TutorTube: Moles and Stoichiometry

Summer 2020

Introduction

Hello and welcome to TutorTube, where The Learning Center's Lead Tutors help you understand challenging course concepts with easy to understand videos. My name is Ethan, Lead Tutor for biology and chemistry. In today's video, we will explore moles and stoichiometry. Let's get started!

Moles

A mole is nothing but a certain number of some "thing." We call it Avagadro's number. Just like a dozen is 12 of something, a mole is $6.022x10^{23}$ of something. It has been defined to mean that number. Therefore, if I have one mole of eggs, that means I have $6.022x10^{23}$ eggs.

The purpose of the mole is to bridge the gap between the macro world and the micro world. For example, we can represent five grams of iron in terms of the number of moles. We simply divide the five grams by the molar mass of iron. Molar mass is defined as the number of grams in one mole of a given element. Iron has a molar mass of 55.84 grams/mole. So, five grams divided by 55.84 grams/mole gives us 0.089 moles of iron.

$$5.0\ g\ Fe\ x\ \frac{1\ mole\ Fe}{55.84\ g\ Fe} = 0.089\ mol\ Fe$$

Here we see the practicality of using moles. If we were to represent five grams of iron in term of the number of atoms of iron, we would get $5.3x10^{22}$ atoms of iron.

$$0.089\ mol\ Fe\ x\ \frac{6.022x10^{23}\ atoms\ Fe}{1\ mole\ Fe} = 5.3x10^{22}\ atoms\ Fe$$

This is a much more cumbersome number to work with. Basically, we use moles to be able to represent the number of atoms/molecules with a smaller, easier to work with number.

Like I said before, each element has a specific molar mass. That is, one mole of an element weighs "X" number of grams. This is based on its atomic weight. Here we see iron, hydrogen, and carbon. One atom of hydrogen is much smaller than one atom of iron. Therefore, hydrogen weighs less and has a smaller molar mass than iron.

You can get the molar mass of any element from the periodic table.

So, we understand the molar mass of elements, but what about the molar mass of compounds? Well, to find the molar mass of a compound, you simply add the molar masses of the individual elements that make up the compound.

For example, say we want to find the molar mass of Fe_2O_3. We take the molar mass of iron and multiply it by two. Then we take the molar mass of oxygen and multiply it by three. Finally, we add the two products together.

For iron, that's 55.84 grams/mole times two, since we have two atoms of iron in each molecule of Fe_2O_3. For oxygen, that's 15.99 grams/mole times three, since we have three atoms of oxygen in each molecule of Fe_2O_3. Once we add those together, we get that the molar mass of Fe_2O_3 is 159.65 grams/mole.

$$
\begin{aligned}
MM\ of\ Fe_2O_3 &= (MM\ of\ Fe\ x\ 2) + (MM\ of\ O\ x\ 3) \\
&= \left(55.84\frac{g}{mole}\ x\ 2\right) + \left(15.99\frac{g}{mole}\ x\ 3\right) \\
&= 159.65\frac{g}{mole}
\end{aligned}
$$

We can also use moles to find the mass of a single atom of a given element. Say we wanted to find the mass of one atom of carbon.

Well, we start with the molar mass of carbon, which is 12.011 grams/mole. Then, we divide by the number of atoms in one mole, which is $6.022x10^{23}$. And, we get $1.99x10^{-23}$ grams for one atom of carbon. It's important to pay attention to the units here. Whenever we are doing conversion like this, we want to think about what units we want to get rid of and what units we want to end up with. We're starting with grams/mole, which is molar mass, but we want to end up with the number of grams/atom. Therefore, we put one mole in the numerator of our conversion factor to cancel out the moles found in the denominator of the previous term. In the end we are left with grams/atom just like we wanted.

$$MM\ of\ C = \frac{12.011g}{1\ mole}\ x \frac{1\ mole}{6.022x10^{23}\ atoms} \Rightarrow 1.99x10^{-23} \frac{g}{atom}$$

Anytime we are using moles, it's going to be involved in some conversion of units. A question might ask, "How many moles are present in five kilograms of gold?"

