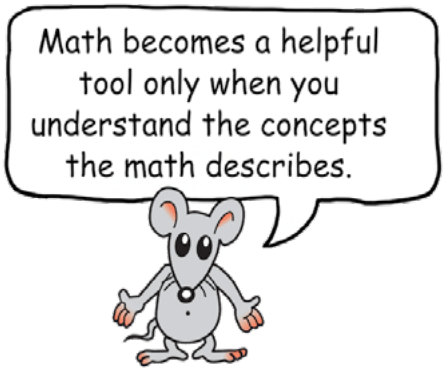
Chapter 9
CALCULATION CORNER
Masses of Reactants and Products

The coefficients of a chemical equation tell us the ratio by which reactants react and products form. The following equation, for example, tells us that every 1 mole of methane, CH_4, reacts to produce 2 moles of water, H_2O.

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

If you were given 16 g of methane, CH_4, how many grams of water, H_2O, would form? From the text, you should know that 16 g of methane, CH_4, is 1 mole (formula mass 16 amu). So, 16 g of methane would yield 2 moles of water. But how many grams are 2 moles of water? Well, if 1 mole of water, H_2O, equals 18 g (formula mass 18 amu), then 2 moles equals 36 g. Thus, 16 g of methane, CH_4, would yield 36 g of water, H_2O. Let's look at this process from a step-by-step mathematical point of view.



SAMPLE PROBLEM 1

What mass of water is produced when 16 g of methane, CH_4 (formula mass 16 amu), reacts with oxygen, O_2, in the following reaction?

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

SOLUTION:

Step 1. Convert the given mass to moles:

Conversion factor

$$(16\ \text{g}\ \cancel{CH_4})\left(\frac{1\ \text{mole}\ CH_4}{16\ \text{g}\ \cancel{CH_4}}\right) = 1\ \text{mole}\ CH_4$$

Step 2. Use the coefficients of the balanced equation to find out how many moles of H_2O are produced from this many moles of CH_4:

Conversion factor

$$(1\ \cancel{\text{mole}\ CH_4})\left(\frac{2\ \text{moles}\ H_2O}{1\ \cancel{\text{mole}\ CH_4}}\right) = 2\ \text{moles}\ H_2O$$

Step 3. Now that you know how many moles of H_2O are produced, convert this value to grams of H_2O:

Conversion factor

$$(2\ \cancel{\text{moles}\ H_2O})\left(\frac{18\ \text{g}\ H_2O}{1\ \cancel{\text{mole}\ H_2O}}\right) = 36\ \text{g}\ H_2O$$

Steps 1 through 3 can be combined into a single equation that starts with what you are given (16 g of CH_4) and calculates that which is asked for:

$$(16\ \text{g}\ \cancel{CH_4})\underbrace{\left(\frac{1\ \text{mole}\ \cancel{CH_4}}{16\ \text{g}\ \cancel{CH_4}}\right)}_{\text{step 1}}\underbrace{\left(\frac{2\ \text{moles}\ \cancel{H_2O}}{1\ \text{mole}\ \cancel{CH_4}}\right)}_{\text{step 2}}\underbrace{\left(\frac{18\ \text{g}H_2O}{1\ \text{mole}\ \cancel{H_2O}}\right)}_{\text{step 3}} = 36\ \text{g}\ H_2O$$

This technique of combining a series of conversion factors is an application of what you learned in the unit conversion Calculation Corner of Chapter 1. Also, within each conversion factor, the unit that you want to change goes in the denominator and that which you want to obtain goes in the numerator.

The method of converting grams of a substance to moles (step 1), then from moles of this substance to moles of that substance (step 2), followed by moles of that substance to grams (step 3) is called *stoichiometry*. Using stoichiometry, we can calculate the amounts of reactants or products in any chemical reaction.

The methods of stoichiometry are developed much further in upper level chemistry. For our current purposes, we're simply introducing the main idea, which how we keep tabs on atoms and molecules as they react to form products.

Nonetheless, for a special assignment, you might try your analytical thinking skills on the following problems. First, try to deduce the answer based on what you know about the law of mass conservation, and then follow the mathematical steps to check your answers.

SAMPLE PROBLEM 2

Show that 44 g of carbon dioxide, CO_2, is produced when 16 g of methane, CH_4, reacts with oxygen, O_2. How many grams of oxygen, O_2, are needed for this reaction?

SOLUTION:

The 16 g of methane, CH_4, is one mole, which reacts with oxygen to produce one mole of carbon dioxide, CO_2, which you know because of the coefficients in the balanced chemical equation shown previously. One mole of carbon dioxide (formula mass 44 amu) is 44 g.

So, the 16 g of methane reacts with oxygen to produce 44 g of carbon dioxide plus 36 g of water. The mass of the products (44 g + 36 g = 80 g) must be equal to the mass of the reactants (16 g + ? = 80 g). We can calculate that the methane reacted with 64 g of oxygen, which, interestingly enough, is 2 moles, as we see from the balanced equation.

