

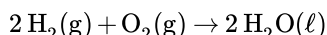
4.1: Stoichiometry

Learning Objectives

- Define *stoichiometry*.
- Relate quantities in a balanced chemical reaction on a molecular basis.

Consider a classic recipe for pound cake: 1 pound of eggs, 1 pound of butter, 1 pound of flour, and 1 pound of sugar. (That's why it's called "pound cake.") If you have 4 pounds of butter, how many pounds of sugar, flour, and eggs do you need? You would need 4 pounds each of sugar, flour, and eggs.

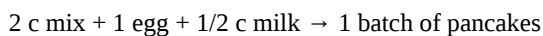
Now suppose you have 1.00 g H₂. If the chemical reaction follows the balanced chemical equation



then what mass of oxygen do you need to make water?

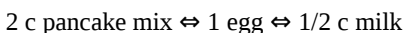
Curiously, this chemical reaction question is very similar to the pound cake question. Both of them involve relating a quantity of one substance to a quantity of another substance or substances. The relating of one chemical substance to another using a balanced chemical reaction is called **stoichiometry**. Using stoichiometry is a fundamental skill in chemistry; it greatly broadens your ability to predict what will occur and, more importantly, how much is produced.

Let us consider a more complicated example. A recipe for pancakes calls for 2 cups (c) of pancake mix, 1 egg, and 1/2 c of milk. We can write this in the form of a chemical equation:



If you have 9 c of pancake mix, how many eggs and how much milk do you need? It might take a little bit of work, but eventually you will find you need 4½ eggs and 2¼ c milk.

How can we formalize this? We can make a conversion factor using our original recipe and use that conversion factor to convert from a quantity of one substance to a quantity of another substance. This is similar to the way we constructed a conversion factor between feet and yards in Chapter 2. Because one recipe's worth of pancakes requires 2 c of pancake mix, 1 egg, and 1/2 c of milk, we actually have the following mathematical relationships that relate these quantities:



where \Leftrightarrow is the mathematical symbol for "is equivalent to." This does not mean that 2 c of pancake mix equal 1 egg. However, *as far as this recipe is concerned*, these are the equivalent quantities needed for a single recipe of pancakes. So, any possible quantities of two or more ingredients must have the same numerical ratio as the ratios in the equivalence.

We can deal with these equivalences in the same way we deal with equalities in unit conversions: we can make conversion factors that essentially equal 1. For example, to determine how many eggs we need for 9 c of pancake mix, we construct the conversion factor:

$$\frac{1 \text{ egg}}{2 \text{ c pancake mix}}$$

This conversion factor is, in a strange way, equivalent to 1 because the recipe relates the two quantities. Starting with our initial quantity and multiplying by our conversion factor,

$$9 \text{ c } \cancel{\text{pancake mix}} \times \frac{1 \text{ egg}}{2 \text{ c } \cancel{\text{pancake mix}}} = 4.5 \text{ eggs}$$

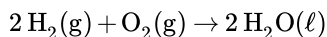
Note how the units *cups pancake mix* canceled, leaving us with units of *eggs*. This is the formal, mathematical way of getting our amounts to mix with 9 c of pancake mix. We can use a similar conversion factor for the amount of milk:

$$9 \text{ c } \cancel{\text{pancake mix}} \times \frac{\frac{1}{2} \text{ c milk}}{2 \text{ c } \cancel{\text{pancake mix}}} = 2.25 \text{ c milk}$$

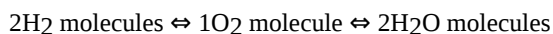
Again, units cancel, and new units are introduced.

A balanced chemical equation is nothing more than a *recipe for a chemical reaction*. The difference is that a balanced chemical equation is written in terms of atoms and molecules, not cups, pounds, and eggs.

For example, consider the following chemical equation:



We can interpret this as, literally, "two hydrogen molecules react with one oxygen molecule to make two water molecules." That interpretation leads us directly to some equivalencies, just as our pancake recipe did:



These equivalences allow us to construct conversion factors:

$$\frac{2 \text{ molecules } \text{H}_2}{1 \text{ molecule } \text{O}_2} \quad \frac{2 \text{ molecules } \text{H}_2}{2 \text{ molecules } \text{H}_2\text{O}} \quad \frac{1 \text{ molecule } \text{H}_2}{2 \text{ molecules } \text{H}_2\text{O}}$$

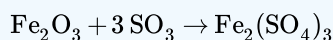
and so forth. These conversions can be used to relate quantities of one substance to quantities of another. For example, suppose we need to know how many molecules of oxygen are needed to react with 16 molecules of H_2 . As we did with converting units, we start with our given quantity and use the appropriate conversion factor:

$$16 \text{ molecules } \text{H}_2 \times \frac{1 \text{ molecule } \text{O}_2}{2 \text{ molecules } \text{H}_2} = 8 \text{ molecules } \text{O}_2$$

Note how the unit *molecules H₂* cancels algebraically, just as any unit does in a conversion like this. The conversion factor came directly from the coefficients in the balanced chemical equation. This is another reason why a properly balanced chemical equation is important.

✓ Example 4.1.1

How many molecules of SO_3 are needed to react with 144 molecules of Fe_2O_3 given this balanced chemical equation?



Solution

We use the balanced chemical equation to construct a conversion factor between Fe_2O_3 and SO_3 . The number of molecules of Fe_2O_3 goes on the bottom of our conversion factor so it cancels with our given amount, and the molecules of SO_3 go on the top. Thus, the appropriate conversion factor is

$$\frac{3 \text{ molecules } \text{SO}_3}{1 \text{ molecule } \text{Fe}_2\text{O}_3}$$

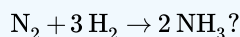
Starting with our given amount and applying the conversion factor, the result is

$$144 \text{ molecules } \text{Fe}_2\text{O}_3 \times \frac{3 \text{ molecules } \text{SO}_3}{1 \text{ molecule } \text{Fe}_2\text{O}_3} = 432 \text{ molecules } \text{SO}_3$$

We need 432 molecules of SO_3 to react with 144 molecules of Fe_2O_3 .

? Exercise 4.1.1

How many molecules of H_2 are needed to react with 29 molecules of N_2 to make ammonia if the balanced chemical equation is:



Answer

87 molecules

Chemical equations also allow us to make conversions regarding the number of atoms in a chemical reaction, because a chemical formula lists the number of atoms of each element in a compound. The formula H_2O indicates that there are two hydrogen atoms and one oxygen atom in each molecule, and these relationships can be used to make conversion factors:

$$\frac{2 \text{ atoms } H}{1 \text{ molecule } H_2O} \quad \frac{1 \text{ molecule } H_2O}{1 \text{ atom } O}$$

Conversion factors like this can also be used in stoichiometry calculations.

✓ Example 4.1.2

How many molecules of NH_3 can you make if you have 228 atoms of H_2 ?

Solution

From the formula, we know that one molecule of NH_3 has three H atoms. Use that fact as a conversion factor:

$$228 \text{ atoms } H \times \frac{1 \text{ molecule } NH_3}{3 \text{ atoms } H} = 76 \text{ } NH_3$$

? Exercise 4.1.2

How many molecules of $Fe_2(SO_4)_3$ can you make from 777 atoms of S?

Answer

259 molecules

Summary

Quantities of substances can be related to each other using balanced chemical equations.

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