13-31 The partial pressures of a gas mixture are given. The mole fractions, the mass fractions, the mixture molar mass, the apparent gas constant, the constant-volume specific heat, and the specific heat ratio are to be determined.

Properties The molar masses of CO_2, O_2 and N_2 are 44.0, 32.0, and 28.0 kg/kmol, respectively (Table A-1). The constant-volume specific heats of these gases at 300 K are 0.657, 0.658, and 0.743 kJ/kg·K, respectively (Table A-2a).

Analysis The total pressure is

$$P_{\text{total}} = P_{\text{CO2}} + P_{\text{O2}} + P_{\text{N2}} = 12.5 + 37.5 + 50 = 100 \text{ kPa}$$

Partial pressures
CO_2, 12.5 kPa
O_2, 37.5 kPa
N_2, 50 kPa

The volume fractions are equal to the pressure fractions. Then,

$$y_{\text{CO2}} = \frac{P_{\text{CO2}}}{P_{\text{total}}} = \frac{12.5}{100} = \mathbf{0.125}$$

$$y_{\text{O2}} = \frac{P_{\text{O2}}}{P_{\text{total}}} = \frac{37.5}{100} = \mathbf{0.375}$$

$$y_{\text{N2}} = \frac{P_{\text{N2}}}{P_{\text{total}}} = \frac{50}{100} = \mathbf{0.50}$$

We consider 100 kmol of this mixture. Then the mass of each component are

$$m_{\text{CO2}} = N_{\text{CO2}} M_{\text{CO2}} = (12.5 \text{ kmol})(44 \text{ kg/kmol}) = 550 \text{ kg}$$
$$m_{\text{O2}} = N_{\text{O2}} M_{\text{O2}} = (37.5 \text{ kmol})(32 \text{ kg/kmol}) = 1200 \text{ kg}$$
$$m_{\text{N2}} = N_{\text{N2}} M_{\text{N2}} = (50 \text{ kmol})(28 \text{ kg/kmol}) = 1400 \text{ kg}$$

The total mass is

$$m_m = m_{\text{N2}} + m_{\text{O2}} + m_{\text{Ar}} = 550 + 1200 + 1400 = 3150 \text{ kg}$$

Then the mass fractions are

$$\text{mf}_{\text{CO2}} = \frac{m_{\text{CO2}}}{m_m} = \frac{550 \text{ kg}}{3150 \text{ kg}} = \mathbf{0.1746}$$

$$\text{mf}_{\text{O2}} = \frac{m_{\text{O2}}}{m_m} = \frac{1200 \text{ kg}}{3150 \text{ kg}} = \mathbf{0.3810}$$

$$\text{mf}_{\text{N2}} = \frac{m_{\text{N2}}}{m_m} = \frac{1400 \text{ kg}}{3150 \text{ kg}} = \mathbf{0.4444}$$

The apparent molecular weight of the mixture is

$$M_m = \frac{m_m}{N_m} = \frac{3150 \text{ kg}}{100 \text{ kmol}} = \mathbf{31.50 \text{ kg/kmol}}$$

The constant-volume specific heat of the mixture is determined from

$$\begin{aligned} c_v &= \text{mf}_{\text{Co2}} c_{v,\text{CO2}} + \text{mf}_{\text{O2}} c_{v,\text{O2}} + \text{mf}_{\text{N2}} c_{v,\text{N2}} \\ &= 0.1746 \times 0.657 + 0.3810 \times 0.658 + 0.4444 \times 0.743 \\ &= \mathbf{0.6956 \text{ kJ/kg} \cdot \text{K}} \end{aligned}$$

The apparent gas constant of the mixture is

$$R = \frac{R_u}{M_m} = \frac{8.314 \text{ kJ/kmol} \cdot \text{K}}{31.50 \text{ kg/kmol}} = \mathbf{0.2639 \text{ kJ/kg} \cdot \text{K}}$$

The constant-pressure specific heat of the mixture and the specific heat ratio are

$$c_p = c_v + R = 0.6956 + 0.2639 = \mathbf{0.9595 \text{ kJ/kg} \cdot \text{K}}$$

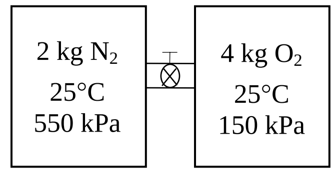
$$k = \frac{c_p}{c_v} = \frac{0.9595 \text{ kJ/kg} \cdot \text{K}}{0.6956 \text{ kJ/kg} \cdot \text{K}} = \mathbf{1.379}$$

13-34 The masses, temperatures, and pressures of two gases contained in two tanks connected to each other are given. The valve connecting the tanks is opened and the final temperature is measured. The volume of each tank and the final pressure are to be determined.

