

Stoichiometry

Mole Theory

The Mole and Avogadro's Number Page [1 of 2]

I ask the people at Thinkwell to get me a stuffed mole to use as a prop. This is what they came up with. That was not a mole. But let me tell what a mole is, to a chemist at least. And to do that, let's go back to a balanced chemical reaction, such as 2 hydrogen molecules plus an oxygen molecule goes to 2 water molecules. And notice we can multiply a balanced reaction by any number. In this case, let's multiply it by 2, and we still have a balanced reaction: 4 molecules of hydrogen plus 2 molecules of oxygen goes to 4 molecules of water. And we could express that differently. We could say 2 pairs – 4 is just 2 pairs – 2 pairs of hydrogen molecules plus 1 pair of oxygen molecules goes to 2 pairs of water molecules. These are exactly equivalent.

Well, pair is a collective noun. It means 2. And other kinds of collective nouns, like a dozen means 12, we could put that kind of word in here as well. 2 dozen hydrogen molecules plus 1 dozen oxygen molecules goes to 2 dozen water molecules is still a balanced reaction.

Now we get to the term mole, and we're going to write this as 2 moles of hydrogen molecules plus 1 mole of oxygen molecules goes to 2 moles of water molecules, where a mole just happens to be a really big number. Its value is approximately – that's what this little squiggly line equal sign is – it's approximately 6.022×10^{23} things. So a dozen is 12 things, a pair is 2 things and a mole is 6.022×10^{23} things. Now, this number has been named Avogadro's number in honor of a scientist who lived in the late 1700's to the mid-1800's, who first started thinking about the idea of why we might need a way to count the number of particles in a sample. And that person was Avogadro. His whole name was Lorenzo Romano Amedeo Carlo Avogadro de Quaregna et de Ceretto, a really cool name.

Now, one thing to point out is there's nothing particularly special about this number. What scientists needed was a really, really big number. And the reason why they needed a really, really big number is because this number, it turns out, connects things that are on the atomic molecular level with macroscopic things, things that you can measure in the lab. And we'll see why that's true later on. But, for right now, just accept that it's a really big number and we're going to use it to count things. It's a collective noun, like a dozen or like a pair.

Now, the particular scientific definition of a mole is a mole is an amount of substance that contains as many elementary entities, i.e., atoms or molecules or formula units, as there are atoms in exactly 12 grams of carbon-12, for carbon-12 is the isotope of carbon that has 6 protons and 6 neutrons. And again, this is an arbitrary definition, but it represents a big number. In other words, there are lots, and lots, and lots of atoms of carbon-12 in 12 grams of carbon-12. There are Avogadro's number of those carbon atoms in carbon-12. And you might ask, "Why are we using carbon for our definition?" And if you think about it, carbon is sort of the first element in periodic table that you can weigh, and that isn't really toxic or reactive. Think about it. Hydrogen is a gas; it's hard to weigh a gas. Helium is a gas; it's hard to weigh a gas. Lithium turns out to be a very reactive metal. Beryllium turns out to be actually quite toxic. The people who have worked in making nuclear bombs have been poisoned by beryllium. There's a lawsuit pending with the United States Government. Boron turns out to be very reactive with oxygen to form boric oxide, and so finally we get to carbon, and carbon is graphite – at least one of the forms is graphite – and it's relatively easy to weigh and it doesn't react with much. Pencil leads hang around forever. So that's why the standard is based on carbon as opposed to something else.

Now, one of the questions that you might be asked and one of the things that we might be interested in is converting moles to numbers of particles or vice versa, in other words, converting moles to numbers of particles or numbers of particles to moles. And it turns out that again 1 mole, abbreviated "mole" is equal to 6.022×10^{23} things. And while I'm on the subject, let me show you my props here. This is ethanol. Good to drink, maybe not this concentrated, since this is pure ethanol. And if we could look on an atomic molecular scale and count the number of ethanol molecules in this sample, we'd find that there are 6.022×10^{23} molecules of ethanol. Here's water – same idea, 6.022×10^{23} molecules of ethanol. Here we have baking soda, a household ingredient, and this sample contains 6.022×10^{23} formula units of sodium bicarbonate. Another way to think of it is it contains 6.022×10^{23} atoms of sodium and similarly the same number of hydrogen, the same number of carbon and 3 times that number of oxygen. Here's sodium chloride, table salt, here's sodium hydroxide, a key ingredient in drain cleaners. And one thing you'll notice right away is that the volumes are very different for our mole samples. There's quite a bit greater volume of ethanol than there is water here. And, if I turn these around, you might be able to see better than the volumes of these compounds are also quite different. So Avogadro's number is a measure of numbers of particles, not about volume, and we're also going to see not about mass. But we'll come to that later on.

