Lecture 1 Notes, Immaculata Week, July-August 2014, Charles H. Mahler, Lycoming College

My email address is mahler@lycoming.edu – please contact me if you have questions.

Our topic for this lecture was the mole concept. We started with a demonstration: burning a candle in a dish filled with water. We discussed how you might measure the candle wax burning away (reacting) – you could weigh the candle before and after burning, or if it burned long enough, measure the height change. When I put a beaker over the candle, it eventually went out as it used up all the oxygen in the air inside the beaker. Although it can be difficult to measure gas changes, this was easy to see. The water was "sucked up" into the beaker (as the oxygen was used up and less gas was present inside, the pressure in the beaker dropped and the air pressure outside forced some of the water up inside the beaker).

In some classes we got into a discussion of the reactions going on – candle wax is a hydrocarbon (contains only carbon, C, and hydrogen, H), so it should produce only carbon dioxide, CO_2, and water, H_2O, on burning in air. The CO_2 is also a gas (and we make one molecule of it for every molecule of oxygen consumed to make CO_2), so producing CO_2 does not change the volume of gas. However, water is a liquid at room temperature and converting some oxygen gas into liquid water reduces the amount and volume of gas in the beaker.

Many things in science can be measured (like mass, volume, pressure), however when we want to relate these measurements to reactions, we need to have some way of knowing the number of atoms or molecules or ions involved, since balanced chemical reaction equations use these numbers. The mole concept allows us to relate measurable properties like mass to numbers of particles (atoms, molecules, ions), and vice versa.

Next we talked about "counting numbers" like a dozen (12), baker's dozen (13), and score (20), as well as time counting numbers like the decade (10), century (100), and millennium (1000). The mole concept also uses a counting number called Avogadro's number, which is 6.022×10^{23} particles per mole (where particles are typically atoms or molecules or ions, but could be anything you can count).

We also reviewed scientific notation as needed (so the power of 10 is the number of zeroes, and one thousand or 1,000 would be 10^3 (3 zeroes) while one million or 1,000,000 would be 10^6 (6 zeroes). If we round Avogadro's number to 6×10^{23} that would be six followed by twenty three zeroes. The Hubble Deep Field talk from Goddard said that the number of stars in the observable universe was roughly Avogadro's number (or it was roughly the number of galaxies in the universe – different people recalled it differently).

Chemistry deals with atoms and molecules, which are really small. One mole of water contains 6.022×10^{23} water molecules and this is only 18 milliliters of liquid water (a little over 3 teaspoons, since 1 tsp = 5 mL or slightly more than a tablespoon, since 1 tbsp = 15 mL).

Avogadro's number (6.022×10^{23}) is defined as the number of carbon atoms in 1 mole of the isotope ^{12}C, which weighs exactly 12.00000 grams. A single atom of ^{12}C weighs exactly 12

atomic mass units (or 12 amu), so a mole is the counting number chosen to make either an atom or a mole of an element weigh the same number (in amu for the atom and g for the mole).

Next we considered diamonds, which are nearly pure carbon. The Hope Diamond weighs about 45 carats, so how many moles of carbon and carbon atoms does it contain? We need to know that 1 carat = 0.200 g (exactly) and since we were working on the chalkboard we rounded atomic masses to the nearest gram, so carbon is 12 grams/mole. The Hope Diamond is about 45 carats.

(45 carat)(0.200 gram/carat)(1 mole C/12 grams) = 0.75 moles of C in the Hope Diamond

(0.75 moles)(6.022 x 10^{23} C atoms,mole) = 4.5 x 10^{23} C atoms in the Hope Diamond

We reviewed calculating molar masses. The mass of the molecule is the sum of the mass of the atoms in it, so water is 1 oxygen atom (16 g/mol) plus 2 hydrogen atoms (each 1 g/mol). Water or H_2O is 16 + 1 + 1 = 18 g/mol (rounded to the nearest 1 g/mol). Since the density of water is 1 gram = 1 milliliter, one mole of water is 18 grams is 18 milliliters. We practiced finding molar masses (using atomic masses rounded to the ones place). So methane CH_4 = 16 g/mol and sulfuric acid or H_2SO_4 is 98 g/mol.

We can also use moles with balanced reactions, so we reviewed balancing chemical reaction equations. The number of atoms has to be the same on both sides of the equation (the reactants are on the left and the products are on the right). It is usually easiest to focus on an element found in only one reactant and one product and balance that first, then move on to another element until all elements are balanced. Some examples follow:

So to balance the combustion of propane (C_3H_8) in oxygen (O_2) forming water (H_2O) and carbon dioxide (CO_2), the unbalanced reaction is

____ C_3H_8 + ____ O_2 → ____ CO_2 + ____ H_2O

Focus on the carbon first. There are three C atoms in propane on the reactant side, so it will make three carbon dioxide molecules as product. Next look at hydrogen: there are eight H atoms in propane, so it will make four water molecules (since each water contains two H atoms). This leaves only oxygen to balance. On the products side there are now 6 O atoms from carbon dioxide plus four O atoms from water, for a total of ten O atoms. This requires five oxygen molecules (O_2), since each molecules of oxygen gas contains two O atoms.

