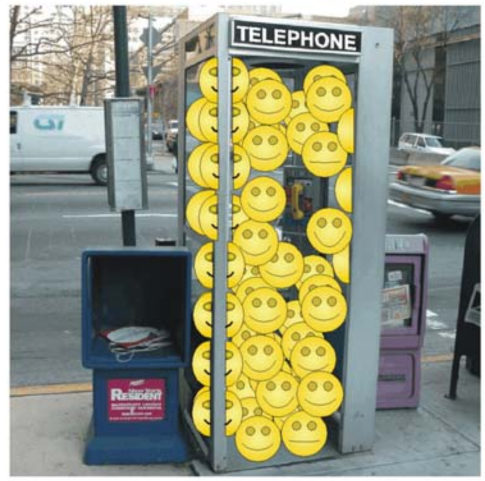
Gas Stoichiometry

The gas laws make it clear that there is a relationship between the volume, the number of moles, and the mass of a gas. You learned how to determine the mass of any reactant or product in a chemical reaction from that of any other using the balanced equation. The relationship between the masses of the reagents involved in a reaction is:

$$m_1 \rightarrow mol_1 \rightarrow mol_2 \rightarrow m_2$$

When any of the reagents is a gas, a relationship exists between the volume and the number of moles as well, as defined by the ideal gas law:



A popular prank among the gas molecules in engineering fraternities was seeing how many of them could squeeze into a telephone booth. Unfortunately the gas laws took most of the fun out of it by ruining the surprise.

Sample Problem 1

How many grams of rust (Fe_2O_3) form when iron reacts with 25.0 L of oxygen at 25°C and 200. kPa?

Step 1: Write a balanced equation
$4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Step 2: Substitute values into the gas equation to get the number of moles of gas

$$n = \frac{PV}{RT} = \frac{(200.\,kPa)(1atm)(25.0L)}{(101.3kPa)\left(0.0821\frac{L\cdot atm}{mol\cdot K}\right)(298K)} = 2.02mol$$

Step 3: Solve the remaining problem by the factor label method.

$$2.02mol_{O_2}\left(\frac{2mol_{Fe_2O_3}}{3mol_{O_2}}\right)\left(\frac{159.7g_{Fe_2O_3}}{1mol_{Fe_2O_3}}\right) = 215g_{Fe_2O_3}$$

Problems of gas stoichiometry can generally be solved by the approach above, but under some circumstances the work can be simplified. At constant temperature and pressure, volume-volume problems can be handled simply by using Avogadro's law ($V \propto n$) because all the other variables in the gas laws cancel out. Since the number of moles and the volumes are proportional, and the coefficients of the balanced equation are mole ratios, these problems can be solved by setting up a proportion.

Sample Problem 2

How many milliliters of ammonia are formed when 150.mL of hydrogen combines with nitrogen at constant temperature and pressure?

Step 1: Write a balanced equation
$N_2 + 3H_2 \rightarrow 2NH_3$

Step 2: Set up a proportion and solve

$$\frac{3mol_{H_2}}{150.ml_{H_2}} = \frac{2mol_{NH_3}}{x} \qquad x = 100ml_{NH_3}$$

Problems at STP can be simplified even when mass-volume problems are done because at STP the molar volume (GMV) of a gas is always 22.4 L. Since $22.4\,L = 1\,mol$ at STP, the GMV can be used in a factor label problem in much the same way as the molar mass (GFM).

Sample Problem 3

How many liters of oxygen are liberated when 18.4 g of potassium chlorate decompose at STP?

Step 1: Write a balanced equation.
$2KClO_3 \rightarrow 2KCl + 3O_2$

Step 2: Solve by the factor label method

$$18.4g_{KClO_3}\left(\frac{1mol_{KClO_3}}{122.6g_{KClO_3}}\right)\left(\frac{3mol_{O_2}}{2mol_{KClO_3}}\right)\left(\frac{22.4L_{O_2}}{1mol_{O_2}}\right) = 5.04L$$

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Answer the questions below using the procedures described on the previous page. [*NOTE*: The equations provided may not be balanced.]

1. If 35.0 L of propane burns, how many liters of carbon dioxide will form at the same temperature and pressure? [$C_3H_8(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$]

2. If 250. mL of oxygen at STP are consumed when magnesium burns, how many grams of magnesium oxide form? [$Mg(s) + O_2(g) \rightarrow MgO(s)$]

3. Hydrogen peroxide decomposes to release oxygen. How much space does the oxygen occupy if 40.8 g of hydrogen peroxide decomposes at –13 °C and 2.40 atm? [$H_2O_2(aq) \rightarrow H_2O(\ell) + O_2(g)$]

4. Most of the carbon dioxide in the blood is carried as carbonic acid [H_2CO_3]. It decomposes in the alveoli to release carbon dioxide. How many grams of carbonic acid would have to decompose to release 15.0 mL of carbon dioxide into the lungs at 37 °C and 1 atm? [$H_2CO_3(aq) \rightarrow H_2O(\ell) + CO_2(g)$]

5. The Hindenburg, a German airship kept afloat by 1.98×10^5 kL of hydrogen at STP, exploded as it landed at the Lakehurst Naval Air Station in New Jersey on May 6, 1937. Assuming all the hydrogen was consumed in the explosion, how many kilograms of water formed? [$H_2(g) + O_2(g) \rightarrow H_2O(g)$]