Basic Chemistry Explained

Chapter 1: The structure of the atom

Chapter 2. The periodic table and the trends between properties of elements

1. The beginnings of the periodic table

With the knowledge of the subatomic particles, the discovery of many new elements was possible. As new elements were discovered, many scientists started to notice similarities between elements and began to classify them.

The scientist John Newlands suggests that when the elements are aligned by the increment in atomic mass, every eighth element the properties will be similar. For example, the eighth element will have the same properties than the first element, the ninth element will have the same properties than the second element, and so on This is known as the law of octaves. However, when applied to elements with higher atomic mass, the law of octaves started to fail.

Maybe the law of octaves did not fit in all cases; however, the concept of different elements with similar properties was accurate. Rather than force all elements to follow the law of octaves, the chemist Dmitri Mendeleev created a table, putting the elements in groups by chemical properties. For example, in Mendeleev´s table sodium (Na) and lithium (Li) will be grouped together because both are shiny metals that react strongly with water. Mendeleev´s table will be the first version of the current periodic table. Because Mendeleev organized the elements using the atomic mass just like Newlands did before, there were some problems in the position of some elements. Mendeleev decided to follow the chemical behavior rather than the atomic mass. Following this logic, Mendeleev changed the position of some elements in the table based on chemical behavior. In some cases, he left holes in the table because he believed the holes are reserved for undiscovered elements.

Many years later, new elements were discovered that fit almost perfectly in the reserved spaces in Mendeleev´s table. Although Mendeleev´s table was accepted as the correct way to organize the elements, there are many improvements made by the contribution of other scientists. Sir William Ramsay added the noble gases to the table as a new group,

Moseley organized the table based on the atomic number rather than the atomic mass with his experiment with X-ray wavelength. All of these improvements and the discovery of more elements will lead to the development of the periodic table that we use nowadays.

2. Metals, metalloids and non-metals

Now that we discussed how the periodic table was created, we can start to analyze the behavior of the different elements. One of the first groups that can be observed in the periodic table is the group of metals and non-metals. There is a tendency in the division of metals and non-metals.

Elements that are on the right side of the periodic table are considered non-metals while elements that are on the left side are considered metals. Hydrogen is the only element on the left side that is a non-metal. There is also a diagonal line of elements that serve as a division between metal and non-metals. The elements in the diagonal part are known as metalloids (Figure 1).

The properties of metals (elements in red in Figure 1) are:

- They can be ductile (transform into wires) and malleable (transform into sheets)

4. Metallic bonds

When two metallic atoms interact, the valence electrons of both metallic atoms are free to move around the atoms. There is not an exchange of electrons between atoms instead the metal atoms act as a nucleus and the electrons are gathered around this new nucleus. This unique type of bonding between metals is called the **metallic bonding**.

This type of bonding structure is the reason for the unique properties of metals such as malleability (transform into sheets), ductility (transform into wires), and conductivity.

5. Covalent compounds and the covalent bond

We discuss previously about the interaction between metallic and non-metallic (ionic compounds) and metallic and metallic (metallic bond) but what happens when two non-metallics atoms interact. In this case, we have two atoms that are fighting to gain electrons. The ionic bond between non-metals is very difficult because any of the non-metal atoms want to give away electrons so a different interaction happens between these atoms. Rather than compete for electrons, both non-metallic atoms achieve the noble gas configuration by sharing their valence electrons. The bond that occurs by sharing electrons is called a **covalent bond**. With the Lewis structure, we can display how the covalent bond occurs between two non-metals (Figure 3).

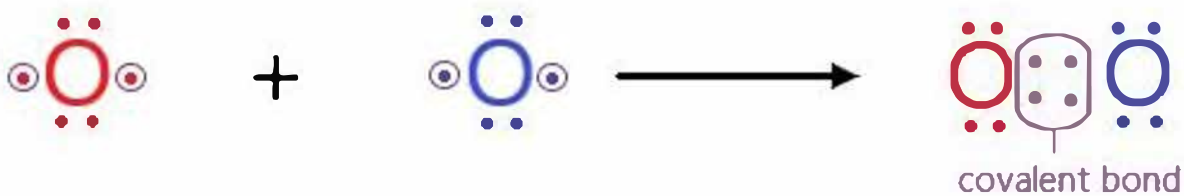

Figure 3. Formation of the covalent bond between Oxygen atoms (O)

In figure 3, the electrons that are inside the purple circle are the electrons that will form the covalent bond. By sharing these 4 electrons, both atoms of oxygen achieve 8 electrons. Usually in nature, oxygen is found as the molecule O_2 rather than the element O because the molecule O_2 (with 8 valence electrons) is more stable than the element O (with 6 valence electrons).