Assumptions Under specified conditions both N_2 and O_2 can be treated as ideal gases, and the mixture as an ideal gas mixture

Properties The molar masses of N_2 and O_2 are 28.0 and 32.0 kg/kmol, respectively. The gas constants of N_2 and O_2 are 0.2968 and 0.2598 kPa·m^3/kg·K, respectively (Table A-1).

Analysis The volumes of the tanks are



$$V_{N_2} = \left(\frac{mRT}{P}\right)_{N_2} = \frac{(2\text{ kg})(0.2968\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})}{550\text{ kPa}} = \mathbf{0.322\ m^3}$$

$$V_{O_2} = \left(\frac{mRT}{P}\right)_{O_2} = \frac{(4\text{ kg})(0.2598\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})}{150\text{ kPa}} = \mathbf{2.065\ m^3}$$

$$V_{\text{total}} = V_{N_2} + V_{O_2} = 0.322\text{ m}^3 + 2.065\text{ m}^3 = 2.386\text{ m}^3$$

Also,

$$N_{N_2} = \frac{m_{N_2}}{M_{N_2}} = \frac{2\text{ kg}}{28\text{ kg/kmol}} = 0.07143\text{ kmol}$$

$$N_{O_2} = \frac{m_{O_2}}{M_{O_2}} = \frac{4\text{ kg}}{32\text{ kg/kmol}} = 0.125\text{ kmol}$$

$$N_m = N_{N_2} + N_{O_2} = 0.07143\text{ kmol} + 0.125\text{ kmol} = 0.1964\text{ kmol}$$

Thus,

$$P_m = \left(\frac{NR_uT}{V}\right)_m = \frac{(0.1964\text{ kmol})(8.314\text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(298\text{ K})}{2.386\text{ m}^3} = \mathbf{204\ kPa}$$

13-55 The volume fractions of components of a gas mixture are given. This mixture is expanded isentropically to a specified pressure. The work produced per unit mass of the mixture is to be determined.

Assumptions All gases will be modeled as ideal gases with constant specific heats.

Properties The molar masses of H_2, He, and N_2 are 2.0, 4.0, and 28.0 kg/kmol, respectively (Table A-1). The constant-pressure specific heats of these gases at room temperature are 14.307, 5.1926, and 1.039 kJ/kg·K, respectively (Table A-2a).

Analysis We consider 100 kmol of this mixture. Noting that volume fractions are equal to the mole fractions, mass of each component are

$$m_{\text{H2}} = N_{\text{H2}} M_{\text{H2}} = (30\text{ kmol})(2\text{ kg/kmol}) = 60\text{ kg}$$
$$m_{\text{He}} = N_{\text{He}} M_{\text{He}} = (40\text{ kmol})(4\text{ kg/kmol}) = 160\text{ kg}$$
$$m_{\text{N2}} = N_{\text{N2}} M_{\text{N2}} = (30\text{ kmol})(28\text{ kg/kmol}) = 840\text{ kg}$$

30% H_2
40% He
30% N_2
(by volume)
5 MPa, 600°C

The total mass is

$$m_m = m_{\text{H2}} + m_{\text{He}} + m_{\text{N2}} = 60 + 160 + 840 = 1060\text{ kg}$$

Then the mass fractions are

$$\text{mf}_{\text{H2}} = \frac{m_{\text{H2}}}{m_m} = \frac{60\text{ kg}}{1060\text{ kg}} = 0.05660$$
$$\text{mf}_{\text{He}} = \frac{m_{\text{He}}}{m_m} = \frac{160\text{ kg}}{1060\text{ kg}} = 0.1509$$
$$\text{mf}_{\text{N2}} = \frac{m_{\text{N2}}}{m_m} = \frac{840\text{ kg}}{1060\text{ kg}} = 0.7925$$

The apparent molecular weight of the mixture is

$$M_m = \frac{m_m}{N_m} = \frac{1060\text{ kg}}{100\text{ kmol}} = 10.60\text{ kg/kmol}$$

The constant-pressure specific heat of the mixture is determined from

$$\begin{aligned} c_p &= \text{mf}_{\text{H2}} c_{p,\text{H2}} + \text{mf}_{\text{He}} c_{p,\text{He}} + \text{mf}_{\text{N2}} c_{p,\text{N2}} \\ &= 0.05660 \times 14.307 + 0.1509 \times 5.1926 + 0.7925 \times 1.039 \\ &= 2.417\text{ kJ/kg}\cdot\text{K} \end{aligned}$$

