78. The following problems concern quantitative analysis of two chemical compounds.

(a) A compound known to contain only the elements carbon, hydrogen, nitrogen, and oxygen was analyzed in the laboratory.

(i) A sample of the compound with mass 0.4788 g was sent through a series of tests that converted all combined nitrogen into nitrogen gas. The nitrogen gas was collected by water displacement and yielded a volume of 37.80 mL, measured at 23.8°C and 746.0 mmHg. According to a chemical handbook, at this temperature, the vapor pressure of water is 22.1 mmHg. Using the results of this experiment, calculate the mass percent of nitrogen in the compound.

(ii) In a separate experiment, 12.96 mg of the compound was burned in a pure oxygen atmosphere. Products collected were 35.14 mg carbon dioxide and 8.638 mg water. Using the results of this experiment, calculate the mass percent of carbon and hydrogen in the compound.

(iii) Explain how to use data from both experiments to calculate the mass percent of oxygen in the compound.

(b) In a separate experiment, a different compound is shown to consist of 25.4% by mass carbon, 3.20% by mass hydrogen, 37.5% by mass chlorine, and 33.9% by mass oxygen.

(i) Determine the empirical formula of the compound.

(ii) Identify additional information about the compound that is needed in order to determine the molecular formula.

(Answer)

78. Overall strategy: This problem calls for application of principles of stoichiometry and the General Gas Law.

(a) (i) Use the General Gas Law to determine the number of moles of N_2.

$$n = \frac{PV}{RT}$$

$$= \frac{\frac{746}{760}\text{ atm} \times 0.0378\text{ L}}{0.0821\text{ L atm mol}^{-1}\text{ K}^{-1} \times 296.8\text{ K}}$$

$$= 0.001478\text{ mol } N_2$$

Convert this to mass of nitrogen.

$$(0.001478)\text{mol } N_2 \times \frac{28.0\text{ g } N_2}{1\text{mol } N_2} = 0.04141\text{ g } N_2$$

Compare to the original mass of the compound to determine the percent by mass.

$$\frac{0.04141\text{ g } N_2}{0.4788\text{ g compound}} = \mathbf{8.65\%\text{ nitrogen}}$$

(ii) This amount of carbon dioxide contains 9.58 mg C, equivalent to 74.0% by mass of the compound. This amount of water contains 0.9682 mg H, equivalent to 7.47% by mass of the compound.

$$35.14\text{ mg carbon dioxide} \times \frac{12\text{ g C}}{44\text{ g } CO_2} = 9.58\text{ mg C}$$

$$\frac{9.58\text{ mg C}}{12.96\text{ mg of the compound}} = \mathbf{74.0\%\text{ carbon}}$$

$$8.638\text{ mg water} \times \frac{2\text{ g H}}{18\text{ g } H_2O} = 0.9682\text{ g H}$$

$$\frac{0.9682\text{ g H}}{12.96\text{ mg of the compound}} = \mathbf{7.47\%\text{ hydrogen}}$$

(iii) To find the remaining percentage by mass oxygen, subtract the percentages of nitrogen (from part a) and carbon and hydrogen (from part b) from 100%.

$$\%O = 100 - \%N - \%C - \%H$$