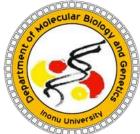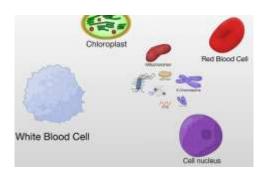# TOOLS OF THE TRADE
LABORATORY WORK IN LIFE SCIENCES

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Week 3
Basic concepts from ATOMS to MOLECULES and to CELLS

16

When there was nothing, there was energy (Physics), and then came the matter (Chemistry) which formed the basis of life (Biology).
                    -Hikmet Geckil

The BASICS

Universe is made of energy and matter. Although it is a great debate how matter formed in the first place, matter is made of atoms which themselves are matter. *Atom*, the basic unit of matter, consists of a dense central nucleus surrounded by a cloud of negatively charged electrons. The atomic nucleus contains a mix of positively charged protons and electrically neutral neutrons (except in the case of hydrogen, which has no neutrons).

As you take the *CHEM101 General Chemistry* and *PHYS101 Introduction to Physics* courses, you will become more and more familiar with the concepts of atomic theory, molecules and mole.

Atom is the basic unit of matter and when broken (which is almost impossible) to its parts (electron, proton, neutron), the parts no longer holds the property of that atom (atomic theory says atoms can neither be created nor destroyed). In this context, a *cell* is the basic unit of living organisms and when it is broken apart it no longer represents cell or organism.
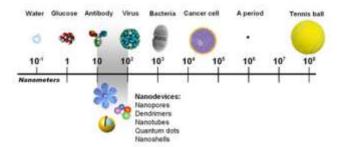
While cells come together to make an organism, atoms join together to make a molecule. A *molecule* is the smallest particle in a chemical element or compounds that has the chemical properties of that element or compound and are made up of atoms that are held together by chemical bonds.

Thus both atom and molecule are single entities, though the latter may composed of tens, hundreds, thousands, or even millions of atoms. For example, O_2 (O=O) is a molecule of two oxygen atoms, the simplest amino acid glycine (NH_2CH_2COOH) is a molecule made of 11 atoms and one of the smallest

proteins insulin (a hormone) is also a molecule made of 51 amino acids and thus hundreds of atoms. And still our largest chromosome, the chromosome 1, is made from a single DNA molecule with millions of bases and billions of atoms.
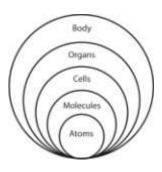
Thus a molecule can be a small entity like CO, CO_2, O_2, N_2, CH_4 etc. and a really large one such as a protein and nucleic acid (DNA and RNA).

The atomic mass, Avogadro number, Dalton, atom theory, molar mass, molarity, etc...

The *atomic mass* or *dalton* is the standard unit that is used for indicating mass on an atomic or molecular scale. It is defined as one twelfth of the carbon atom and has a value of 1.66×10^{-24} g ($1/6.02 \times 10^{23}$). For example, the atomic mass of O_2 (that is a single molecular oxygen) which we breath is $32/6.02 \times 10^{23} = 5.32 \times 10^{-23}$ g. Meantime, atomic mass of O_2 is 32 Dalton.

Irrespective of their sizes, a *mole* (abbreviated as *mol,* not *M*!) of any atom or molecule has about 6.02×10^{23} atoms or molecules. The number 6.02×10^{23} is called Avogadro's number or Avogadro's Constant, after the 19th century scientist Amedeo Avogadro. If you have one mole of oxygen atoms then you have 6.02×10^{23} oxygen atoms. Similarly, if you have one mole of insulin protein then you have 6.02×10^{23} insulin molecules. Thus, the weight in grams of one mole of a substance is whatever 6.02×10^{23} molecules of it weighs – the larger the molecule, the more one mole of it will weigh.

The molecular weight (MWt) gives you the number of grams that is in one mole of the substance (you can calculate the MWt of a certain molecule by summing the atomic weights of the components). For example, the gram molecular weight of NaCl is 58.44: the atomic weight of Na (22.99 g) plus the atomic weight of chlorine (35.45 g). Atomic weights can be found in the periodic table of the elements.

The *molar mass* is defined exclusively as gram of a substance (be an atom or molecule) per mole of that substance. Molar mass is used to convert grams of a substance to moles. For example, the molar mass of water is approximately 18 g·mol^{-1} (that is, if you can count and put 6.02×10^{23} molecules of water, which is one mole water, into a bin (or flask) it will weigh 18 g). Surely, you cannot count these many molecules of water!!! It would take more than your life span.

Example 1.
What is the total mass of all 46 chromosomes in grams (g), nanograms (ng), and picograms (pg)?