The apparent gas constant of the mixture is

$$R = \frac{R_u}{M_m} = \frac{8.314\text{ kJ/kmol}\cdot\text{K}}{10.60\text{ kg/kmol}} = 0.7843\text{ kJ/kg}\cdot\text{K}$$

Then the constant-volume specific heat is

$$c_v = c_p - R = 2.417 - 0.7843 = 1.633\text{ kJ/kg}\cdot\text{K}$$

The specific heat ratio is

$$k = \frac{c_p}{c_v} = \frac{2.417}{1.633} = 1.480$$

The temperature at the end of the expansion is

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (873\text{ K})\left(\frac{200\text{ kPa}}{5000\text{ kPa}}\right)^{0.48/1.48} = 307\text{ K}$$

An energy balance on the adiabatic expansion process gives

$$w_{\text{out}} = c_p (T_1 - T_2) = (2.417\text{ kJ/kg}\cdot\text{K})(873 - 307)\text{ K} = \mathbf{1368\text{ kJ/kg}}$$

13-56 The mass fractions of components of a gas mixture are given. This mixture is enclosed in a rigid, well-insulated vessel, and a paddle wheel in the vessel is turned until specified amount of work have been done on the mixture. The mixture's final pressure and temperature are to be determined.

Assumptions All gases will be modeled as ideal gases with constant specific heats.

Properties The molar masses of N_2, He, CH_4, and C_2H_6 are 28.0, 4.0, 16.0, and 30.0 kg/kmol, respectively (Table A-1). The constant-pressure specific heats of these gases at room temperature are 1.039, 5.1926, 2.2537, and 1.7662 kJ/kg·K, respectively (Table A-2a).

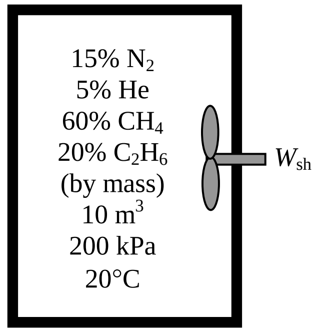
Analysis We consider 100 kg of this mixture. The mole numbers of each component are

$$N_{\text{N2}} = \frac{m_{\text{N2}}}{M_{\text{N2}}} = \frac{15\text{ kg}}{28\text{ kg/kmol}} = 0.5357\text{ kmol}$$

$$N_{\text{He}} = \frac{m_{\text{He}}}{M_{\text{He}}} = \frac{5\text{ kg}}{4\text{ kg/kmol}} = 1.25\text{ kmol}$$

$$N_{\text{CH4}} = \frac{m_{\text{CH4}}}{M_{\text{CH4}}} = \frac{60\text{ kg}}{16\text{ kg/kmol}} = 3.75\text{ kmol}$$

$$N_{\text{C2H6}} = \frac{m_{\text{C2H6}}}{M_{\text{C2H6}}} = \frac{20\text{ kg}}{30\text{ kg/kmol}} = 0.6667\text{ kmol}$$



The mole number of the mixture is

$$N_m = N_{\text{N2}} + N_{\text{He}} + N_{\text{CH4}} + N_{\text{C2H6}} = 0.5357 + 1.25 + 3.75 + 0.6667 = 6.2024\text{ kmol}$$

The apparent molecular weight of the mixture is

$$M_m = \frac{m_m}{N_m} = \frac{100\text{ kg}}{6.2024\text{ kmol}} = 16.12\text{ kg/kmol}$$

The constant-pressure specific heat of the mixture is determined from

$$\begin{aligned} c_p &= \text{mf}_{\text{N2}} c_{p,\text{N2}} + \text{mf}_{\text{He}} c_{p,\text{He}} + \text{mf}_{\text{CH4}} c_{p,\text{CH4}} + \text{mf}_{\text{C2H6}} c_{p,\text{C2H6}} \\ &= 0.15 \times 1.039 + 0.05 \times 5.1926 + 0.60 \times 2.2537 + 0.20 \times 1.7662 \\ &= 2.121\text{ kJ/kg}\cdot\text{K} \end{aligned}$$

The apparent gas constant of the mixture is

$$R = \frac{R_u}{M_m} = \frac{8.134\text{ kJ/kmol}\cdot\text{K}}{16.12\text{ kg/kmol}} = 0.5158\text{ kJ/kg}\cdot\text{K}$$

