Science-1A Lecture: Week-12, Friday, April 9, 2021

Moles, Acids & Bases, pH and Flint, MI, Tragedy

Moles and Molarity

When we buy eggs, we do not buy them one at a time, but in groups of 12 called a dozen which we abbreviate as "doz" or "dz".

When we do chemistry, we do not work with atoms one at a time, but with atoms in groups of $6.02214076 \times 10^{23}$ called a **mole** which we abbreviate as "**mol**".

1 dozen = 12 thingies, usually eggs
1 mol = $6.02214076 \times 10^{23}$ thingies, usually atoms, molecules, or ions
1 mol ≈ 6.02×10^{23} thingies, usually atoms, molecules, or ions

Note: The symbol ≈ means approximately equal to.

In chemistry, we usually deal with amounts of the chemicals that we can easily weigh and mix, not individual atoms and molecules. We therefore talk of moles of each chemical. For example, when we write the chemical equation

$$CH_4 + 2\,O_2 \Rightarrow CO_2 + 2\,H_2O + 892\,kJ \quad ,$$

we are describing 1 mol of methane CH_4 burned with 2 mol of oxygen O_2 to produce 1 mol of carbon dioxide CO_2 and 2 mol of water H_2O while releasing 892 kJ = 892000 J of energy. 1 mol of CH_4 contains 1 mol of carbon and 4 mol of hydrogen with a total molecular mass of

$$(1\ \text{mol}) \times (12.01\ \text{g/mol}) + (4\ \text{mol}) \times (1.01\ \text{g/mol}) = 16.05\ \text{g} .$$

But methane is a gas and weighing gasses is difficult. At standard conditions of temperature and pressure (293.15 K and 101325 Pa), gasses such as CH_4, O_2, and CO_2 all have a volume of about 24 L/mol so we just need to measure their volumes to determine how many moles of each we have. For H_2O, we need make it all gas or all liquid in order to measure it.

The number $6.02214076 \times 10^{23}$ is called the **Avogadro constant** and is determined by very careful experiments to be the number of carbon atoms in exactly 12.0000000 g of isotopically pure carbon-12 (Carbon with 6 protons, 6 neutrons and 6 electrons). The value in our periodic table of 12.011 g/mol is actually an average that includes other carbon isotopes found in nature and is the value we must normally use when doing chemistry.

A handout to explain working with moles which emphasizes the similarity with buying eggs is at *https://yosemitefoothills.com/Science-1A/Handouts/Week-12/CalculatingMolecularMasses.pdf* .

Acids and Bases

Water is crucial to life on Earth because chemical reactions happen most easily in water solutions like blood and the protoplasm in living cells. Some molecules release a hydrogen when placed in water, others acquire extra hydrogens, and these alterations often change single bonds to double bonds and visa versa.

For example, the fatty acids shown on page 5 of our molecular diagrams handout all have a **hydroxide** –OH group at one end. In water or blood, that hydroxide group releases its hydrogen to become a negative oxygen ion $–O^-$. In a lab, we will study amino acids which have a carboxyl group –COOH that loses its hydrogen to become a $–COO^-$ ion. Famous strong acids like hydrochloric acid HCl, sulfuric acid H_2SO_4, and nitric acid HNO_3 all release a hydrogen ion when added to water. That is why they are called **acids** – they increase the concentration of H^+ ions when added to water.

Other molecules, such as ammonia NH_3 acquire a hydrogen ion when placed in water to become ammonium NH_4^+ . Those molecules are called **bases**.

Near the end of this note, we calculate that absolutely pure water at room temperature has one molecule out of every 555 million break in two ions with the reaction

$$H_2O \Leftrightarrow H^+ + OH^-$$

When a water molecule breaks into its ions, the ions might immediately find each other and recombine, but it is also possible that they will wander apart and search out ions elsewhere in the solution with which they can combine. An equilibrium condition will exist where the number of water molecules spontaneously breaking apart will be balanced by the number of H^+ and OH^- ions that run into each other and combine to make a new water molecule.

1 out of 555 million might seem insignificant, but with 10^{21} water molecules in a drop of water, this breaking apart and recombining happens continually. **This natural concentration of H^+ ions marks a level of above which something is considered an acid and below which something is considered a base.** The effect of these ions is easily observed in measurements of the electrical conductivity of water and its solutions as well as in its effect on chemical reactions in the water solution.

