Colegio de
San Francisco de Paula
NATURAL SCIENCES
DEPARTMENT

CHEMICAL REACTIONS

WHY DO ATOMS CLUSTER?

The attraction which keeps atoms united one to each other to form a molecule is called **chemical bond**. The atoms place themselves in the molecule so that the energy of the entity is minimal.

As the noble gases have very little tendency to form compounds they exist as monoatomic molecules. Their atoms have eight electrons in their outermost electron shell (except for helium, which has two). Because of this electronic structure the noble elements do seldom react to form compounds. In 1916 Kossel and Lewis stated that this configuration was so stable that the rest of the elements would lose, gain or share electrons in order to achieve the same electronic structure of the noble gas closest to them in the Periodic Table. This is the "octet rule".

Atoms that loose or gain electrons become charged, and are called ions. An atom that loses electrons becoming positively charged is called a **positive ion or cation**. And an atom that gains electrons having as a result an excess of negative electrical charge is called a **negative ion or anion**.

When magnesium, for instance, loses two electrons it obtains the same electronic configuration as neon. If it is an oxygen atom gains two electrons, this reaches the same electronic configuration as neon.

In the formation of a compound, the atoms tend to lose, gain or share electrons in order to have eight electrons in their last electron shell, this is, to complete their "octet".

This rule is very useful in simple cases but it cannot be considered a general law as it fails in some cases.

► Oxygen atoms have six electrons in its outermost electron shell.
a) Try to tell if it has the tendency to gain two electrons or lose six.
b) What is the formula of the most frequent oxygen ion?

► If the calcium atom has the atomic number Z = 20, tell how many protons and electrons the ion Ca^{2+} will have.

WHAT IS A CHEMICAL REACTION?

A chemical reaction describes chemical changes. Chemical reactions are represented by chemical formulas.

$C + O_2 \rightarrow CO_2$ (← That is a chemical equation)

Reactants → Product

In a chemical reaction the starting materials are the **reactants** and the new substances formed are the **products**.

Reagents and reactants: A reagent is a substance that reacts with different substances. A reactant is a substance that is taking part in a specific reaction.

A chemical reaction is represented by a **chemical equation**: A **chemical equation** is the expression that shows the chemical formulas of reactants and products.

A chemical reaction involves a change in the atomic bonds forming the initial substances (reactants), to give different ones (products).

The French chemist **Antoine Laurent de Lavoisier** (1743-1794) carried out a great amount of experiments with different chemical reactions, where he measured the mass of all the components of a reaction; that is the mass of the reactants as well as the mass of the products. From the results of his experiments he stated the following law known as the **law of conservation of mass**.

The law of conservation of mass states that in a chemical reaction mass is conserved. That is to say that the total mass of the reactants equals the total mass of the products or that the number of atoms at the beginning and the end has to be the same.

When writing a chemical equation, as mass is conserved during a chemical reaction, it is very important that the equation is balanced. An equation is balanced when we have same number of atoms of each element on both sides of the arrow.

Ex: $H_2 + O_2 \rightarrow H_2O$

- This is the reaction between hydrogen and oxygen to give water. However, it is not balanced, as there is not the same number of atoms of each element on both sides of the arrow.

- As there are 2 atoms of H on each side of the arrow, the H is balanced. But there are 2 atoms of O to the left of the arrow and only 1 atom of O to the right of the arrow. In order to balance the equation, we must add the number 2 to the water molecule (to the right of the arrow).

$$H_2 + O_2 \rightarrow \mathbf{2}\ H_2O$$

- The number we have added is now multiplying the entire chemical formula and it is called the **stoichiometric coefficient.**

- We now have 2 atoms of O on both sides of the arrow, but as a result the balance of H has been upset. We now have 4 atoms of H to the right of the arrow and only 2 atoms to the left.

- In order to balance the equation now we need to add a stoichiometic coefficient 2 to the H_2 on the left hand side.

$$\mathbf{2}\ H_2 + O_2 \rightarrow \mathbf{2}\ H_2O$$

The equation is now balanced. Just count the number or atoms of each element on each side of the arrow in order to verify.

The stoichiometric coefficients in the chemical equations allow us to make statements such as:

Two moles of H_2O are produced for every two moles of H_2 consumed
Two moles of H_2O are produced form every one mole of O_2 consumed.
Two moles of H_2 are consumed for every one mole of O_2 consumed.

We can turn such statements into conversion factors called stoichiometric factors. A stoichiometric factor relates the amounts on a mole basis, of any two substances involved in a chemical reaction, thus a stoichiometric factors is a mole ration.

ACTIVITIES:

1.- Given the following chemical reaction:
Potassium chlorate (s) → Potassium chloride + O_2 (g)
Atomic masses: H:1; K:39; Cl: 35.5; O:16

a) Write the balanced chemical equation.
b) Prove the law of conservation of mass.
c) How many moles of potassium chlorate are consumed?
d) How many particles of potassium chloride are produced?

