[
B \approx -V_m (1-Z) = -(1.35)(1-.82) = -0.243 \text{ L/mol}
\]
4. (6 points) The critical molar volume of Br₂ is 135 cm³ mol⁻¹ and the critical pressure is 102 atm. Use this information to calculate the van der Waals constants \( a \) and \( b \) for bromine. Be sure you show units with your answers.

\[
V_c = 3 \ell
\]

\[
b = \frac{1}{3} V_c = \frac{1}{3} (135) \approx 45.0 \text{ cm}^3/\text{mol}
\]

\[
\rho_c = \frac{a}{27 \ell^2}
\]

\[
a = \rho_c \cdot 27. \ell^2 = (102 \text{ atm}) (27) (45.0 \text{ cm}^3/\text{mol})^2
\]

\[
= 5.58 \times 10^6 \text{ cm}^6/\text{atm/}\text{mol}^2 = 5.58 \text{ L}^2/\text{atm/}\text{mol}^2
\]

5. (8 points) 8.00 moles of a perfect gas are allowed to expand isothermally at a temperature of 400 K, from an initial volume of 10.0 L to a final volume of 100.0 L, against a constant external pressure equal to the final pressure of the gas. Calculate \( q \), \( w \), \( \Delta U \), and \( \Delta H \) for the gas.

\[
\rho_p = \rho_{ext} = \frac{nRT}{V_f} = \frac{8.00 \text{ mol} (0.08206 \text{ L atm/mol K}) (400 \text{ K})}{100.0 \text{ L}}
\]

\[
= 2.63 \text{ atm}
\]

\[
w = -\rho_{ext} \Delta V = -(2.63 \text{ atm}) (100.0 - 10.0 \text{ L}) (101.325 \text{ J/L atm})
\]

\[
= -23.9 \text{ kJ}
\]

\[
\Delta U = 0 \quad (T = \text{ const})
\]

\[
\Delta H = \Delta U + \Delta (nRT) = \Delta U + \Delta (nRT) = 0 + 0 = 0
\]

\[
q = \Delta U - w = 0 - w = +23.9 \text{ kJ}
\]

6. (6 points) An ideal gas, when expanded adiabatically and reversibly from 380 K and 3.00 atm to a final pressure of 1.00 atm, is found to have a temperature of 278 K. What is the molar heat capacity \( C_{V, m} \) for the gas?

\[
\frac{1}{R} \ln \left( \frac{T_2}{T_1} \right) = \frac{1}{C_{p, m}} \ln \left( \frac{P_2}{P_1} \right)
\]

\[
C_{p, m} = \frac{R \ln \left( \frac{P_2}{P_1} \right)}{\ln \left( \frac{T_2}{T_1} \right)} = \frac{8.314 \ln \left( \frac{150}{3.00} \right)}{\ln \left( \frac{278}{380} \right)} \approx 29.2 \text{ J/mol K}
\]

\[
C_{V, m} = C_{p, m} - R = 29.2 - 8.3 = 20.9 \text{ J/mol K}
\]
7. a. (4 points) Calculate the enthalpy change $\Delta_{n}H^{\circ}$ at 25°C for the reaction
$\text{N}_2\text{O}_4(\text{g}) \rightarrow 2\text{NO}_2(\text{g}),$
using data from Table 2C.7, p. 876.

\[
\Delta_{n}H^{\circ} = 2 \Delta_{f}H^{\circ}(\text{NO}_2) - \Delta_{f}H^{\circ}(\text{N}_2\text{O}_4)
\]
\[
= 2(33.18) - 9.16
\]
\[
= 57.20 \text{ kJ}
\]

b. (6 points) The molar heat capacities $C_{p,m}^{\circ}$ for $\text{N}_2\text{O}_4$ and $\text{NO}_2$ are given in Table 2C.7 as 77.28 and 37.20 J mol$^{-1}$ K$^{-1}$, respectively, and may be assumed to be temperature-independent. Calculate $\Delta_{r}H^{\circ}$ for the reaction of part (a) at 300°C.

\[
\Delta C_{p}^{\circ} = 2 C_{p,m}^{\circ}(\text{NO}_2) - C_{p,m}^{\circ}(\text{N}_2\text{O}_4)
\]
\[
= 2(37.20) - 77.28 = -2.88 \text{ J/mol} \cdot \text{K}
\]
\[
= -2.88 \times 10^{-3} \text{ kJ/mol} \cdot \text{K}
\]

\[
\Delta H^{\circ}(300) = \Delta H^{\circ}(298) + \Delta C_{p}^{\circ} \Delta T
\]
\[
\Delta H^{\circ}(573) = \Delta H^{\circ}(298) + (-2.88 \times 10^{-3} \text{ kJ/mol} \cdot \text{K})(573 - 298)
\]
\[
= \Delta H^{\circ}(298) - .79
\]
\[
= 57.20 - .79
\]
\[
= 56.41 \text{ kJ}
\]