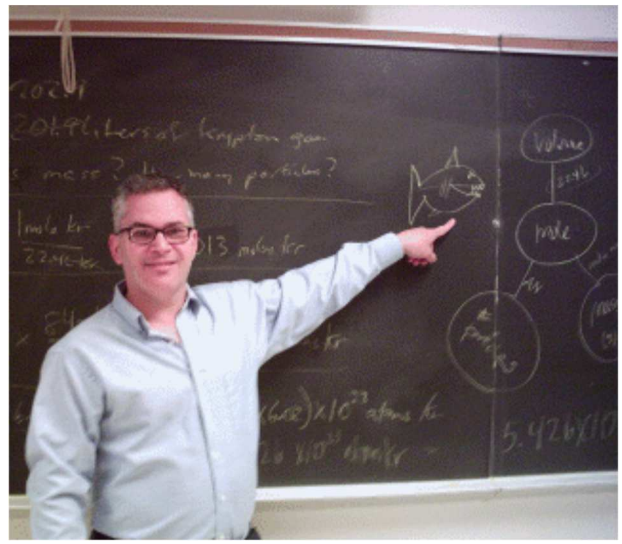
MOLES, % COMPOSITION & EMPIRICAL FORMULAS BASICS

MOLES

Any time that you get to draw a shark in chemistry class is a good day. Fishing is not one of my favorite "sports", but I do enjoy fishing at Wegmans for shark (and for salmon). This is your teacher in the fall of 2006, it's the first picture of me on the website!

Near the shark is the "mole island" concept map of how moles are related to mass, volume, & the number of particles.

The Mole is central to your understanding much more chemistry; you must work hard to truly grasp the significance of moles.



Avogadro's number sets the basic ratio between the mole and how many particles it is. Like a dozen is twelve, a mole is exactly 6.02×10^{23} particles.

Half of a dozen is six, and half of a mole is half of Avogadro's Number, or 3.01×10^{23} particles. This relationship of moles to an exact number of particles allows us to mathematically connect masses of substances to the number of particles present.

Particles can be atoms if the substance comes in atoms, like the noble gases, or the metals. Sometimes particles can be FU's, or formula units - if the substance is an ionic compound. Particles can also be molecules - when if the substance is made from two non-metals joined into a molecular compound. Particles can even be ions, if you want to count how many ions are present in a substance. Having a mole of anything of "real" size is a problem. A mole of atoms is a huge number but they are so mad small, a mole of atoms is also pretty small. Having a mole of something the size of a banana would be larger than the moon.

Besides the "mole to number of particles" ratio, there is a special mass relationship between atoms on the periodic table and the concept of moles. If you look at your Periodic Table, and see that one atom of Helium has an atomic mass of 4.00260 amu (which we usually round to 4 amu), the mass of ONE MOLE OF HELIUM is 4.00260 grams, which is also usually rounded to just 4 grams.

The units change between single atoms (ams's) and moles (grams), but the periodic table provides the numbers. We can use these numbers to determine how many grams one mole of any element is, and to determine the MOLAR MASS of any compound (by just adding up individual atomic mole masses by the ratios of atoms in the compound - see below)

Examples include

atom	atomic mass	molar mass
niobium	93 amu	93 grams/mole
zinc	65 amu	65 grams/mole
sulfur	32 amu	32 grams/mole
silicon	28 amu	28 grams/mole
NaCl	23 + 35 = 58 amu	58 grams/mole
NaOH	23 + 16 + 1 = 40 amu	40 grams/mole
$C_6H_{12}O_6$	72 + 12 + 96 = 180 amu	180 grams/mole