Covalent bonds present properties like:

- Low melting point (usually as a liquid or a gas at room temperature).
- No solubility in water.
- Terrible conductivity of electricity

6. Polarity and hydrogen bonding

Usually in covalent bonds, if the ability to attract electrons (also called electronegativity) of both atoms is similar or close to similar, the electrons are shared equally and there is no charge in the compound. The molecule O_2 in the previous example is a good example of this type of covalent compound. This type of covalent compound is known as nonpolar.

Water, one of the most important molecules for the development of life on the planet, is also a covalent compound. However, properties of water are completely different than other covalent compounds.

Parts per millions (ppm) is a type of concentration that is not used regularly in the daily life; however, it is very important in many industries like the food industry and the water treatment industry. Parts per million is defined as milligrams of the solute per liter or per weight of solvent and it is useful when you have very small amounts of solute in solution.

Example. An aqueous solution has 0.005g of molecular oxygen (O_2) dissolved in 100 mL of water. Calculate the concentration in parts per million (ppm). Atomic mass: O = 15.999 g/mol

To calculate parts per million, we do not need the molar mass because ppm uses mass instead of moles. The information from the example is: 0.005 g of O_2 in 100 mL of water.

$$\frac{0.005\ g\ O_2}{100\ mL\ H_2O}$$

First, we can transform the grams of oxygen into milligrams of oxygen using the Factor-Label Method.

$$\frac{0.005\ g\ O_2}{100\ mL\ H_2O} x \frac{1000\ mg\ O_2}{1\ g\ O_2}$$

Now, we can transform the milliliter (mL) of water into liter (L) of water

$$\frac{0.005\ g\ O_2}{100\ mL\ H_2O} x \frac{1000\ mg\ O_2}{1\ g\ O_2} x \frac{1000\ mL\ H_2O}{1\ L\ H_2O}$$

After eliminating similar units from the equation, we have the concentration of the solution in ppm

$$\frac{0.005\ \cancel{g\ O_2}}{100\ \cancel{mL\ H_2O}} x \frac{1000\ mg\ O_2}{1\ \cancel{g\ O_2}} x \frac{1000\ \cancel{mL\ H_2O}}{1\ L\ H_2O} = \frac{50\ mg\ O_2}{1\ L\ H_2O} = 50\ ppm\ O_2$$

It is important to understand what is the concentration that we are calculating to decide how to calculate. For molarity and molality, we need the solute in moles. For molarity, the solution needs to be in units of volume while in molality the solvent needs to be in units of weight. For ppm both the solute and the solvent need to be in units of weight. Analyzing the exercise before start calculating is the key to avoid mistakes.

4. Colligative properties of solutions

Colligative properties are properties of solution that are influenced by the concentration of solute in the solution. The type of solute that is added to the solution is not important for colligative properties. The colligative properties that we are going to study are boiling point elevation, freezing point depression and lowering of vapor pressure (Raoult´s Law).

Liquids that have a solute dissolve will increase their boiling temperature. This is known as the **boiling point elevation.** A common example of this property is the addition of salt into water. The boiling temperature of water will increase, according to the amount of salt added. The boiling point elevation can be expressed as a mathematical equation.

$$\Delta T_b = k_b * m * i$$

In the equation: ΔT_b represents the increment of the boiling temperature, k_b is a constant that depends on the solvent (for example, the constant of water is 0.515 °C/m), m is the molality of

The equilibrium constant equations for these two reactions are:

$$K_a = \frac{[H_3O^+][A^-]}{[HA]} \text{ or } K_a = \frac{[H^+][A^-]}{[HA]} \qquad K_b = \frac{[HB^+][OH^-]}{[B]}$$

Where K_a is the ionization constant of acids and K_b is the ionization constant for bases. The higher the value of the ionization constant, the stronger the acid or base is. However, we only use ionization constants for weak acids and bases.

