13–38 A rigid tank that contains 1 kg of N2 at 25°C and 300 kPa is connected to another rigid tank that contains 3 kg of O2 at 25°C and 500 kPa. The valve connecting the two tanks is opened, and the two gases are allowed to mix. If the final mixture temperature is 25°C, determine the volume of each tank and the final mixture pressure.

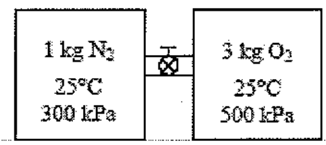
Assumptions Under specified conditions both N_2 and O_2 can be treated as ideal gases, and the mixture as an ideal gas mixture

Properties The molar masses of N_2 and O_2 are 28.0 and 32.0 kg/kmol, respectively (Table A-1)

Analysis The volumes of the tanks are

$$V_{N_2} = \left(\frac{mRT}{P}\right)_{N_2} = \frac{(1\text{ kg})(0.2968\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})}{300\text{ kPa}} = \underline{\mathbf{0.295\ m^3}}$$

$$V_{O_2} = \left(\frac{mRT}{P}\right)_{O_2} = \frac{(3\text{ kg})(0.2598\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})}{500\text{ kPa}} = \underline{\mathbf{0.465\ m^3}}$$



$$V_{total} = V_{N_2} + V_{O_2} = 0.295\text{ m}^3 + 0.465\text{ m}^3 = 0.76\text{ m}^3$$

Also,

$$m_{N_2} = 1\text{ kg} \longrightarrow N_{N_2} = \frac{m_{N_2}}{M_{N_2}} = \frac{1\text{ kg}}{28\text{ kg/kmol}} = 0.03571\text{ kmol}$$

$$m_{O_2} = 3\text{ kg} \longrightarrow N_{O_2} = \frac{m_{O_2}}{M_{O_2}} = \frac{3\text{ kg}}{32\text{ kg/kmol}} = 0.09375\text{ kmol}$$

$$N_m = N_{N_2} + N_{O_2} = 0.03571\text{ kmol} + 0.09375\text{ kmol} = 0.1295\text{ kmol}$$

Thus,

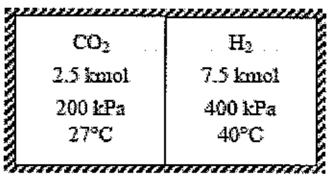
$$P_m = \left(\frac{NR_uT}{V}\right)_m = \frac{(0.1295\text{ kmol})(8.314\text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(298\text{ K})}{0.76\text{ m}^3} = \underline{\mathbf{422.2\ kPa}}$$

13–52 An insulated rigid tank is divided into two compartments by a partition. One compartment contains 2.5 kmol of CO2 at 27°C and 200 kPa, and the other compartment contains 7.5 kmol of H2 gas at 40°C and 400 kPa. Now the partition is removed, and the two gases are allowed to mix. Determine (*a*) the mixture temperature and (*b*) the mixture pressure after equilibrium has been established. Assume constant specific heats at room temperature for both gases.

Assumptions **1** Under specified conditions both CO_2 and H_2 can be treated as ideal gases, and the mixture as an ideal gas mixture. **2** The tank is insulated and thus there is no heat transfer. **3** There are no other forms of work involved.

Properties The molar masses and specific heats of CO_2 and H_2 are 44.0 kg/kmol, 2.0 kg/kmol, 0.657 kJ/kg.°C, and 10.183 kJ/kg.°C, respectively. (Tables A-1 and A-2b).

Analysis (*a*) We take both gases as our system. No heat, work, or mass crosses the system boundary, therefore this is a closed system with $Q = 0$ and $W = 0$. Then the energy balance for this closed system reduces to



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

$$0 = \Delta U = \Delta U_{CO_2} + \Delta U_{H_2}$$

$$0 = [mc_v(T_m - T_1)]_{CO_2} + [mc_v(T_m - T_1)]_{H_2}$$

Using c_v values at room temperature and noting that $m = NM$, the final temperature of the mixture is determined to be

$$(2.5 \times 44 \text{ kg})(0.657 \text{ kJ/kg}\cdot°\text{C})(T_m - 27°\text{C}) + (7.5 \times 2 \text{ kg})(10.183 \text{ kJ/kg}\cdot°\text{C})(T_m - 40°\text{C}) = 0$$

$$T_m = \underline{\mathbf{35.8°C}} \quad (308.8 \text{ K})$$

(*b*) The volume of each tank is determined from

$$V_{CO_2} = \left(\frac{NR_uT_1}{P_1}\right)_{CO_2} = \frac{(2.5 \text{ kmol})(8.314 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(300 \text{ K})}{200 \text{ kPa}} = 31.18 \text{ m}^3$$

$$V_{H_2} = \left(\frac{NR_uT_1}{P_1}\right)_{H_2} = \frac{(7.5 \text{ kmol})(8.314 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(313 \text{ K})}{400 \text{ kPa}} = 48.79 \text{ m}^3$$