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So let's come back to our definition of a mole. A mole of fluorine atoms represents 6.022 times 10^{23} fluorine atoms. And we can use these kinds of expressions to create conversion factors. And our conversion factors are always going to be valued at exactly 1. And what I mean by that is, if we take this equation and we divide both sides of this equation by 6.022 times 10^{23} – and remember, bring the units along for the ride – then we get this expression: 1 mole of fluorine atoms divided by 6.022 times 10^{23} fluorine atoms. And if we divide both sides of this expression by 6.022 times 10^{23} , then what we get is that this fraction is equal to 1. And that's just doing some algebra. Divide both sides by the same thing and this becomes this, and this divided by 6.022×10^{23} becomes a 1. And now it's dimensionless. And now, let's do it the opposite way. Let's divide both sides of this equation by 1 mole of fluorine atoms instead, and we get this expression. And now, the left-hand side of the expression would be exactly equal to 1. So these two expressions represent conversion factors that are exactly equal to 1. In other words, 1 mole of fluorine represents exactly the same thing as 6.022 times 10^{23} fluorine atoms. Now, you could always multiply a mathematical expression by a 1 and get exactly the same thing back. And that's why these things constitute conversion factors, and let's see how they work.

We can ask the question, "How many moles of helium does 1.0 times 10^{20} atoms represent?" Now, this is a very big number of atoms, but we'll recognize immediately that this number is less than Avogadro's number, so the number of moles of helium is going to be less than 1. We have some fractions of 1 mole. And the way we answer the question is to say moles of helium is equal to the number of atoms of helium, which is 1.0 times 10^{20} atoms times a conversion factor. Now what conversion factor do we want to use? And I'll show you that our choices are having the moles in the basement, or in the denominator, or moles in the numerator. And, in this case, we want to cancel out the atoms. And if we want to cancel out the atoms, then that means atoms has to be in the denominator and moles has to be in the numerator. So we have 1 mole in the numerator and 6.022 times 10^{23} atoms in the denominator. We could write mole of helium and atoms of helium, but it's implied that that's what this would be. So now we plug this into our calculator, or work this out on your slide rule or work it out longhand, and you'd get 1.7 times 10^{-4} moles. So this is a number that is less than 1, which is good, because we said that this number was less than Avogadro's number, so this number we expected to be less than 1. And this is the number of moles that is exactly equivalent to 1.0×10^{20} atoms of helium.

All right, let's look at another question and go at it from the other direction, which is how many molecules of ethanol are there in 0.37 moles of ethanol, where this is the molecular formula for ethanol? How do we do that? Well, we say 0.37 moles times another conversion factor, and this time we want moles in the denominator and molecules in the numerator, because we want the moles to cancel out. Remember, something upstairs cancels with something downstairs. So we get that 1 mole – and again, we could write this as 1 mole of ethanol, but we'll just write it as 1 mole – and 6.022 times 10^{23} molecules. And this could say molecules of ethanol, but it's implied that that's what this is. And we multiply these two numbers now. The moles are going to cancel, and let's explicitly cancel the moles. We should have done that in the last problem. We can cancel the units. Molecules is going to come out, and I don't have my calculator, so I don't know what the answer is. But we can now answer the question, "How many atoms does this represent?" and what we would have to do is just multiply the number of hydrogen atoms – actually, here's a calculator. Let's go ahead and work this out, if we can figure out how to turn it on. .37 times 6.022 is equal to – what do we expect? Well, we expect a number that's going to be smaller than this number. Because we have less than 1 mole, we're going to end up with a number that is smaller than Avogadro's number, and the number turns out to be 2.2 times 10^{23} , and this is molecules.

And now, let's answer this last question. How many hydrogen atoms does this represent? And note each molecule of ethanol consists of 6 atoms of hydrogen, also 2 atoms of carbon and 1 atom of oxygen. So, if we want to know the number of hydrogen atoms, we have to multiply 2.2 times 10^{23} molecules, and now let's write down "of ethanol", to be explicit, times 6 atoms of hydrogen – you can't quite read that, let's slide this over – 6 atoms of hydrogen per 1 molecule of ethanol. And if we work that out – times 6 – 1.3 times 10^{24} . And this now atoms of hydrogen.

So, using these units of 1 or factors of 1, we can very quickly convert from molecules to moles. What we're going to see in the next unit is that we can convert from grams, something that we can measure on a macroscopic scale, to moles, as well. And that's where the idea of a mole is going to really be useful.