Problem 1A.4

Gas-mixture viscosities at low density. The following data[2] are available for the viscosities of mixtures of hydrogen and Freon-12 (dichlorodifluoromethane) at 25°C and 1 atm:

Mole fraction of H_2:	0.00	0.25	0.50	0.75	1.00
$\mu \times 10^6$ (poise):	124.0	128.1	131.9	135.1	88.4

Use the viscosities of the pure components to calculate the viscosities at the three intermediate compositions by means of Eqs. 1.4-15 and 16.

Sample answer: At 0.5, $\mu = 0.01317$ cp.

Solution

Eqs. 1.4-15 and 16 in the text are a pair of formulas that allow us to compute the viscosity of a mixture with N chemical species.

$$\mu_{\text{mix}} = \sum_{\alpha=1}^{N} \frac{x_\alpha \mu_\alpha}{\displaystyle\sum_{\beta=1}^{N} x_\beta \Phi_{\alpha\beta}}, \tag{1.4-15}$$

where $\Phi_{\alpha\beta}$ is

$$\Phi_{\alpha\beta} = \frac{1}{\sqrt{8}}\left(1 + \frac{M_\alpha}{M_\beta}\right)^{-1/2}\left[1 + \left(\frac{\mu_\alpha}{\mu_\beta}\right)^{1/2}\left(\frac{M_\beta}{M_\alpha}\right)^{1/4}\right]^2. \tag{1.4-16}$$

When the mole fraction of H_2 is 0.00, the gas mixture is made up wholly of dichlorodifluoromethane, which has the molecular formula Cl_2F_2 and a tetrahedral geometry. If

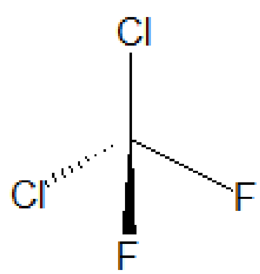

Figure 1: The Freon-12 molecule.

we let Freon-12 be species 1, then $\mu_1 = 124.0 \times 10^{-6}$ poise and $M_1 = 2(35.45) + 2(19.00) = 108.9$ g/mol. When the mole fraction of H_2 is 1.00, the gas mixture is made up wholly of hydrogen gas. Let H_2 be species 2. Then $\mu_2 = 88.4 \times 10^{-6}$ poise and $M_2 = 2(1.008) = 2.016$ g/mol. We have to calculate three values of μ_{mix}: (1) when $x_1 = 0.75$ and $x_2 = 0.25$, (2) when $x_1 = 0.5$ and $x_2 = 0.5$, and (3) when $x_1 = 0.25$ and $x_2 = 0.75$. Write out the

[2] J. W. Buddenberg and C. R. Wilke, *Ind. Eng. Chem.* **41**, 1345–1347 (1949).

terms of each sum in Eq. 1.4-15.

$$\begin{aligned}\mu_{\text{mix}} &= \sum_{\alpha=1}^{2} \frac{x_\alpha \mu_\alpha}{\sum_{\beta=1}^{2} x_\beta \Phi_{\alpha\beta}} \\ &= \frac{x_1\mu_1}{\sum_{\beta=1}^{2} x_\beta \Phi_{1\beta}} + \frac{x_2\mu_2}{\sum_{\beta=1}^{2} x_\beta \Phi_{2\beta}} \\ &= \frac{x_1\mu_1}{x_1\Phi_{11} + x_2\Phi_{12}} + \frac{x_2\mu_2}{x_1\Phi_{21} + x_2\Phi_{22}}\end{aligned}$$

Use Eq. 1.4-16 to determine Φ_{11}, Φ_{12}, Φ_{21}, and Φ_{22}.

$$\Phi_{11} = \frac{1}{\sqrt{8}}\left(1 + \frac{M_1}{M_1}\right)^{-1/2}\left[1 + \left(\frac{\mu_1}{\mu_1}\right)^{1/2}\left(\frac{M_1}{M_1}\right)^{1/4}\right]^2 = 1$$

$$\Phi_{12} = \frac{1}{\sqrt{8}}\left(1 + \frac{M_1}{M_2}\right)^{-1/2}\left[1 + \left(\frac{\mu_1}{\mu_2}\right)^{1/2}\left(\frac{M_2}{M_1}\right)^{1/4}\right]^2 \approx 0.0984095$$

$$\Phi_{21} = \frac{1}{\sqrt{8}}\left(1 + \frac{M_2}{M_1}\right)^{-1/2}\left[1 + \left(\frac{\mu_2}{\mu_1}\right)^{1/2}\left(\frac{M_1}{M_2}\right)^{1/4}\right]^2 \approx 3.78970$$

$$\Phi_{22} = \frac{1}{\sqrt{8}}\left(1 + \frac{M_2}{M_2}\right)^{-1/2}\left[1 + \left(\frac{\mu_2}{\mu_2}\right)^{1/2}\left(\frac{M_2}{M_2}\right)^{1/4}\right]^2 = 1$$

Plug all the numbers into the formula for μ_{mix} and then multiply the results by 10^6. Therefore,

Mole fraction of Cl_2F_2 (x_1):	0.75	0.50	0.25
Mole fraction of H_2 (x_2):	0.25	0.50	0.75
$\mu_{\text{mix}} \times 10^6$ (poise):	127.2	131.3	134.8

These numbers are in excellent agreement with the data.