Partial Pressures in Mixtures of Gases

Problem 6-89

What is the partial pressure of $Cl_2(g)$, in millimeters of mercury, at STP in a gaseous mixture that consists of 46.5% N_2, 12.7%Ne, and 40.8% Cl_2, by mass?

Solution:
This problem is actually fairly easy in concept but is complicated by the mass percentage. Gas law problems involving partial pressures are easier solved in mole fraction.

To get mole fraction Cl_2, though, we'll need to calculate the molar equivalent of 100 g of gas mixture.

First, define the percentage:

$$46.5\%\ {}^{\mathrm{w}}\!/_{\mathrm{w}}\ \mathrm{N_2} = \frac{46.5\ \mathrm{g\ N_2}}{100\ \mathrm{g\ mix}}$$

Now redefine the percentages as mol-mass ratios:

$$C_{\mathrm{N_2}} = \frac{46.5\ \mathrm{g\ N_2} / 28.01\ {}^{\mathrm{g}}\!/_{\mathrm{mol}}}{100\ \mathrm{g\ mix}} = 0.01660\ \tfrac{\mathrm{mol\ N_2}}{\mathrm{g\ mix}}$$

$$C_{\mathrm{Ne}} = \frac{12.7\ \mathrm{g\ Ne} / 20.18\ {}^{\mathrm{g}}\!/_{\mathrm{mol}}}{100\ \mathrm{g\ mix}} = 0.006293\ \tfrac{\mathrm{mol\ Ne}}{\mathrm{g\ mix}}$$

$$C_{\mathrm{Cl_2}} = \frac{40.8\ \mathrm{g\ Cl_2} / 70.906\ {}^{\mathrm{g}}\!/_{\mathrm{mol}}}{100\ \mathrm{g\ mix}} = 0.005754\ \tfrac{\mathrm{mol\ Cl_2}}{\mathrm{g\ mix}}$$

Since we're dealing with gases here, we can simply add the molar quantities to get total moles of gas per g of gas mixture:

$$C_{\mathrm{T}} = 0.01660\ \tfrac{\mathrm{mol\ N_2}}{\mathrm{g\ mix}} + 0.006293\ \tfrac{\mathrm{mol\ Ne}}{\mathrm{g\ mix}} + 0.005754\ \tfrac{\mathrm{mol\ Cl_2}}{\mathrm{g\ mix}} = 0.02865\ \tfrac{\mathrm{mol\ gas}}{\mathrm{g\ mix}}$$

Now that the hard step is out of the way, we can calculate the mole fraction, X, of $\mathrm{Cl_2}$ in the mixture:

$$X_{\mathrm{Cl_2}} = \frac{0.005754\ \mathrm{mol\ Cl_2}}{1\ \mathrm{g\ mix}\ (0.02865\ \tfrac{\mathrm{mol\ gas}}{\mathrm{g\ mix}})} = 0.2009\ \tfrac{\mathrm{mol\ Cl_2}}{\mathrm{mol\ mix}}$$

And, finally, calculate the $P_{\mathrm{Cl_2}}$:

$$P_{\mathrm{Cl_2}} = 0.2009\ \tfrac{\mathrm{mol\ Cl_2}}{\mathrm{mol\ mix}} \times 1.00\ \mathrm{atm} = 0.201\ \mathrm{atm}$$