The Mole and Stoichiometry

You already know how to count in groups, such as groups of dozen. For example, a dozen=12 items. A half dozen would be 6 items. Ten dozen would be 120 items. Dozens count in groups of 12. Similarly, a gross counts in groups of 144. Because atoms are so small, chemists need to count in groups of mole. One mole is 6.02×10^{23} items. A half mole would be 3.01×10^{23} items, while ten mole would be 6.02×10^{24} items.

The mole unit gets a convenient abbreviation: mol. 1mol = 6.02×10^{23} items. The number, 6.02×10^{23}, is known as Avogadro's number, so 1mol=Avogadro's number of items. Because the mole is so large, it is typically used to count small items like atoms and molecules. A dozen donuts might be nice to order, but a mol of donuts, if your order could be filled, would bury the Earth in donuts. A mol of chemical, though, tends to be a comfortable amount to hold in a small beaker.

We continue to use the unit analysis method for mol calculations.

Example: Convert 0.120 mol of sodium atoms into individual atoms.

$$0.120 \text{mol Na} \times \frac{6.02 \times 10^{23} \text{ Na atoms}}{1 \text{ mol Na}} = 7.22 \times 10^{22} \text{ Na atoms}$$

Example: Convert 1.25×10^{21} atoms of sodium to mol.

$$1.25 \times 10^{21} \text{ atoms Na} \times \frac{1 \text{ mol Na}}{6.02 \times 10^{23} \text{ Na atoms}} = 2.08 \times 10^{-3} \text{ mol Na atoms}$$

If you are having trouble following the mol, remember that you would follow the same process for converting the dozen to individual items. (The difference is that 1dozen=12 items, whereas 1mol=6.02×10^{23} items.)

$$0.120 \text{dozen donuts} \times \frac{12 \text{ donuts}}{1 \text{ dozen donuts}} = 1.44 \text{ donuts}$$

Chemists use the mol to count atoms. Because the mol is so large, counting atoms and molecules is done indirectly by mass. If we knew the mass of atoms, such as the mass of one atom or a group of 1mol of atoms, then we could convert the number of atoms to a mass and back again. The mass of atoms appears on the periodic table as the atomic mass. Conveniently, the atomic mass on the periodic table provides the mass in grams for a 1mol quantity of atoms.

Looking at hydrogen on the periodic table, 1mol of H atoms has a mass of 1.008g. For He, 1 mol of He atoms has a mass of 4.003g. Some elements are diatomic when they

appear in chemistry. The elements hydrogen, oxygen, nitrogen, chlorine, bromine, iodine, and fluorine are all diatomic (2 atoms). One mol of the element hydrogen has a mass of 2.016g, and one mol of oxygen has a mass of 31.998g. Recall that the acronym HONClBrIF can be used to remember the diatomic elements.

Another name for the mass of one mole of something is the **molar mass**. The molar mass of oxygen is 31.998g, meaning 31.998g of oxygen=1mol oxygen. The molar mass allows chemists to count out chemicals in groups of mol by using the laboratory balance. (Counting chemicals is important when trying to mix them in the correct quantities.)

To calculate the molar mass of a compound, add the molar masses of the elements it contains.

Example: Calculate the molar mass of $Mg(NO_3)_2$.
Solution: When learning molar mass, it may be easier to set up a table.

atom	atomic mass	number	subtotal
Mg	24.305	1	24.305
N	14.007	2	28.014
O	15.999	6	95.994
		Molar Mass	148.313

This means that a mass of 148.313g of $Mg(NO_3)_2$ counts out 6.02×10^{23} units of $Mg(NO_3)_2$.

Example: Calculate the molar mass of $Ca_3(PO_4)_2$.
Solution: Verify that you get 310.174g = 1mol $Ca_3(PO_4)_2$.

Coefficients of chemical reactions provide the ratios by mol, much like a recipe card provides the ratio by amount.

1 box brownie mix + 2 eggs --> 1 brownie batter

$C(s) + 2H_2(g) \rightarrow CH_4(g)$

The recipe says that 1 box of brownie mix and 2 eggs gives one brownie batter. In mol, this would be 1 mol brownie mix plus 2 mol eggs gives 1 mol brownie batter.

The chemical reaction says a similar thing to the recipe: 1 carbon atom plus 2 hydrogen molecules gives one molecule of $CH_4(g)$. In mol, this would be1 mol carbon atoms plus 2 mol hydrogen molecules gives one mol of $CH_4(g)$. Because the atom is so small, chemists mostly think of chemical reactions as mixing in groups of mol (rather than individual atoms and molecules).

Using the recipe card (or chemical reaction), we can convert amounts of one chemical (or ingredient) to another.

Example: 2.5 boxes of brownie mix needs how many eggs?

Solution: 2.5 boxes brownie mix 2 eggs

$$x\frac{\text{2 eggs}}{\text{1 box brownie mix}} = 5 \text{ eggs.}$$

Similarly, 2.5mol boxes of brownie mix needs 5.0 mol of eggs.

A chemical reaction works the same way as a recipe.

Example: 2.5mol carbon needs how much hydrogen?
Solution: 2.5mol C 2 mol H_2

$$x\frac{\text{2 mol } H_2}{\text{1 mol C}} = 5.0 \text{ mol } H_2$$

Chemistry involves one additional difficulty. We cannot count a mol by hand. We need to do it by mass. All that remains is to convert 2.5mol C to grams C and 5.0mol H_2 to grams H_2 so that we can get the masses on the laboratory balance. We already learned how to do this before using the molar mass on the periodic table.

2.5mol C 12.011g C

$$x\frac{\text{12.011g C}}{\text{1 mol C}} = 30\text{g C.}$$

and

5.0mol H_2 2.016gH_2

$$x\frac{\text{2.016g } H_2}{\text{1mol } H_2} = 10\text{g } H_2.$$

If we mix 30g of C and 10g of H_2, we mix enough to get 2.5 mol of CH_4. Using the molar mass, this would be 40g of CH_4.

A separate lesson shows an example of a mass-mass stoichiometry problem. This type of problem asks, for example, the mass of H_2 that reacts with 30g of C. The first step is to covert grams C into moles C. The second step is to convert moles of C into moles H_2 using the balanced chemical reaction (the recipe card above). The third step is to covert moles H_2 into g H_2. The answer is 10g H_2, which is the same answer to the problem above (only it is worked in a different order).

See the separate lesson for a mass-mass stoichiometry problem.