Thus,

$$V_m = V_{CO_2} + V_{H_2} = 31.18 \text{ m}^3 + 48.79 \text{ m}^3 = 79.97 \text{ m}^3$$

$$N_m = N_{CO_2} + N_{H_2} = 2.5 \text{ kmol} + 7.5 \text{ kmol} = 10.0 \text{ kmol}$$

and

$$P_m = \frac{N_mR_uT_m}{V_m} = \frac{(10.0 \text{ kmol})(8.314 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(308.8 \text{ K})}{79.97 \text{ m}^3} = \underline{\mathbf{321 \text{ kPa}}}$$

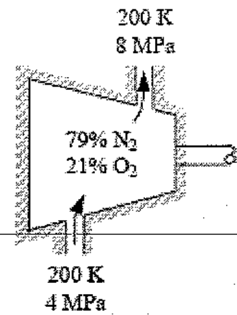
13–65 Air, which may be considered as a mixture of 79 percent N2 and 21 percent O2 by mole numbers, is compressed isothermally at 200 K from 4 to 8 MPa in a steady-flow device. The compression process is internally reversible, and the mass flow rate of air is 2.9 kg/s. Determine the power input to the compressor and the rate of heat rejection by treating the mixture (*a*) as an ideal gas and (*b*) as a nonideal gas and using Amagat's law.

Assumptions 1 This is a steady-flow process. 2 The kinetic and potential energy changes are negligible.

Properties The molar mass of air is 29.0 kg/kmol. (Table A-1).

Analysis The mass flow rate of air can be expressed in terms of the mole numbers as

$$\dot{N} = \frac{\dot{m}}{M} = \frac{2.90\ \text{kg/s}}{29.0\ \text{kg/kmol}} = 0.10\ \text{kmol/s}$$



(*a*) Assuming ideal gas behavior, the Δh and Δs of air during this process is

$$\Delta\bar{h} = 0\ \text{(isothermal process)}$$

$$\Delta\bar{s} = \bar{c}_p \ln\frac{T_2}{T_1}^{\nearrow 0} - R_u \ln\frac{P_2}{P_1} = -R_u \ln\frac{P_2}{P_1}$$

$$= -(8.314\ \text{kJ/kg}\cdot\text{K})\ln\frac{8\ \text{MPa}}{4\ \text{MPa}} = -5.763\ \text{kJ/kmol}\cdot\text{K}$$

Disregarding any changes in kinetic and potential energies, the steady-flow energy balance equation for the isothermal process of an ideal gas reduces to

$$\dot{E}_{in} - \dot{E}_{out} = \Delta\dot{E}_{system}^{\nearrow 0\ \text{(steady)}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{in} + \dot{N}\bar{h}_1 = \dot{Q}_{out} + \dot{N}\bar{h}_2$$

$$\dot{W}_{in} - \dot{Q}_{out} = \dot{N}\Delta\bar{h}^{\nearrow 0} = 0 \longrightarrow \dot{W}_{in} = \dot{Q}_{out}$$

Also for an isothermal, internally reversible process the heat transfer is related to the entropy change by $Q = T\Delta S = NT\Delta\bar{s}$,

$$\dot{Q} = \dot{N}T\Delta\bar{s} = (0.10\ \text{kmol/s})(200\ \text{K})(-5.763\ \text{kJ/kmol}\cdot\text{K}) = -115.3\ \text{kW} \rightarrow \dot{Q}_{out} = 115.3\ \text{kW}$$

