STOICHIOMETRY

How can one determine the amount of product formed from a specific reactant? Or the relationship between different compounds in an equation?

This is where you use stoichiometry.

Take for example pizza, if 1 crust, 3 cups of cheese, and 1 cup of sauce make one pizza, how much pizza can you make with 9 cups of cheese assuming you have all other ingredients?

We solve these equations with a process called *dimensional analysis*.

Through dimensional analysis, we chemists can convert between several different units from quantity to mass to volume and many more.

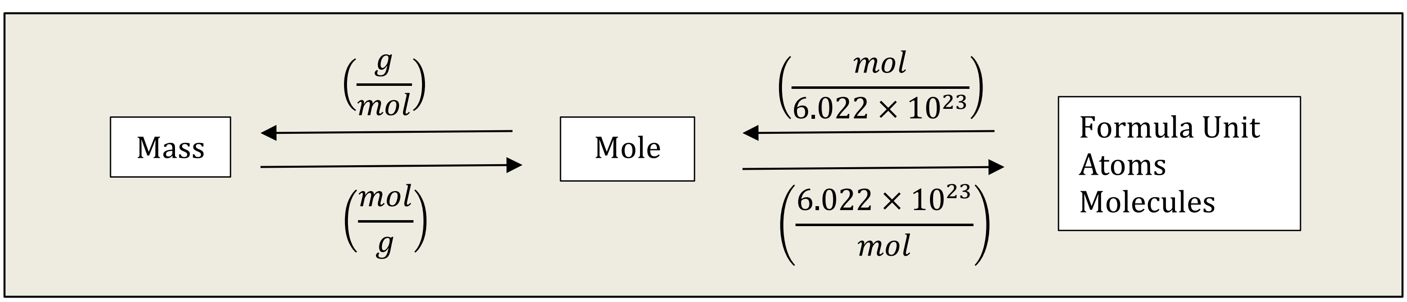
Here is an example of a conversion done by dimensional analysis:

$$\frac{9\ \cancel{\text{cups of Cheese}}}{} \times \frac{1\ \text{pizza}}{3\ \cancel{\text{cups of Cheese}}} = 3\ \text{pizzas}$$

Something to note when doing dimensional analysis is that all units should cancel except for the final answer.

In the context of chemistry, your dimensional analysis may look more like this:

$$\frac{45\ \cancel{\text{g } NH_3}}{1} \times \frac{1\ \text{mol}\ \cancel{NH_3}}{17\ \cancel{\text{g } NH_3}} \times \frac{6.022 \times 10^{23}\ \cancel{\text{molecules } NH_3}}{1\ \cancel{\text{mol } NH_3}} \times \frac{3\ \text{H atoms}}{1\ \cancel{\text{molecule } NH_3}} = 4.8 \times 10^{24}\ \text{H atoms}$$



Now when doing Stoichiometry, we almost always convert to and from the unit Mole, the base unit amount of a substance.

Let's look at some conversions!

Moles/Mass

When using the mass of any element or compound in dimensional analysis, you will convert using that substance's molar mass. This is found from the atomic mass on the periodic table.

For example, the molar mass of carbon is 12.0111 g/mol. Knowing this information, one can find the mass in grams of carbon when given an amount in moles or vise versa.

Ex. How many grams of carbon are found in .726 moles of carbon?

$$\begin{array}{c|c} .726\ \cancel{\text{mol C}} & 12.0111\text{ g C} \\ \hline 1 & 1\ \cancel{\text{mol C}} \end{array} = 8.72\text{ g C}$$

You Try!

1. How many grams of Calcium are in 8.743 mole of Calcium?

2. If you have 6.37 grams of Chlorine, how many moles are in this sample?

Mole/Molecules

When converting between moles and molecules of a substance, one would use Avagadro's number, 6.022×10^{23} molecules/mol as the constant.

Ex. How many gold atoms are there in a sample of 1.28 moles of gold?

$$\frac{1.28\ \cancel{\text{mol Au}}}{1} \times \frac{6.022 \times 10^{23}\ \text{atoms Au}}{1\ \cancel{\text{mol Au}}} = 7.71 \times 10^{23}\ \text{atoms Au}$$

You Try!

3. How many water molecules are in a sample of 3.094 mol of water?

4. How many mole of $MgCl_2$ are 1.9×10^{24} atoms of $MgCl_2$?

Mass/Molecule

When going back and forth from grams to number of molecules, one has to establish the value for moles of that substance as a segue and cancel the moles unit in the dimensional analysis. See this in the example below:

Ex. How many molecules of $NaBH_4$ are in a sample of 197 grams?

$197\ \cancel{g\ NaBH_4}$	$1\ \cancel{mol\ NaBH_4}$	6.022×10^{23} molecules $NaBH_4$	$= 3.14 \times 10^{24}$ molecules $NaBH_4$
1	$37.83\ \cancel{g\ NaBH_4}$	$1\ \cancel{mol\ NaBH_4}$	

You Try!