1 C_3H_8 + 5 O_2 → 3 CO_2 + 4 H_2O

For something like the combustion of butane (C_4H_{10}) in oxygen (O_2) forming water (H_2O) and carbon dioxide (CO_2), the unbalanced reaction is:

____ C_4H_{10} + ____ O_2 → ____ CO_2 + ____ H_2O

Carbon gives us four carbon dioxides and hydrogen gives us five waters. This gives a total of 15 oxygen atoms required on the reactant side. Some are OK with “thirteen halves” ($^{13}/_{2}$ or 6.5) as

the coefficient for oxygen (especially if the focus is on moles, as half a mole is still a huge number of molecules).

$$1\ C_4H_{10} + 6.5\ O_2 \rightarrow 4\ CO_2 + 5\ H_2O$$

Others focus on the balanced equation in terms of molecules and do not like the idea of a non-integer number of molecules, so in that case multiply all coefficients by two to get

$$2\ C_4H_{10} + 13\ O_2 \rightarrow 8\ CO_2 + 10\ H_2O$$

Other reactions we balanced included:

$2\ H_2 + O_2 \rightarrow 2\ H_2O$	(burn hydrogen to make water)
$SO_3 + H_2O \rightarrow H_2SO_4$	(making sulfuric acid)
$Fe_2O_3 + 3\ H_2SO_4 \rightarrow 3\ H_2O + Fe_2(SO_4)_3$	("rust" plus sulfuric acid)

The last example shows iron oxide dissolving in sulfuric acid, to make water and iron (III) sulfate. It is an example of being able to balance groups of atoms (in this case the "SO_4" group, which is the sulfate ion).

We did the **hands-on activity** building molecules from candy and toothpicks and using them to balance a simple reaction. The reaction we looked at was the combustion of methane (CH_4) in oxygen (O_2) forming water (H_2O) and carbon dioxide (CO_2), the unbalanced reaction is:

$$\_\_\_\_\ CH_4 + \_\_\_\_\ O_2 \rightarrow \_\_\_\_\ CO_2 + \_\_\_\_\ H_2O$$

I had everyone make one methane molecule (using mini-marshmallows for H atoms and either fruit slice candy or Dots candy for the C atom and toothpicks for the bonds). I also had everyone make an oxygen molecule (with two candies of the same color as the oxygen atoms). Then I had everyone take apart their reactant molecules and try to make product molecules – the trick is that you need two oxygen molecules to balance the reaction, so you have to come up and get more candy. This is useful for beginning students to help them focus on the ideas that molecules are made of atoms and that the number and kind of atoms are conserved in a chemical reaction. You can also use such candy molecules to look at things like geometries of molecules (Valence Shell Electron Pair Repulsion or VSEPR theory) and if you are not allowed to use candy in your classroom, then Legos or modeling clay work too.

The final balanced reaction is: $1\ CH_4 + 2\ O_2 \rightarrow 1\ CO_2 + 2\ H_2O$ (we usually do not show "1" explicitly).

We also looked at the number of moles of propane in a 100 gallon propane tank:

(80 lb)(2.2 kg/lb)(1000 g/kg)(1 mole propane/44 g C_3H_8) = 4000 moles of propane

For the high school teachers we looked at weight percentage. For example methane is 16 g/mol, of which 12 g/mol is C and 4 g/mol is H (rounded), so it is 25% (4/16) hydrogen, H, and 75% (12/16) carbon, C. We also looked briefly at the idea of elemental analysis. For example if you burn a hydrocarbon that contains only C and H, then trap the carbon dioxide and water and weigh how much of each is produced, you can work backwards from moles of each to moles of C and H and figure out the relative ratios of each in the hydrocarbon. You can also figure out masses of each and find weight percentages of C and H in the original compound.

The last topic we looked at was kinds of formulas. We had been dealing with molecular formulas, which show the number of atoms in a molecule (so water has two hydrogen atoms and one oxygen atom, or methane has one carbon atom and four hydrogen atoms).

You can also look at the empirical formula, which is the simplest ratio of atoms in the molecule. Sometimes the molecular formula is the simplest ration (water is H_2O in either the molecular or empirical formula), but sometimes the empirical formula is different. For example, a simple sugar might have the formula $C_6H_{12}O_6$ which has the simplest CH_2O (which is also the empirical formula of formaldehyde). We looked at the example of two hydrocarbons with different molecular formulas and the same empirical formula: acetylene is C_2H_2 and is used in welding and cutting torches, while benzene is C_6H_6 and is a minor component of gasoline. Their molecules and molecular formulas are different, but the simplest ratio of C to H in each is the same at 1:1, so their empirical formula is the same: CH. Salts and ionic compounds use the empirical formula as they do not have molecules present. So in table salt there is one sodium ion for each chloride ion and the ratio is 1:1 in NaCl.