Then the constant-volume specific heat is

$$c_v = c_p - R = 2.121 - 0.5158 = 1.605\text{ kJ/kg}\cdot\text{K}$$

The mass in the container is

$$m_m = \frac{P_1 V_m}{RT_1} = \frac{(200\text{ kPa})(10\text{ m}^3)}{(0.5158\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293\text{ K})} = 13.23\text{ kg}$$

An energy balance on the system gives

$$W_{\text{sh,in}} = m_m c_v (T_2 - T_1) \longrightarrow T_2 = T_1 + \frac{W_{\text{sh,in}}}{m_m c_v} = (293\text{ K}) + \frac{100\text{ kJ}}{(13.23\text{ kg})(1.605\text{ kJ/kg}\cdot\text{K})} = \mathbf{297.7\text{ K}}$$

Since the volume remains constant and this is an ideal gas,

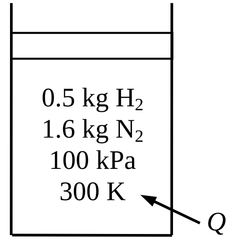
$$P_2 = P_1 \frac{T_2}{T_1} = (200\text{ kPa})\frac{297.7\text{ K}}{293\text{ K}} = \mathbf{203.2\text{ kPa}}$$

13-68 A piston-cylinder device contains a gas mixture at a given state. Heat is transferred to the mixture. The amount of heat transfer and the entropy change of the mixture are to be determined.

Assumptions **1** Under specified conditions both H_2 and N_2 can be treated as ideal gases, and the mixture as an ideal gas mixture. **2** Kinetic and potential energy changes are negligible.

Properties The constant pressure specific heats of H_2 and N_2 at 450 K are 14.501 kJ/kg.K and 1.049 kJ/kg.K, respectively. (Table A-2b).

Analysis (*a*) Noting that $P_2 = P_1$ and $\mathcal{V}_2 = 2\mathcal{V}_1$,



$$\frac{P_2\mathcal{V}_2}{T_2} = \frac{P_1\mathcal{V}_1}{T_1} \longrightarrow T_2 = \frac{2\mathcal{V}_1}{\mathcal{V}_1}T_1 = 2T_1 = (2)(300\text{ K}) = 600\text{ K}$$

From the closed system energy balance relation,

$$E_{\text{in}} - E_{\text{out}} = \Delta E_{\text{system}}$$

$$Q_{\text{in}} - W_{b,\text{out}} = \Delta U \quad \rightarrow \quad Q_{\text{in}} = \Delta H$$

since W_b and ΔU combine into ΔH for quasi-equilibrium constant pressure processes.

$$\begin{aligned} Q_{\text{in}} &= \Delta H = \Delta H_{H_2} + \Delta H_{N_2} = \left[mc_{p,\text{avg}}(T_2 - T_1)\right]_{H_2} + \left[mc_{p,\text{avg}}(T_2 - T_1)\right]_{N_2} \\ &= (0.5\text{ kg})(14.501\text{ kJ/kg}\cdot\text{K})(600 - 300)\text{K} + (1.6\text{ kg})(1.049\text{ kJ/kg}\cdot\text{K})(600 - 300)\text{K} \\ &= \mathbf{2679\,kJ} \end{aligned}$$

(*b*) Noting that the total mixture pressure, and thus the partial pressure of each gas, remains constant, the entropy change of the mixture during this process is

$$\begin{aligned} \Delta S_{H_2} &= \left[m(s_2 - s_1)\right]_{H_2} = m_{H_2}\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}^{\nearrow 0}\right)_{H_2} = m_{H_2}\left(c_p \ln\frac{T_2}{T_1}\right)_{H_2} \\ &= (0.5\text{ kg})(14.501\text{ kJ/kg}\cdot\text{K})\ln\frac{600\text{ K}}{300\text{ K}} \\ &= 5.026\text{ kJ/K} \end{aligned}$$

$$\begin{aligned} \Delta S_{N_2} &= \left[m(s_2 - s_1)\right]_{N_2} = m_{N_2}\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}^{\nearrow 0}\right)_{N_2} = m_{N_2}\left(c_p \ln\frac{T_2}{T_1}\right)_{N_2} \\ &= (1.6\text{ kg})(1.049\text{ kJ/kg}\cdot\text{K})\ln\frac{600\text{ K}}{300\text{ K}} \\ &= 1.163\text{ kJ/K} \end{aligned}$$

$$\Delta S_{\text{total}} = \Delta S_{H_2} + \Delta S_{N_2} = 5.026\text{ kJ/K} + 1.163\text{ kJ/K} = \mathbf{6.19\,kJ/K}$$