It turns out that if we know the concentration of H^+ ions, we can easily deduce the concentration of OH^- ions. If the concentration of H^+ ions is doubled without adding more OH^- ions, the existing OH^- ions will be more likely to meet an H^+ ions and recombine. The concentration of OH^- ions will therefore be decreased by the addition of the new H^+ ions. It will, in fact, be halved. Tripling the H^+ ions concentration will cause the concentration of OH^- ions to become 1/3 as great.

Similarly, if lye, a concentrated NaOH and KOH solution, is added to pure water, the Na^+ and K^+ ions will separate from the OH^- ions leaving an excess of OH^- ions. Those will then wander around and join with some of the H^+ ions to make water. The net result will be a lower concentration of H^+ ions. Tripling the OH^- ion concentration will result in the H^+ ion concentration becoming 1/3 as great.

We therefore only need to know the H^+ concentration to characterize the chemical behavior in a water solution since the equilibrium balance in water will determine the OH^- ion concentration.

pH

The concentration of H^+ ions has such a strong effect on chemical reactions in water, there is a special quantity **pH** to represent it. Blood is a water solution so all of our body chemistry is sensitive to the pH of our blood. Similarly, plant roots are sensitive to the pH of the surrounding soil.

The concentration of H^+ ions varies from more than 1 mol/L for very strong acids to less than 10^{-14} mol/L for very strong bases, so we compress this range by using a logarithmic scale for pH:

$$pH = -\log_{10}[H^+ mol/L] \quad \text{with its companion inverse formula} \quad [H^+] = 10^{-pH} mol/L$$

When using these formulas, it is crucial to realize that the concentration units are mol/L. The minus sign in these formulas is there to make the pH value a positive number, but it also is a way to trip up student calculations. Pure water has a pH very nearly 7.0 . So using the second formula above, the concentration of hydrogen ions in pure water (represented in square brackets) is

$$[H^+] = 10^{-7.0} mol/L = 1.0 \times 10^{-7.0} mol/L = 0.00000010 mol/L \quad .$$

Blood is a bit different with a pH close to 7.4. This corresponds to a hydrogen ion concentration in blood of

$$[H^+]=10^{-7.4}\,mol/L=3.98\times10^{-8}\,mol/L=0.0000000398\,mol/L \quad .$$

Notice that you can do 10^{-7} in your head, but you need your calculator to do $10^{-7.4}$.

The number of moles in 1 L of water, which has a mass of 1000 g is obtained by dividing 1000 g/L by the molecular mass of water

$$\frac{1000\,g/L}{2\times(1.01\,g/mol)+1\times(16.00\,g/mol)}=\frac{1000\,g/L}{18.02\,g/mol}=55.5\,mol/L \quad .$$

Near the top of this note, we calculated the molecular mass of methane CH_4, here we did it for H_2O using values from our Periodic Table for the molecular mass of hydrogen (1.01 g/mol) and for oxygen atoms (16.00 g/mol). With this result, we can calculate the ratio of moles of pure water to the moles of hydrogen ions in that water and obtain the 555 million value mentioned above:

$$\frac{[H_2O]}{[H^+]}=\frac{55.5\,mol/L}{1.0\times10^{-7}\,mol/L}=55.5\times10^{7}=555 \text{ million} \quad \text{for pure water pH=7.0}$$

Flint, MI, Tragedy

You now can better understand the Flint, Michigan, disaster where faulty science and political arrogance allowed lead contamination into a town's drinking water system. Be sure to view the hour-long NOVA video at *https://www.pbs.org/video/poisoned-water-jhhegn/* .

Also, see a 10-minute video focused on Dr. Mona Hanna-Attisha at *https://www.youtube.com/watch?v=pd2qxi2mF_4*

We will have more to say about pH in a later lab session when we steep red cabbage to make an inexpensive pH indicator solution.

This a lecture, not a lab, but please report that you have done the following:

1. Read this note.
2. Studied the analogy between dozen and moles at *https://yosemitefoothills.com/Science-1A/Handouts/Week-12/CalculatingMolecularMasses.pdf* .
3. Watched the hour-long Nova about Flint, MI.
4. Watched the 10-minute video about Dr. Mona Hanna-Attisha's contribution to uncovering the truth about the Flint, MI, health problems.