To solve this, we need to know certain data on chromosomes. Chromosomes are threads of DNA and proteins and each chromosome has a single molecule of linear DNA in varying size. As it has been known from human genome project and may be before that, we know that humans have about 6 billion nucleotide pairs in their diploid genomes (i.e., 46 chromosomes) and each nucleotide pair (A=T, G=C plus ribose sugar and phosphate groups) is about 670 daltons.

6×10^9 nucleotide pairs x (670 Daltons/nucleotide pairs) x (1.66×10^{-24} g/Dalton) = 6.7×10^{-12} g = 6.7×10^{-9} mg = 6.7×10^{-6} µg = 6.7×10^{-3} ng = 6.7 pg

Molarity (*M*) is unit of concentration equal to the number moles of solute (or molar mass) in per 1 liter of solution (that is *M*= g mol of a substance/L or simply mol/L solution). For example, 1 *M* glucose solution is 1 mol glucose/L or 180 g glucose/L, while 1 *M* NaCl solution is 1 mol NaCl/L or 58 g NaCl/L. Do not confuse amount (mol) with concentration (M)

Remember! Use dimensional analysis method to solve your problems. Otherwise, you may feel overwhelmed...

Example 2.
If we have 12 grams of glucose in a 200 ml glucose solution, what is the molarity (mol/L) of this solution?

12g glucose/200ml x 1mol/180g glucose x 1000ml/L = 0.333 M (or 0.333 mol/L)

We can ask the same in reverse. How many grams glucose in 200 ml 0.333 M glucose?

0.333 M = 0.333 mol/L
0.333 mol/L x 0.2 L x 180g glucose/mol = 12 g glucose

Example 3.
How many grams *of* NaCl do you need in order to make 200 mL a 0.5 M solution.?

First recognize that most of the time, when you set up a problem and say "*of*" it is a signal to multiply.   Recast the M as mol/L and you will see that if you do multiply, you will have almost cancelable volume terms (change the 200 mL to 0.2 L, or 1 L to 1000 mL).

0.2 L x 0.5 mol/L = 0.1 mol
Since the molecular weight (MW) of NaCl is 58.4 g/mol
0.1 mol x 58.4

Now you need to get find the number of grams in that many moles. Of course, the way to do that is with the formula weight (FW) or molecular weight (MW). (For NaCl, the FW or MWt is 58.4, so there are 58.4 g in one mole) Arrange this so that moles cancel and leave you with grams:

grams NaCl = 200 mL x (0.5 mol/1000mL)   x   58.4 g/mole = ?g
That's all, now just do the arithmetic!

Example 4.
You want 300 mL of a 0.14 M solution of NaCl, and you have a stock solution of 4 M NaCl.

Hint: always write *what I ask from you* (which is to prepare 300 mL of a 0.14 M solution of NaCl) to the top of division line (i.e., numerator) and *the stock that I give you* to the denominator.

So above problem can be solved as:
300 mL 0.14 M/ 4 M = 10.5 mL (Ms cancels each other out!)

> Add 10.5 mL stock solution of NaCl to 289.5 mL water. So, the final concentration of your solution will be 0.14 M.

Practice problems

1. How many moles of HCl are contained in 1.2 L of a 2 M solution?
2. What is the molarity of a solution that has 60.0 grams of potassium hydroxide dissolved in enough water so that the total volume is 2 liters?
3. How many moles of H_2SO_4 are dissolved in 4.90 liters of a 2.3 M H_2SO_4 solution?
4. What is the molarity of a NaOH solution where 5 g of sodium hydroxide is dissolved in a 200 mL volume?
5. How many grams of HCl are in 0.8 liters of a 4.12 M HCl solution?
6. Describe the preparation of 2 liters of 0.6 M HCl from concentrated HCl solution (e.g., 30% w/w, d= 1.2 g/ml)
7. How many mL of 0.2 M solution do I need to make 5 L of a 20 mM solution?
8. How much 8M urea will you add to 20 mL of a solution such that the final concentration is 1 M?

Normality (N) is simply the "molarity" multiplied by the number of equivalents per mole (the number moles of hydroxide or hydronium ions per mole) for the molecule (i.e, N = nM where n is the number of H^+ or OH^- lost to the solution). In other words normality is mole equivalents of solute/L solution and N is used for acids and bases to express the concentration of the ion that contributes to the pH.

While the normality of HCL, NaOH, KOH, NaCL is equal to their molarities, 1 M H_2SO_4 is equal to 2 N. H_2SO_4 dissociates into H^+ and SO^{4-} ions in water. For every mole of H_2SO_4 that dissociates in solution, 2 moles of H^+ and 1 mole of SO^{4-} ions are formed (i.e.,. a solution of 1 M H_2SO_4 could also be expressed as 2N H_2SO_4).

