How do we count teeny tiny particles? The Mole is a Chemist's Dozen

Name___________________

Atoms are so incredibly tiny, it is very difficult to count them. The period at the end of this sentence contains between 10^{16} and 10^{17} carbon atoms of ink. On average, a single carbon atom has a mass of 2.00×10^{-23} g. Since even the very best laboratory balance can detect no less than 10^{-5} grams so in order for us to be able to measure atoms we need to "weigh" far more than one single atom. As we have discussed in class you need an extremely large amount of atoms to register even a gram on the balance. Bakers sell donuts by the dozen, but if chemists tried to weigh a dozen atoms, they would never even see them or be able to record them on the balance.

Just as a dozen is 12 items, chemists must work with a far larger dozen. That very large dozen that is used to count atoms and molecules is called a mole.

A mole contains 602,214,200,000,000,000,000,000 items. Those items are usually atoms, molecules, or ions.

Of course we will write this number as $6.02214199 \times 10^{23}$ items/mole (called Avogadro's Number N_A)

Most of the time, 3 significant figures will be enough for our purposes = 6.02×10^{23} (the 6.02 are significant)
The average atomic masses in the periodic chart are the masses for 1 mole of atoms for each particular element. For the element helium, 6.02 x $\times 10^{23}$ helium atoms have a mass of 4.0 g. in other words, 1 mole of helium atoms has a mass of 4.00 g. This of course can be written, 4.00 g/mole (grams per 1 mole)

This 4.00 g/mole is often called the molar mass (the mass of one mole). You teacher will use MM as an abbreviation for molar mass.

This allows chemists to convert between mass and amount and numbers of particles. You need to be able to make these calculations quickly and efficiently.

For instance, if 1 mole of helium has a mass of 4.0 g then 2 moles of helium must have a mass of 8.0 g.

Since 1 mole of helium atoms is 6.02×10^{23} atoms, then 2 moles would of course be equal to 1.20×10^{24} atoms.

Conversely, if you took the mass of some amount of helium and it weighed 2.0 g, that amount would be 0.50 mole. and this would of course be 3.01×10^{23} atoms of helium.

You MUST learn the unit labels on Avogadro's number and molar mass and then you can use these numbers "right-side-up" or "upside-down" as you work dimensional analysis problems.

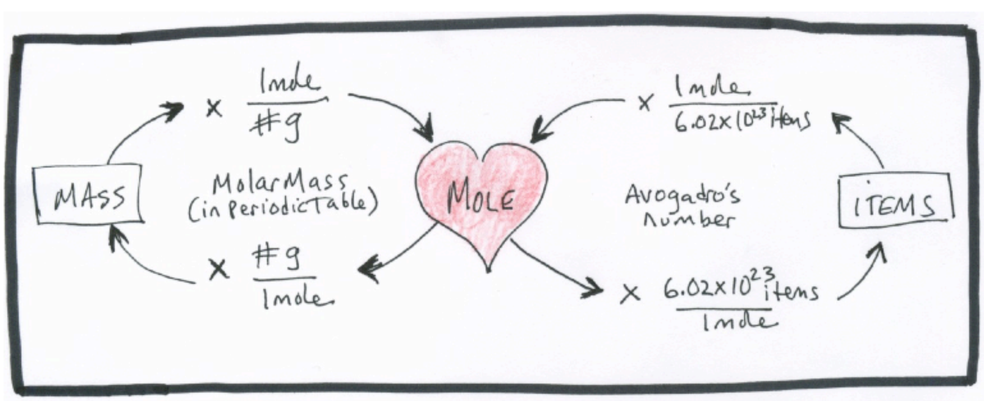
For any substance:

$$\frac{6.02\times10^{23}\,items}{1mol} \text{ or } \frac{1mol}{6.02\times10^{23}\,items}$$

You can substitute atoms, molecules, ions, units, electrons etc for the term "items" as appropriate.

For oxygen gas O_2: $\frac{32g}{1mol}$ or $\frac{1mol}{32g}$

The actual number of grams varies from element to element and compound to compound. Use the periodic table to find the correct value.



Just how do we know this HUGE number??? More on the back.

Avogadro's Number N_A
Just how do chemists know this number?

The information on this back page is purely information and will not be asked on a test or quiz.

Did Avogadro know this number in 1811?

N_A the number 6.02×10^{23} (or more accurately $6.02214199 \times 10^{23}$) has been estimated in a number of ways. In 1811, Amadeus Avogadro was not aware of this number when he was working with gases in the early 1800's. The number was given the name in honor of him many years later.

How was this number measured?

Early estimates of N_A's value were made by calculations that estimated the number of molecules in a given volume of gas, based on estimates of molecular diameter, and mean free path (Loschmidt 1865). In 1873 Maxwell estimated that Loschmidt's number (the number of molecules in 1 cm^3 of gas at normal temperature and pressure) was 1.9×10^{19}. Given that there are 22,400 cm^3 in a mole of gas at normal temperature and pressure, this leads to an estimate of the number of molecules in a mole of 4.3×10^{23}. Slightly later, Kelvin obtained an estimate of the number of molecules in a gas from the scattering of light, and his data would give a value of 5×10^{23}.

Consideration of Brownian motion (random molecular motion) led to some of the more accurate determinations of Loschmidt's number around the beginning of the 1900's. J. Perrin (1908) is the first person to have used the term Avogadro's number for the number of particles in a mole. He estimated it to be between 6.5×10^{23} and 6.9×10^{23} from studies of Brownian motion. By 1914 Brownian motion methods had led to an estimate of 6.03×10^{23}.

Radioactive methods were used by a number of investigators to directly count the number of alpha particles emitted from radium and uranium. Rutherford and Geiger estimated that Avogadro's number was 6.2×10^{23}.

Could I determine Avogadro's number?

Very thin layers of oil (sodium oleate) assumed to be one molecule thick can be spread onto a surface of water. In 1924 Lecomte du Nouy estimated the size of a molecule and combined that estimate with the size of the oil layer to determine the number of molecules in a mole as 6.004×10^{23}.

In another experiment, electron flow (amperage or current) and time are measured in order to obtain the number of electrons passing through the electrochemical cell. The number of atoms in a weighed sample is related to electron flow in order to calculate Avogadro's number. (We do this in AP chem.)

How is Avogadro's number determined today?

Modern methods of determining Avogadro's number rely on the use of x-ray crystallography to get precise dimensions in crystals. Alternatively, mass spectrometric measurements have extended the accuracy of Avogadro's number to $6.02214199 \times 10^{23}$ These methods can produce extremely precise values for N_A with an error of less than $\pm$ 0.000 000 1 , although let's remember, that's still give or take a few billion atoms or molecules.