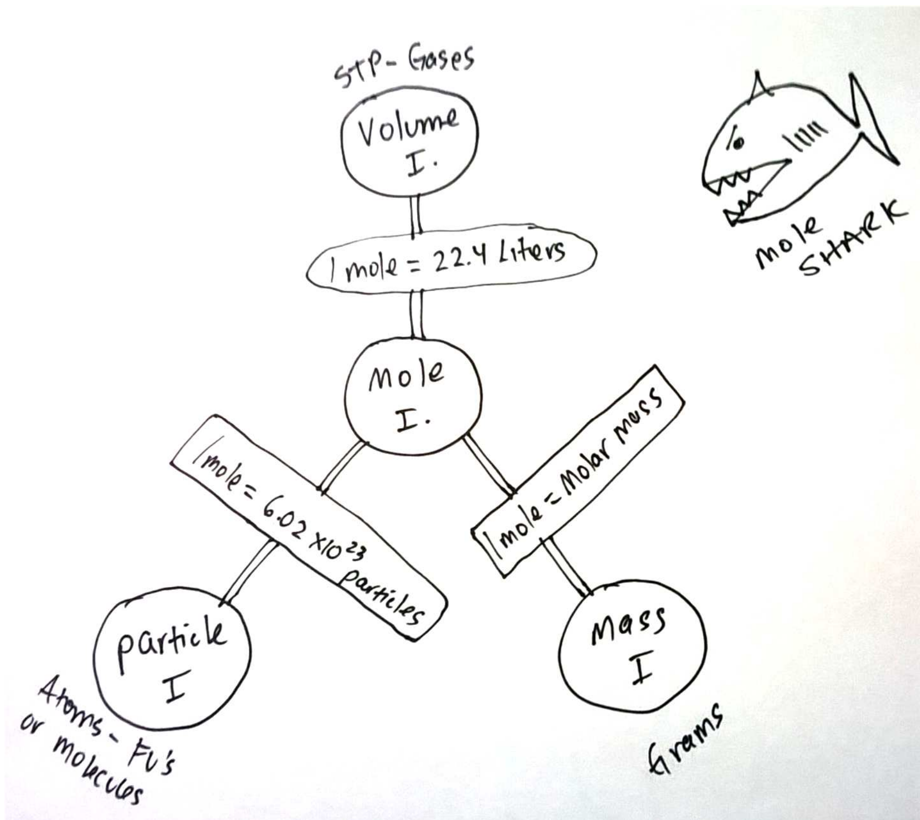
With gases, the mole to volume relationship is the "simplest" to connect. At standard temperature and pressure (zero centigrade and one atmosphere pressure), one mole of any gas is equal to 22.4 Liters of volume. In our class the gas parameters of pressure and temperature will be at STP until we study gases later in the year. So, the number to remember is 22.4 Liters.

Examples include

gas	formula	volume at STP
1 mole of helium	He	22.4 liters
1 mole of carbon dioxide	CO_2	22.4 liters
2 moles of krypton	Kr	44.8 liters
one half mole neon	Ne	11.2 liters
1.0 mole nitrogen dioxide	NO_2	22.4 liters
3.0 moles iodine gas	I_2	67.2 liters

Mole Islands… The drawing below describes the connection between MOLES in the middle, with the "islands" that surround it. The only way to make your way from any island to another is to take the ONLY BRIDGE available, and PAY THE TOLL as indicated. Use the tolls to make your conversions factors. If you "cheat" and try to skip the mole conversion, the sharks will eat you. Stay on the "BRIDGES"!

Going from one part of the diagram to another (going from one island to another) you may only use the bridges as shown. Each bridge has its own toll to pay, indicated in THE MIDDLE OF THE BRIDGE. Use these "tolls" to convert from one unit to another (for example, from LITERS TO MOLES, or MOLES TO GRAMS, or MOLES TO NUMBER OF PARTICLES).



If you try to take a short cut, the MOLE SHARK will eat you, and it won't be pretty. There are NO SHORT CUTS. That said, the biggest mole problem is just 2 conversions at most.

Mole Math Problems always start on one island, you either start with a known number of grams, or a known number of particles, or a known number of liters of a gas. You could even start with a known number of moles. No matter what, you will do some conversions. Only do the steps in the order that the bridges show you. If you ever try to go from liters (top) to grams (bottom right) straight away, you are in the ocean and in danger!

Moles are central to chemistry and this diagram will help you keep it all straight. Everything can be converted to moles, moles can be converted to all other units you will ever need (or want!) It will require practice, and if you don't practice, it will become very apparent.