Therefore,

$$\dot{W}_{in} = \dot{Q}_{out} = \mathbf{115.3\ kW}$$

(*b*) Using Amagat's law and the generalized charts, the enthalpy and entropy changes of each gas are determined from

$$\bar{h}_2 - \bar{h}_1 = R_u T_{cr}(Z_{h_1} - Z_{h_2}) + (\bar{h}_2 - \bar{h}_1)_{ideal}^{\nearrow 0}$$

$$\bar{s}_2 - \bar{s}_1 = R_u(Z_{s_1} - Z_{s_2}) + (\bar{s}_2 - \bar{s}_1)_{ideal}$$

where

$$N_2:\quad \left.\begin{array}{l} P_{R_1} = \dfrac{P_{m,1}}{P_{cr,N_2}} = \dfrac{4}{3.39} = 1.18 \\ T_{R_1} = T_{R_2} = \dfrac{T_m}{T_{cr,N_2}} = \dfrac{200}{126.2} = 1.58 \\ P_{R_2} = \dfrac{P_{m,2}}{P_{cr,N_2}} = \dfrac{8}{3.39} = 2.36 \end{array}\right\} \begin{array}{l} Z_{h_1} = .47\ \ Z_{s_1} = 0.2 \\ Z_{h_2} = 0.9\ \ Z_{s_2} = 0.45 \end{array} \quad \text{(Tables A-29 and A-30)}$$

$$
\mathrm{O_2}: \quad
\left.
\begin{aligned}
P_{R_1} &= \frac{P_{m,1}}{P_{\mathrm{cr,O_2}}} = \frac{4}{5.08} = 0.787 \\
T_{R_1} &= T_{R_2} = \frac{T_m}{T_{\mathrm{cr,O_2}}} = \frac{200}{154.8} = 1.29 \\
P_{R_2} &= \frac{P_{m,2}}{P_{\mathrm{cr,O_2}}} = \frac{8}{5.08} = 1.575
\end{aligned}
\right\}
\begin{aligned}
Z_{h_1} &= .55,\ Z_{s_1} = .35 \\
Z_{h_2} &= 1.15\ Z_{s_2} = .75
\end{aligned}
\quad \text{(Tables A-29 and A-30)}
$$

Then,

$$
\begin{aligned}
\bar{h}_2 - \bar{h}_1 &= y_i \Delta \bar{h}_i = y_{\mathrm{N_2}} (\bar{h}_2 - \bar{h}_1)_{\mathrm{N_2}} + y_{\mathrm{O_2}} (\bar{h}_2 - \bar{h}_1)_{\mathrm{O_2}} \\
&= (0.79)(8.314)(126.2)(.47 - .09) + (0.21)(8.314)(154.8)(.55 - 1.15) + 0 \\
&= -518.59\ \mathrm{kJ/kmol \cdot K} \\
\bar{s}_2 - \bar{s}_1 &= y_i \Delta \bar{s}_i = y_{\mathrm{N_2}} (\bar{s}_2 - \bar{s}_1)_{\mathrm{N_2}} + y_{\mathrm{O_2}} (\bar{s}_2 - \bar{s}_1)_{\mathrm{O_2}} \\
&= (0.79)(8.314)(0.2 - .45) + (0.21)(8.314)(0.35 - 0.75) + (-5.763) \\
&= -8.104\ \mathrm{kJ/kmol \cdot K}
\end{aligned}
$$

Thus,

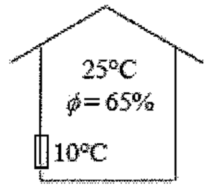
$$
\dot{Q}_{\mathrm{out}} = -\dot{N} T \Delta \bar{s} = -(0.10\ \mathrm{kmol/s})(200\ \mathrm{K})(-8.104\ \mathrm{kJ/kmol \cdot K}) = 162.08\ \mathrm{kW}
$$

$$
\begin{aligned}
\dot{E}_{\mathrm{in}} - \dot{E}_{\mathrm{out}} &= \Delta \dot{E}_{\mathrm{system}}^{\nearrow 0\ \mathrm{(steady)}} = 0 \\
\dot{E}_{\mathrm{in}} &= \dot{E}_{\mathrm{out}} \\
\dot{W}_{\mathrm{in}} + \dot{N}\bar{h}_1 &= \dot{Q}_{\mathrm{out}} + \dot{N}\bar{h}_2 \\
\dot{W}_{\mathrm{in}} &= \dot{Q}_{\mathrm{out}} + \dot{N}(\bar{h}_2 - \bar{h}_1) \longrightarrow \dot{W}_{\mathrm{in}} = 162\ \mathrm{kW} + (0.10\mathrm{kmol/s})(-51.9\ \mathrm{kJ/kmol}) = 110.1\ \mathrm{kW}
\end{aligned}
$$

14–27 A house contains air at 25°C and 65 percent relative humidity. Will any moisture condense on the inner surfaces of the windows when the temperature of the window drops to 10°C?

