9.6: Combining Stoichiometry and the Ideal Gas Laws

With an understanding of the ideal gas laws, it is now possible to apply these principles to chemical stoichiometry problems. For example, zinc metal and hydrochloric acid (hydrogen chloride dissolved in water) react to form zinc (II) chloride and hydrogen gas according to the equation shown below:

2 HCl *(aq)* + Zn *(s)* → $ZnCl_2$ *(aq)* + H_2 *(g)*

Example 9.6.1:

A sample of pure zinc with a mass of 5.98 g is reacted with excess hydrochloric acid and the (dry) hydrogen gas is collected at 25.0 ˚C and 742 mm Hg. What *volume* of hydrogen gas would be produced?

Solution

This is a "single state" problem, so we can solve it using the ideal gas law, *PV* = *nRT*. In order to find the volume of hydrogen gas (*V*), we need to know the number of *moles* of hydrogen that will be produced by the reaction. Our stoichiometry is simply *one mole of hydrogen per mole of zinc*, so we need to know the number of moles of zinc that are present in 5.98 grams of zinc metal. The temperature is given in centigrade, so we need to convert into Kelvin, and we also need to convert mm Hg into atm.

Conversions:

$$25.0\ C + 273 = 298\ K$$

$$(742\ mm\ Hg) \times \left(\frac{1\ atm}{760\ mm\ Hg}\right) = 0.976\ atm$$

$$(5.98\ g\ Zn) \times \left(\frac{1.00\ mol}{65.39\ g\ Zn}\right) = 0.0915\ mol$$

Substituting:

$$PV = nRT$$

$$(0.976\ atm) \times V = (0.0915\ mol)(0.0821\ L\ atm\ mol^{-1} K^{-1})(298\ K)$$

$$V = \frac{(0.0915\ mol)(0.0821\ L\ atm\ mol^{-1} K^{-1})(298\ K)}{(0.976\ atm)} = 2.29\ L$$

We can also use the fact that one mole of a gas occupies 22.414 L at STP in order to calculate the number of moles of a gas that is produced in a reaction. For example, the organic molecule ethane (CH_3CH_3) reacts with oxygen to give carbon dioxide and water according to the equation shown below:

2 CH_3CH_3 *(g)* + 7 O_2 *(g)* → 4 CO_2 *(g)* + 6 H_2O *(g)*

Example 9.6.1:

An unknown mass of ethane is allowed to react with excess oxygen and the carbon dioxide produced is separated and collected. The carbon dioxide collected is found to occupy 11.23 L at STP; what mass of ethane was in the original sample?

Solution

Because the volume of carbon dioxide is measured at STP, the observed value can be converted directly into *moles of carbon dioxide* by dividing by 22.414 L mol^{-1}. Once moles of carbon dioxide are known, the stoichiometry of the problem can be used to directly give moles of ethane (molar mass 30.07 g mol^{-1}), which leads directly to the *mass* of ethane in the sample.

$$(11.23\ L\ CO_2) \times \left(\frac{1\ mol}{22.414\ L}\right) = 0.501\ mol\ CO_2$$

Reaction stoichiometry:

$$(0.501\ mol\ CO_2) \times \left(\frac{2\ mol\ CH_3CH_3}{4\ mol\ CO_2}\right) = 0.250\ mol\ CH_3CH_3$$

The ideal gas laws allow a quantitative analysis of whole spectrum of chemical reactions. When you are approaching these problems, remember to *first* decide on the *class* of the problem:

- If it is a “single state” problem (a gas is produced at a single, given, set of conditions), then you want to use *PV = nRT.*
- If it is a “two state” problem (a gas is changed from one set of conditions to another) you want to use

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

- If the volume of gas is quoted at STP, you can quickly convert this volume into moles with by dividing by 22.414 L mol^{-1}.

Once you have isolated your approach ideal gas law problems are no more complex that the stoichiometry problems we have addressed in earlier chapters.

Exercise 9.6.1

1. An automobile air bag requires about 62 L of nitrogen gas in order to inflate. The nitrogen gas is produced by the decomposition of sodium azide, according to the equation shown below

2 NaN_3 *(s)* → 2 Na *(s)* + 3 N_2 *(g)*

What mass of sodium azide is necessary to produce the required volume of nitrogen at 25 ˚C and 1 atm?

2. When Fe_2O_3 is heated in the presence of carbon, CO_2 gas is produced, according to the equation shown below. A sample of 96.9 grams of Fe_2O_3 is heated in the presence of excess carbon and the CO_2 produced is collected and measured at 1 atm and 453 K. What volume of CO_2 will be observed?

2 Fe_2O_3*(s)* + 3 C *(s)* → 4 Fe *(s)* + 3 CO_2 *(g)*

3. The reaction of zinc and hydrochloric acid generates hydrogen gas, according to the equation shown below. An unknown quantity of zinc in a sample is observed
to produce 7.50 L of hydrogen gas at a temperature of 404 K and a pressure of 1.75 atm. How many moles of zinc were in the sample?

Zn *(s)* + 2 HCl *(aq)* → $ZnCl_2$ *(aq)* + H_2 *(g)*