MOLAR MASS

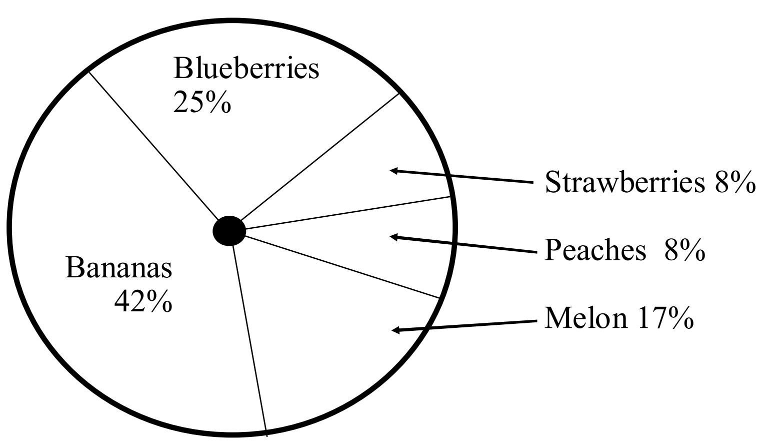
By definition, how many grams exactly one mole of a substance weighs. If it is just an element, read the atomic mass on the periodic table, and change the "AMU" units to "GRAMS" instead. If it is a compound, write the PROPER FORMULA of the compound, and multiply the number of atoms by the proper atomic masses, and then add them all up. Units will be GRAMS PER MOLE.

Determine the MOLAR MASS of sodium hydroxide NaOH It has 3 atoms, one each of sodium, oxygen, and hydrogen.	Molar Mass of NaOH Na - sodium 1 x 23 = 23 O - oxygen 1 x 16 = 16 H - hydrogen 1 x 1 = 1 sum = 40 grams/mole
Determine the MOLAR MASS of sulfur trioxide SO_3 It has 4 atoms, one sulfur, and 3 oxygen atoms.	Molar Mass of SO_3 S - sulfur 1 x 32 = 32 O - oxygen 3 x 16 = 48 sum = 80 grams/mole

% Composition by Mass

When you make a good fruit salad (I think) you should include about 5 pounds of bananas, one pound of strawberries, three pounds of blueberries, one pound of ripe peaches, and two pounds of melon. 12 pounds is a good fruit salad.

If I asked, what percent of the fruit salad is bananas? You would divide 5/12 and say it's about 42% bananas. The blueberries make up 3/12 pounds, so they make up 25% of the fruit salad. 1/12 of the salad is about 8%, so we can say that it's about 8% strawberries and 8% peaches. Finally, the melon is 17% of the total salad. That sums to 100% of the salad. Chemistry can be like making fruit salad (and doing math to it).



For example, what is the proportion of magnesium in magnesium hydroxide by mass? To figure this out, you need first to set up the molar mass of the compound, then use the formula for % composition by mass and calculate.

$Mg(OH)_2$

Mg 1 x 24 = 24
O 2 x 16 = 32
H 2 x 1 = 2
58 g/mole

% comp by mass of Mg in magnesium hydroxide

Mg $\frac{24\text{ g}}{58\text{ g}} \times 100\% = 41.4\%$

<u>% COMPOSITION BY MASS</u>

All this means is if you have a particular compound, you can use the periodic table to determine its molar mass. Once you get that, you can determine what percentage of any of the types of atoms in that compound. Just like the fruit salad example and the MgO example above.

Another real world example is this: if you take a piece of chewing gum you can know its total mass just by weighing it on a balance. The gum is made up of an indigestible chewy pink part, and sugar. If you chew the gum long enough all the sugar dissolves onto your tongue and you swallow it. When the gum is lousy tasting, the sugar is gone, you're just chewing the indigestible part. If you weigh this tasteless piece of gum, you find it weighs much less than before.

The missing mass is the missing sugar (it's not really missing, you just ate it!). You could determine the % Composition by Mass of the sugar in the gum by this formula:

$$\boxed{\%\text{ Comp of Sugar in Gum} = \frac{\text{Mass of missing sugar}}{\text{Mass of gum originally}} \times 100\%}$$

Another example… Find the % composition of chlorine in hydrogen chloride (HCl).

<u>HCl</u>

H - Hydrogen 1 x 1 = 1
Cl - Chlorine 1 x 35 = 35

MOLAR MASS = 36 g/mole

<u>% Composition by Mass</u>

$\frac{\text{mass of the part}}{\text{mass of the whole}} \times 100\%$

$\frac{35\text{g}}{36\text{g}} \times 100\% = 97.2\%$ chlorine by mass

Another example…. If you have 50.0 grams of HCl, how many grams would be chlorine?

50.0 grams HCl X 0.972 = 48.6 grams is chlorine [97.2% = 0.972 AS A DECIMAL]

And Another example…

If you have 312 grams of HCl, how many grams would be chlorine?