Osmolarity is the molarity of particles (nondissociable solute) in a solution. For example, 1 M solution of a nondissociable solute is also 1 Osmomolar. In other words, this solution contains 6.02 x 10^{23} particles per liter.

Ionic strength
This term is used to describe the concentrations of charges in solution. In other words, the ionic strength (I) of a solution is a function of the concentration of all ions present in that solution.
$I = \frac{1}{2}\sum_{i=1}^{n} c_i z_i^2$ where, c_i is the molar concentration of ion i (mol·L), z_i is the charge number of that ion, and the sum is taken over all ions in the solution. For a 1:1 electrolyte such as sodium chloride, the ionic strength is equal to the concentration, but for $MgSO_4$ the ionic strength is four times higher.

As the ionic strength of a solution increases, the activity coefficient of an ion decreases. The relationship between ionic strength and the molarity of a solution of ionizable salt depends on the number of ions produced and their net charge. For example both NaCl and KCl have 1:1 net ion charge, while $MgSO_4$ is a 2:2 salt as it yields Mg^{2+} and SO_4^{2-}. Thus, ionic strength of formers are equal to their molarity, while the latter one would have an ionic strength 4xM. Generally multivalent ions contribute strongly to the ionic strength.

Example 5.
Calculate the ionic strength of a 0.02 M $Fe_2(SO_4)_3$ solution.

0.02 M $Fe_2(SO_4)_3$ solution yields 0.04 M Fe^{3+} and 0.06 M SO_4^{2-}

I = (0.04) x $(3)^2$ + (0.06)$(-2)^2$/2 = (0.04) x (3) + (0.06)(4)/2 = 0.30

Percent (%) Solutions
Many experiments involving chemicals call for their use in solution form. That is, two or more substances are mixed together in known quantities. This may involve weighing a precise amount of dry material or measuring a precise amount of liquid.

Percentage by weight (w/v) solutions are prepared as mass of solute (g) per 100 ml solution (final volume). For example, a 10% NaCl solution has ten grams of sodium chloride dissolved in 100 ml of solution. In other words, you dissolve 10 grams of salt in certain amount of water and after salt is dissolved yo make the total volume to 100 ml by adding enough water.

Percentage by volume (v/v) solutions are prepared when the solute is a liquid (volume of solute (ml)/volume of 100 ml solution (final volume)). For example, to prepare 1000ml of a 5% by volume solution of ethylene glycol in water; 5ml ethylene glycol/100 ml x 1000 ml= 50 ml ethylene glycol. Thus, we take 50 ml ethylene glycol and dissolve in certain amount of water and then complete the total volume to 1000 ml with required amount of water.

The w/w percent solutions are less common where you mix both solute and solvent by weighing them. For example, H_2SO_4 has a density around 2 (i.e., 2 g/ml) and water has a density of 1. To prepare 10 % (w/w) sulfuric acid solution. Whe should weigh 10 grams H_2SO_4 (which is about 5 ml) and add 90 grams water (which is 90 ml). As you have noticed the total volume (i.e., final volume) is not 100 ml, but 100 g.

ppm (parts per million)

This is a way of expressing very dilute concentrations of substances. Just as per cent means out of a hundred, so parts per million or *ppm* means out of a million. Usually describes the concentration of something in water or soil. One *ppm* is equivalent to 1 milligram of something per liter of water (mg/l) or 1 milligram of something per kilogram soil (mg/kg).

ppb (parts per billion)

This is even smaller concentration measurement than *ppm*. One *ppb* is one part in 1 billion (i.e., 1μg/L)

20

Practice problems

1. What is % (v/v) alcohol content of wine with 12 mL of alcohol per 100 mL of solution.
2. If you dissolve 5 g sugar in 20 g of water. What is the w/w % concentration of sugar in this solution?
3. Express 2 *M* NaCl as a percent solution.
4. You have 450 g of an NaCl solution that is 35 % NaCl (w/w). What is the mass of NaCl ?
5. Haw many grams of NaOH are required to prepare 250 ml of a 0.02 M solution? Also, express the concentration of this solution in terms of normality, g/L, %(w/v), and osmolarity?
6. A drop of water weighs about 60 mg. How many water molecules are there in a drop of water?
7. How many atoms are in a 3.5 g sample of sodium (Na)?
8. Calculate the ionic strength of a solution containing 0.2 M NaCl and 0.04 M $MgSO_4$?
9. If there is 0.01 g of a certain substance in a liter of solution, how much substance is present as *ppm* or *ppb*?

Recommended

http://preparatorychemistry.com/
http://www.nuffieldfoundation.org/practical-chemistry
The Scale of the Universe: http://apod.nasa.gov/apod/ap120312.html