5. How many molecules of $CuSO_3$ are in 5.7 grams of the compound?

6. What is the mass of 9.64×10^{23} molecules of SeO_2?

Stoichiometry between Molecules

The essence of stoichiometry is to determine the relationships between different molecules in a reaction. Now we have to cancel between molecule specific units, i.e. grams of CO_2 (g CO_2) cannot cancel with grams of O_2 (g O_2). To do this you first convert to moles, the use the **mole ratio**, and convert to what you need to find.

Ex. Consider the following reaction. How many moles of oxygen are required to produce 2.33 moles of water? Assume that there is excess C3H7SH present.

$$\text{C3H7SH(l)} + 6\ \text{O2(g)} \rightarrow 3\ \text{CO2(g)} + \text{SO2(g)} + 4\ \text{H2O(g)}$$

$$\frac{2.33\ \cancel{\text{mol } H_2O}}{1} \times \frac{6\ \text{mol } O_2}{4\ \cancel{\text{mol } H_2O}} = 3.50\ \text{mol } O_2$$

You Try!

7. How many moles of oxygen are formed when 58.6 g of KNO_3 decomposes according to the following reaction? The molar mass of KNO_3 is 101.11 g/mol.

$$4\ KNO_3(s) \rightarrow 2\ K_2O(s) + 2\ N_2(g) + 5\ O_2(g)$$

8. How many moles of nitrogen are formed when 58.6 g of KNO_3 decomposes according to the following reaction? The molar mass of KNO_3 is 101.11 g/mol.

$$4\ KNO_3(s) \rightarrow 2\ K_2O(s) + 2\ N_2(g) + 5\ O_2(g)$$

You Try!

9. According to the following reaction, how many grams of sulfur are formed when 37.4 g of water are formed?

$$2\ H_2S(g) + SO_2(g) \rightarrow 3\ S(s) + 2H_2O(l)$$

10. Consider the following balanced reaction. How many grams of water are required to form 75.9 g of HNO_3? Assume that there is excess NO_2 present. The molar masses are as follows: H_2O = 18.02 g/mol, HNO_3 = 63.02 g/mol.

$$3\ NO_2(g) + H_2O(l) \rightarrow 2\ HNO_3(aq) + NO(g)$$

11. Consider the following balanced reaction. What mass (in g) of CO_2 can be formed from 288 mg of O_2? Assume that there is excess C_3H_7SH present.

$$C_3H_7SH(l) + 6\ O_2(g) \rightarrow 3\ CO_2(g) + SO_2(g) + 4\ H_2O(g)$$

12. A 14.01 g sample of N_2 reacts with 3.02 g of H_2 to form ammonia (NH_3). If ammonia is the only product, what mass of ammonia is formed?

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

Concentration Stoichiometry

Molarity (mol/L) of a substance can also be used as a method of conversion to find the mass, mole, volume and a variety of other quantities of a substance.

Ex. What volume of 0.244 M KCl solution is required to react exactly with 50.0 mL of 0.210 M $Pb(NO_3)_2$ solution?

$$2\ KCl(aq) + Pb(NO_3)_2(aq) \rightarrow PbCl_2(s) + 2\ KNO_3(aq)$$

$50.0\ \cancel{mL}\ \cancel{Pb(NO_3)_2}$	$1\ \cancel{L}\ \cancel{Pb(NO_3)_2}$	$0.210\ \cancel{mol}\ \cancel{Pb(NO_3)_2}$	$2\ \cancel{mol\ KCl}$	$1\ L\ KCl$	= 0.0861 L
1	$1000\ \cancel{mL}\ \cancel{Pb(NO_3)_2}$	$1\ \cancel{L}\ \cancel{Pb(NO_3)_2}$	$1\ \cancel{mol}\ \cancel{Pb(NO_3)_2}$	$0.244\ \cancel{mol}\ \cancel{KCl}$	or 86.1 mL

You Try!

13. What volume of 0.305 M $AgNO_3$ is required to react exactly with 155.0 mL of 0.274 M Na_2SO_4 solution?

$$2\ AgNO_3(aq) + Na_2SO_4(aq) \rightarrow Ag_2S(aq) + Na_2SO_4(aq)$$

14. According to the following reaction, what mass of $PbCl_2$ can form from 235 mL of 0.110 M KCl solution? Assume that there is excess $Pb(NO_3)_2$.

$$2\ KCl(aq) + Pb(NO_3)_2(aq) \rightarrow PbCl_2(s) + 2\ KNO_3(aq)$$

Answer Key

1. 350.4 g
2. 0.180 mol
3. 1.863×10^{24} molecules
4. 3.16 mol
5. 2.4×10^{22} molecules
6. 178 g
7. 0.724 mol
8. 0.290 mol
9. 99.8 g
10. 10.9 g
11. 0.198 g
12. 17.01 g
13. 278 mL
14. 3.59 g