312 grams HCl X 0.972 = 303 grams

The total mass that is chlorine is always 97.2% for HCl

EMPIRICAL FORMULAS

An empirical formula is a math concept more than a chemistry one. It really is the lowest ratio of atoms or ions that make up a formula.

You are familiar with glucose, $C_6H_{12}O_6$, and the ratio of atoms in that is of course 6:12:6, which can be reduced to 1:2:1.

The EMPIRICAL FORMULA for glucose is just CH_2O.

The ratio has NOTHING to do with the actual chemistry, density, molar mass, etc.
It is a way to categorize groups of compounds, and to make you think.

Formulas	Empirical Formulas
$C_5H_{10}O_5$	CH_2O
C_2H_2	CH
C_4H_{10}	C_2H_5
C_8H_{18}	C_4H_9
$MgSO_4$	$MgSO_4$ (this formula cannot be reduced to a lower ratio)
H_2O	H_2O (this formula cannot be reduced to a lower ratio)
CH_4	CH_4 (this formula cannot be reduced to a lower ratio)
$C_{44}H_{88}O_{44}$	CH_2O

Empirical formulas are about the LOWEST RATIO.

Very often the "lowest ratio formula", such as CH_2O, is not even a real compound, it cannot even exist chemical-ly. But the ratio can exist in your mind, or on paper.

An EMPIRICAL FORMULA is more an IDEA than a real thing. Sometimes Empirical Formulas are the same as the formula of the real compounds, like with magnesium sulfate, water, or methane gas.

The last example shows that no matter how big the numbers, the lowest ratio makes the empirical formula.

Types of mole problems… (answers on next page)

There's a limited number of kinds of mole problems. Using your mole island map, you can easily do all of them.

Problems for practice. Answers below in order.

1. How many grams are in 1.0 moles of $NaHCO_3$, which is baking soda?

2. How many moles are in 25.0 grams of baking soda?

3. How many moles is 145.6 liters of helium gas at STP?

4. If you have 2.75 moles of CO_2 gas, how many liters does it take up at STP?

5. If you have 2.75 moles of CO_2 gas, how many particles is that?

6. If you have 3.50×10^{27} atoms of neon gas, how many moles is that?

7. If you have 75.0 grams $Cl_{2(G)}$, how many formula units AND how many liters does it take up at STP?

1 The molar mass of sodium hydrogen carbonate is 84 g/mol.

2 $$\frac{\text{25.0 g baking soda}}{1} \quad \text{X} \quad \frac{\text{1 mole baking soda}}{\text{84 g baking soda}} \quad = \text{0.298 moles baking soda}$$

3 $$\frac{\text{145.6 liters He}}{1} \quad \text{X} \quad \frac{\text{1 mole He}}{\text{22.4 liters He}} \quad = \text{6.50 moles He}$$

4 $$\frac{\text{2.75 moles } CO_2}{1} \quad \text{X} \quad \frac{\text{22.4 liters } CO_2}{\text{1 mole } CO_2} \quad = \text{61.6 liters } CO_2$$

5 $$\frac{\text{2.75 moles } CO_2}{1} \quad \text{X} \quad \frac{\text{6.02 x 1023 molecules } CO_2}{\text{1 mole } CO_2}$$

= 16.555 x 1023 changes to

1.66 x 10 24 molecules CO_2

6 $$\frac{3.50\text{x}10^{27}\text{ atoms Ne}}{1} \quad \text{X} \quad \frac{\text{1 mole Ne}}{6.02 \text{ x } 10^{23}\text{ atoms Ne}} \quad = \frac{3.50}{6.02} \text{ x } \frac{10^{27}}{10^{23}}$$

= $0.581 \text{ x } 10^4$ changes to

$5.81 \text{ x } 10^3$ moles Neon

7 $$\frac{\text{75.0 grams } Cl_2}{1} \quad \text{X} \quad \frac{\text{1 mole } Cl_2}{\text{70 grams } Cl_2} \quad = \text{1.07 moles } Cl_2$$

go to the
next line

$$\frac{\text{1.07 moles } Cl_2}{1} \quad \text{X} \quad \frac{\text{22.4 liters } Cl_2}{\text{1 mole } Cl_2} \quad = \text{24.0 liters } Cl_2$$