Assumptions The air and the water vapor are ideal gases.

Analysis The vapor pressure P_v is uniform throughout the house, and its value can be determined from



$$P_v = \phi P_{g@25°C} = (0.65)(3.1698 \text{ kPa}) = 2.06 \text{ kPa}$$

The dew-point temperature of the air in the house is

$$T_{dp} = T_{sat@P_v} = T_{sat@2.06 \text{ kPa}} = \mathbf{18.0°C}$$

That is, the moisture in the house air will start condensing when the temperature drops below 18.0°C. Since the windows are at a lower temperature than the dew-point temperature, some moisture **will condense** on the window surfaces.

14–46 The air in a room has a pressure of 1 atm, a dry-bulb temperature of 24°C, and a wet-bulb temperature of 17°C. Using the psychrometric chart, determine (*a*) the specific humidity, (*b*) the enthalpy (in kJ/kg dry air), (*c*) the relative humidity, (*d*) the dew-point temperature, and (*e*) the specific volume of the air (in m3/kg dry air).

Analysis From the psychrometric chart (Fig. A-31) we read

(*a*) $\omega = 0.0092 \text{ kg H}_2\text{O / kg dry air}$

(*b*) $h = 47.6 \text{ kJ / kg dry air}$

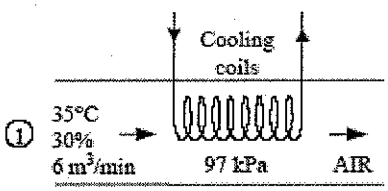
(*c*) $\phi = 49.6\%$

(*d*) $T_{dp} = 12.8°C$

(*e*) $v = 0.855 \text{ m}^3 \text{ / kg dry air}$

14–129 Air enters a cooling section at 97 kPa, 35°C, and 30 percent relative humidity at a rate of 6 m3/min, where it is cooled until the moisture in the air starts condensing. Determine (*a*) the temperature of the air at the exit and (*b*) the rate of heat transfer in the cooling section.

Analysis (*a*) The amount of moisture in the air also remains constant ($\omega_1 = \omega_2$) as it flows through the cooling section since the process involves no humidification or dehumidification. The total pressure is 97 kPa. The properties of the air at the inlet state are



$$P_{v1} = \phi_1 P_{g1} = \phi_1 P_{sat\,@\,35°C} = (0.3)(5.629\text{ kPa}) = 1.69\text{ kPa}$$

$$P_{a1} = P_1 - P_{v1} = 97 - 1.69 = 95.31\text{ kPa}$$

$$v_1 = \frac{R_a T_1}{P_{a1}} = \frac{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(308\text{ K})}{95.31\text{ kPa}} = 0.927\text{ m}^3/\text{kg dry air}$$

$$\omega_1 = \frac{0.622 P_{v1}}{P_1 - P_{v1}} = \frac{0.622(1.69\text{ kPa})}{(97-1.69)\text{ kPa}} = 0.0110\text{ kg H}_2\text{O/kg dry air} \ (= \omega_2)$$

$$h_1 = c_p T_1 + \omega_1 h_{g1} = (1.005\text{ kJ/kg°C})(35°\text{C}) + (0.0110)(2564.6\text{ kJ/kg}) = 63.44\text{ kJ/kg dry air}$$

The air at the final state is saturated and the vapor pressure during this process remains constant. Therefore, the exit temperature of the air must be the dew-point temperature,

$$T_{dp} = T_{sat\,@\,P_v} = T_{sat\,@\,1.69\text{ kPa}} = \mathbf{14.8°C}$$

(*b*) The enthalpy of the air at the exit is

$$h_2 = c_p T_2 + \omega_2 h_{g2} = (1.005\text{ kJ/kg}\cdot°\text{C})(14.8°\text{C}) + (0.0110)(2528.1\text{ kJ/kg}) = 42.78\text{ kJ/kg dry air}$$

Also $\dot{m}_a = \dfrac{\dot{V}_1}{v_1} = \dfrac{6\text{ m}^3/\text{s}}{0.927\text{ m}^3/\text{kg dry air}} = 6.47\text{ kg/min}$

Then the rate of heat transfer from the air in the cooling section becomes

$$\dot{Q}_{out} = \dot{m}_a(h_1 - h_2) = (6.47\text{ kg/min})(63.44 - 42.78)\text{kJ/kg} = \mathbf{134\text{ kJ/min}}$$