To calculate the concentration of hydrogen ions $[H^+]$ for weak acids, we can start working with the reaction and display what is happening until the reaction reaches equilibrium. Initially, we only have the concentration of the weak acid [HA]

$$HA\ (aq) + H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) + A^-\ (aq)$$

Initial	[HA]	0	0

When the weak acid reacts with water, a portion of the weak acid is transformed into hydrogen ions (H_3O^+) and the conjugate base (A^-)

$$HA\ (aq) + H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) + A^-\ (aq)$$

Initial	[HA]	0	0
Equilibrium	[HA] - x	x	x

Notice that we represent the portion of the concentration of weak acid that is transformed into products as the letter x. If we apply these concentrations in the ionization constant equation, we obtained:

$$K_a = \frac{[H_3O^+][A^-]}{[HA]} = \frac{(x)(x)}{([HA] - x)}$$

To find the value of x, we can assume that the value of x is very small in comparison to the value of [HA] so the concentration ([HA] – x) can be expressed as [HA]. The ionization constant equation can be written as:

$$K_a = \frac{(x)^2}{[HA]}$$

When the value of x is calculated, x represents the concentration of both (H_3O^+) and (A^-). This approximation is only considered valid if the **percent ionization** that is calculated with the following equation gives a value than is less than 5%:

$$Percent\ ionization = \frac{[H^+]}{[HA]} x100\% < 5\%$$

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Chapter 9: Oxidation - reduction

Chapter 10: Gases

1. Introduction to gases

The matter can be found in three phases: solid, liquid and gas. In this chapter, we are going to talk about matter in the form of gas and their properties and laws. Gases have the special characteristics of being highly compressible, fill any space or container regardless of size and generate massive pressures.

The concept of pressure that the gases exert to any object or container is the force produced in a specific area as the result of the constant movement and collisions of the gas molecules. If the collision of gas molecules with the surroundings is increased, the pressure that the gas produce will also increase.

Air is a gas that exerts pressure on any object and living being on the planet. People and animals are adapted to deal with the pressure that air exert on their bodies. However, if the normal conditions or the concentration of air is changed, the body of any living being will immediately notice the difference in the air pressure. For example, if people that live their whole life near the sea suddenly move to live at the peak of a mountain, their bodies will feel the change in air pressure because the concentration of air molecules is reduced at higher altitudes in comparison to the concentration of air molecules at lower altitudes.

Scientists use different unit to express the pressure of gases. Usually, chemists use two pressure units: millimeters of Hg and atmosphere. Pressure can be expressed as millimeters of mercury (Hg) thanks to the experiments of Torricelli using columns filled with mercury. According to Torricelli´s experiments, the pressure of air is equal to the pressure exert by a column of mercury with a height of 760 millimeters in standard condition at the sea level. The other unit that is used to express the pressure is the unit atmosphere (atm) that refers to the multiples of standard atmospheric pressure when you are at the sea level. These two units are regularly used the most and the following conversion is used to transform between pressure units: **1 atm = 760 mmHg.**

2. Gas laws

The most important properties for any gas are their volume, pressure and temperature. These properties are often related to each other. For example, the gas pressure can be influenced by changing the temperature or the volume. Scientists developed mathematical relationships between these properties called **gas laws**.

The relation between the gas pressure and the volume was developed by the work of Robert Boyle and thus it was referred to as **Boyle´s Law**. According to Boyle´s Law, when the temperature is constant or without change, there is an inverse relationship between the gas pressure and the volume. This means that the gas pressure will increase when the volume of the gas is reduced. The reason for this behavior is because as the volume of the gas decreased, the number of collisions of gas molecules increase which make the pressure increases. Similarly, when the volume is increased the pressure will decrease because the gas molecules have more space to move and the collisions are reduced. Boyle´s Law can be expressed by the following equation: $\mathbf{P_1V_1 = P_2V_2}$, where P_1 and V_1 represent the initial pressure and volume and P_2 and V_2 represent the final pressure and volume, respectively.