2.- Given the following chemical reaction:
Sodium (s)+ O_2 (g)→ Sodium oxide (s)
Atomic masses: Na: 23; O:16

a) Write the balanced chemical equation.
b) Prove the law of conservation of mass.
c) How many moles of sodium oxide are produced?
d) How many particles of sodium are consumed?

3.- Given the following chemical reaction:
Copper (s)+ Cl_2 (g)→ copper(II) chloride (s)
Atomic masses: Cu: 63.5; Cl:35.5

a) Write the balanced chemical equation.
b) Prove the law of conservation of mass.
c) How many moles of copper and chlorine gas are consumed?
d) How many particles of copper(II) chloride are produced?

TYPES OF REACTIONS

There are many chemical reactions, however, they can be classify into four general types: synthesis, decomposition, single replacement and double replacement reactions.

Synthesis or Combination Reaction

In a synthesis reaction two or more simple substances combine to form a more complex substance: Two or more reactants and only one product.

Ex: $2\ H_2 + O_2 \rightarrow 2\ H_2O$

2 Reactants → 1 product

Decomposition Reaction

In a decomposition reaction one complex substance breaks down into its more simple parts. This is the opposite of a synthesis reaction. One reactant yields two or more products.

Ex: $2\ H_2O \rightarrow 2\ H_2 + O_2$

1 reactant → 2 products

Single displacement reaction

In a single replacement reaction an uncombined element replaces another in a compound. Two reactants yield two products.

Ex: $2\ HCl + Zn \rightarrow ZnCl_2 + H_2$

2 reactants → 2 products

Double displacement reaction

In a double replacement reaction two elements forming part of two different compounds switch places to form a new compound. Two reactants yield two products.

Ex: $HCl + NaOH \rightarrow NaCl + H_2O$

2 reactants → 2 products

HOW FAST OR SLOW DOES A REACTION GO?

Some reactions are very fast, taking less than a second, while others take up to hundreds of years. Sometimes is important to know exactly how fast a reaction is going. That is to say we need to know the **rate** of a reaction.

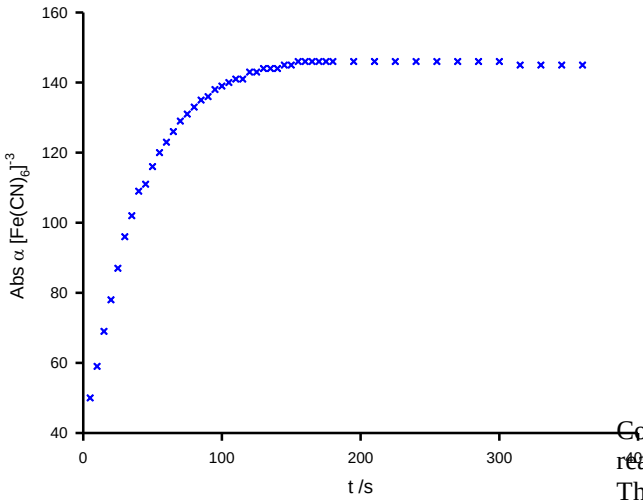
Rate is a measure of how slow or how fast a reaction goes. In chemistry, when we talk about **the rate of a reaction** we are referring to **the speed at which the reaction happens.**

When studying reaction rates we should take into account the **collision theory**. This theory says that combination of the molecules occur when they collide. Therefore, the more collisions take place in a system the more likely combinations of molecules will happen.

When we introduce the time as a factor the expression modifies by stating that the higher the amount of collisions per unit of time, the greater the number of combinations of molecules, and therefore the faster the reaction will take place. As a result a higher rate of reaction will be observed.

But **how do we measure the rate of a chemical reaction?**

As a general rule to find out the speed of a reaction you measure the amount of a reactant used up per unit of time, or the amount of a product formed per unit of time.



Concentration of ferricyanide formed in a reaction varies in time with a determined rate. This can be calculated from data in the graph.

There are different factors that affect the speed or rate of a reaction: concentration, temperature and pressure.

Concentration: as you increase the concentration of the reactants, you increase the speed of reaction. The more substance you have the greater the chance of collisions and therefore the faster the reaction will go. **At higher concentration of reactants, higher reaction rate.**

Temperature: changing the temperature of the reactants will change the rate of reaction. **As you increase the temperature** of a system, the molecules will bounce around faster as they now have a larger kinetic energy. The more they bounce the greater the chance of collisions with the minimum necessary energy and, therefore, the greater the chance of combining. Therefore, **the rate of the reaction will increase** as well. When the temperature increases by 10 ºC the rate approximately doubles. On the other hand, **if you lower the temperature** of a system, its molecules will slow down, and collide less and with less energy. The combination of molecules will as well slow down and **so will the rate of reaction**.