The mass of carbon dioxide produced can also be calculated as follows:

$$(16\ \text{g}\ \cancel{\text{CH}_4})\left(\frac{1\ \text{mole}\ \cancel{\text{CH}_4}}{16\ \text{g}\ \cancel{\text{CH}_4}}\right)\left(\frac{1\ \text{mole}\ \cancel{\text{CO}_2}}{1\ \text{mole}\ \cancel{\text{CH}_4}}\right)\left(\frac{44\ \text{g}\ \text{CO}_2}{1\ \text{mole}\ \cancel{\text{CO}_2}}\right) = 44\ \text{g}\ \text{CO}_2$$

Similarly, the mass of oxygen can be calculated as follows:

$$(16\ \text{g}\ \cancel{\text{CH}_4})\left(\frac{1\ \text{mole}\ \cancel{\text{CH}_4}}{16\ \text{g}\ \cancel{\text{CH}_4}}\right)\left(\frac{2\ \text{moles}\ \cancel{\text{O}_2}}{1\ \text{mole}\ \cancel{\text{CH}_4}}\right)\left(\frac{32\ \text{g}\ \text{O}_2}{1\ \text{mole}\ \cancel{\text{O}_2}}\right) = 64\ \text{g}\ \text{O}_2$$

SAMPLE PROBLEM 3

How many grams of ozone (O_3, 48 amu) can be produced from 64 g of oxygen (O_2, 32 amu) in the reaction shown?

$$3\ \text{O}_2 \rightarrow 2\ \text{O}_3$$

SOLUTION:

According to the law of mass conservation, the amount of mass in the products must equal the amount of mass in the reactants. Given that this reaction involves only one reactant and one product, you should not be surprised to learn that 64 g of reactant produces 64 g of product. Here are the stepwise calculations, which start with *grams* of oxygen and then finds the *moles* of oxygen. The moles of oxygen are then converted to moles of ozone using the coefficients of the equation. This is followed by a conversion of *moles* of ozone to *grams* of ozone:

$$(64\ \text{g}\ \cancel{\text{O}_2})\left(\frac{1\ \text{mole}\ \cancel{\text{O}_2}}{32\ \text{g}\ \cancel{\text{O}_2}}\right)\left(\frac{2\ \text{moles}\ \text{O}_3}{3\ \text{moles}\ \cancel{\text{O}_2}}\right)\left(\frac{48\ \text{g}\ \text{O}_3}{1\ \text{mole}\ \text{O}_3}\right) = 64\ \text{g}\ \text{O}_3$$

SAMPLE PROBLEM 4

What mass of nitrogen monoxide (NO, 30 amu) is formed when 28 g of nitrogen (N_2, 28 amu) reacts with 32 g of oxygen (O_2, 32 amu) in the reaction shown?

$$\text{N}_2 + \text{O}_2 \rightarrow 2\ \text{NO}$$

SOLUTION:

There are several ways to answer this question. One way would be to recognize that 28 g of N_2 is 1 mole of N_2 and 32 g of O_2 is 1 mole of O_2. According to the balanced equation, combining 1 mole of N_2 with 1 mole of O_2 yields 2 moles of NO. Because the mass of 1 mole of NO is 30 g, the mass of 2 moles of NO must be 30 g × 2 = 60 g, which is simply the sum of all the reactants (28 g + 32 g = 60 g). To calculate step- wise, you can start with either the 28 g of N_2 or the 32 g of O_2.

$$(28\ \text{g}\ \cancel{\text{N}_2})\left(\frac{1\ \text{mole}\ \cancel{\text{N}_2}}{28\ \text{g}\ \cancel{\text{N}_2}}\right)\left(\frac{2\ \text{moles}\ \cancel{\text{NO}}}{1\ \text{mole}\ \cancel{\text{N}_2}}\right)\left(\frac{30\ \text{g NO}}{1\ \text{mole}\ \cancel{\text{NO}}}\right) = 60\ \text{g NO}$$

In this reaction, N_2 and O_2 were combined in exactly the right amounts. Do you recognize that there would be too much oxygen if 28 g of N_2 were reacted with 40 g of O_2? If that were the case, then only 32 g of the 40 g of O_2 would react. There would be 8 g of unreacted O_2 left over. Stoichiometry is an area of chemistry rich in opportunities for analytical thinking.

YOUR TURN

1. How many grams of iron oxide, Fe_2O_3, can be produced from the reaction of 25.0 g of iron, Fe, with an unlimited amount of oxygen, O_2? (Not sure where to start? Here's a helpful rule: always start your calculation by writing down that which you are given, which in this case is 25.0 g of Fe. Then proceed with the conversions.)

$$4\ \text{Fe} + 3\ \text{O}_2 \rightarrow 2\ \text{Fe}_2\text{O}_3$$

2. How many grams of iron oxide, Fe_2O_3, can be produced from the reaction of 25.0 g of oxygen, O_2, with an unlimited amount of iron, Fe?

3. How many grams of oxygen, O_2, are required to react with 25.0 g of iron, Fe, to form iron oxide, Fe_2O_3?

4. A 25.0-g sample of iron, Fe, powder is mixed with 25.0 g of oxygen, O_2, gas and heated until all of the Fe has reacted. How many grams of O_2 remain after the reaction is complete?

Answers to Calculation Corners appear at the end of the Chapter Review