To find out, we start with five kilograms of gold, and then we multiply by 1000 to convert to grams. Then we divided by the molar mass of gold, which is 196.966 grams/mole (as found on the periodic table). Finally, we get that five kilograms of gold contains 25.38 moles of gold. Again, pay attention to which units are canceling out and which remain in our final answer. We have kilograms on the top and bottom, so those cancel. And, we have grams on the top and bottom, so those cancel. That leaves us with moles.

$$5.0\ kg\ of\ Au\ x \frac{1000\ g}{1\ kg}\ x \frac{1\ mole}{196.966\ g} \Rightarrow 25.38\ moles$$

Stoichiometry

Using moles is especially important when predicting how much product a reaction will produce. For example, if you were given five grams of tricalcium phosphate, 10 grams of carbon, and seven grams of silicon dioxide, we can predict how many grams of calcium silicate you can produce. Tricalcium phosphate is $Ca_3(PO_4)_2$, carbon is C, silicon dioxide is SiO_2, and calcium silicate is $CaSiO_3$.

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C \rightarrow 6CaSiO_3 + 10CO + P_4$$

Since the mass of different compounds vary, we cannot only base the reaction on how many grams we have. We have to make comparisons on a molecule by molecule basis. We can do this using moles.

If we take each mass and divide by the molar mass, we get the number of moles. For $Ca_3(PO_4)_2$ the molar mass is 310.18 grams/mole. Then, five divided by 310.18 gives 0.016 moles of $Ca_3(PO_4)_2$. We apply the same logic for carbon and SiO_2 to get 0.83 moles of carbon and 0.11 moles of SiO_2 while making sure to use each molecule's respective molar mass.

$$5\ g\ Ca_3(PO_4)_2\ x \frac{1\ mole}{310.18\ g} = 0.016\ mole\ Ca_3(PO_4)_2$$

$$10\ g\ C\ x \frac{1\ mole}{12.011\ g} = 0.83\ mole\ C$$

$$7\ g\ SiO_2\ x \frac{1\ mole}{60.08\ g} = 0.11\ mole\ SiO_2$$

Now that we know how many moles of each compound we have, we need to determine which reagent is the limiting one. The limiting reagent is the reagent we have the least of and will therefore determine how much product we can make. For any reaction, it will only occur in the ratio of the balanced equation. So, in order to determine the limiting reagent, we need to multiply the number of moles that we have for each compound by the stoichiometric coefficient that it has in the balanced equation. For $Ca_3(PO_4)_2$, that's 0.016 moles times a coefficient of two, which equals 0.032. For carbon, we multiply 0.83 by 10 to get 8.3. Finally, for SiO_2 we multiply 0.11 by six to get 0.66. Since $Ca_3(PO_4)_2$ has the smallest number, it is the limiting reagent.

$$5\ g \Rightarrow 0.016\ mole\ Ca_3(PO_4)_2\ x\ 2 = 0.032$$

$$10\ g \Rightarrow 0.83\ mole\ C\ x\ 10 = 8.3$$

$$7\ g \Rightarrow 0.11\ mole\ SiO_2\ x\ 6 = 0.66$$

Our final step is determining the amount of product we will produce based on our limiting reagent.

So, given the original number of moles, 0.016, we multiply by the ratio of $Ca_3(PO_4)_2$ and our product, $CaSiO_3$. In our balanced equation, we have two moles of $Ca_3(PO_4)_2$ for every six moles of $CaSiO_3$. Then, we multiply by the molar mass of $CaSiO_3$ to give 8.27 grams of $CaSiO_3$. Again, it's important to recognize where we placed each of our units for each conversion factor. When we multiply 0.016 moles of $Ca_3(PO_4)_2$ by 6/2, we put the two on the bottom because it has the units of $Ca_3(PO_4)_2$ which cancels with the units of our first term. The we multiply by the molar mass of $CaSiO_3$ because that cancels out our moles of $CaSiO_3$ units. In the end, we our only left with grams of $CaSiO_3$ like we want.

$$5\ g \Rightarrow 0.016\ mole\ Ca_3(PO_4)_2$$

$$0.016\ mole\ Ca_3(PO_4)_2\ x\ \frac{6\ mole\ CaSiO_3}{2\ mole\ Ca_3(PO_4)_2}\ x\ \frac{172.24\ g\ CaSiO_3}{1\ mole\ CaSiO_3} = 8.27\ g\ CaSiO_3$$

Outro

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