Pressure: a change in pressure also affects the rate of a chemical reaction, particularly when dealing with gases. As you increase the pressure the molecules have less space, becoming more concentrated. That greater concentration increases the chance of collisions and therefore the reaction will speed up. **Increasing the pressure will result in a higher rate of reaction.** On the other hand, as you **decrease the pressure,** the molecules will not collide into each other as often and the **rate of the chemical reaction will decrease.**

Surface area: the greater the surface area, the greater the chance of particles colliding with each other and therefore, the greater the combinations. Increasing the surface area will increase the rate of a reaction. The surface area of a reactant will be greater as it is broken up into smaller parts. That is why reactions are carried out in solutions, or if in solid state, pulverized.

The use of a **Catalyst can greatly increase the rate of a chemical reaction**. A catalyst is a substance that changes the rate of a chemical reaction without getting involved in the reaction. **A catalyst remains chemically unchanged.** *In the presence of a catalyst the collisions between molecules will need less energy.* Catalysts are very important in industry since they allow chemical reactions to go fast even at low temperatures; saving fuel and money. You will study catalysts in much more detail in upper courses.

SOLUBILITY AND CONCENTRATION

Remember that **solubility** is the maximum amount of a substance that will dissolve in another substance at a given temperature.

Homogeneous mixtures are called solutions.

In solutions, the solute is dissolved by the solvent. If you have a mixture of water and salt, the solution looks clear. The salt has dissolved in the water. In this solution, the salt is the solute and the water is the solvent.

There are different types of solvents. However, we are only going to study **aqueous solutions**, where the solvent is always water. (*aqua* → water in Latin).

Let's go back to our solution of salt water:

If you take a beaker with 50 mL of water, add a spoonful of salt, and stir the mixture the salt will dissolve. If you keep adding salt to it, eventually you will **saturate** the solution and the salt will no longer dissolve, regardless of how much you stir the solution. Once you pass the point of saturation, you will start to see how the salt settles at the bottom of the beaker. If you now take the solution and heat it up enough, the undissolved salt will dissolve. So, **solubility changes with temperature**. As temperature increases so does the solubility of a substance.

In a saturated solution the amount of solute dissolved is the most the solution can hold at a given temperature. However, you can also have diluted solutions, where the concentration of the solute is much lower.

As you added salt to the solution of the above example, you altered its concentration. Saying that a solution is more or less diluted doesn't tell us much about the actual amount of solute present in a given volume of solution. So, how can we measure the concentration of a solution? There are different ways of measuring the concentration of solutions. However, in this course we are only going to study two of those; **mass concentration**, and **mass percent**.

The **mass concentration** of a solution is the mass of solute in grams per volume of solution in litres.

$$\text{Mass concentration} = \frac{\text{grams of solute}}{\text{litres of solution}}$$

Example:

If we dissolve 6.0 g of table salt (sodium chloride) in enough water to make a 750 mL solution; what would the mass concentration of the solution be?

$$\text{Mass concentration} = \frac{6.0 \text{ g table salt}}{0.750 \text{ L solution}} = 8 \text{ g table salt / L}$$

The **mass percent** of a solution is the mass of solute in grams per mass of solution in grams, multiplied by 100. As the solution contains solute and solvent, the mass of solution will equal the mass of solute plus the mass of solvent.

$$\text{Mass \%} = \frac{\text{grams of solute}}{\text{grams of solution}} \times 100$$

grams of solution = grams of solute + grams of solvent

Exercises:

a) How many grams of table salt do we need to make a 250 mL solution with a mass concentration of 10 g/L?

b) The concentration of a solution is 45 g/L. How many grams of solute do we have in a 350 mL solution?

c) We dissolve 30 g of solute in water to make a 180 mL solution; what is the mass concentration of the solution?

d) A solution of water and sugar has a mass concentration of 20 g/L. If 18 g of sugar were added to the water, what is the volume of our solution?

e) I have two 500 mL samples of salt water, with a mass concentration of 25 g/L and 34 g/L respectively. How much salt does each sample contain?

f) How many grams of solute do I need to prepare a 2.5 dL solution with a mass concentration of 0.01kg/L

g) How many grams of solute do I need to make a 400 cm^3 of a solution with a mass concentration of 12g/L?

h) We dissolve 10 g of solute in water to make a solution with a mass concentration of 2.5g/L. What is the volume, in cm^3, of my solution?

i) Calculate the mass percent of the following solutions: a) 40 g of table salt in 250 g of water; b) 50 g of sugar in 1 kg of solution; c) 12 g silver nitrate in half a litre of pure water.

j) We use 50 mL of pure water to make a NaCl solution. Calculate the amount of NaCl used if the solution is 30% NaCl by mass.