POLO SCOLASTICO 2 “TORELLI”

SEDE DI PERGOLA (PU)

Liceo Scientifico Torelli

CHEMISTRY FOR BIOLOGY

per POTENZIAMENTO LINGUISTICO

by Elena Ferretti

A.S. 2023/2024

This e-book will help the students

at the beginning of their first year here at Liceo Torelli

to understand the principle of chemical reactions

Elena Ferretti

INDEX

1. ATOMIC STRUCTURE

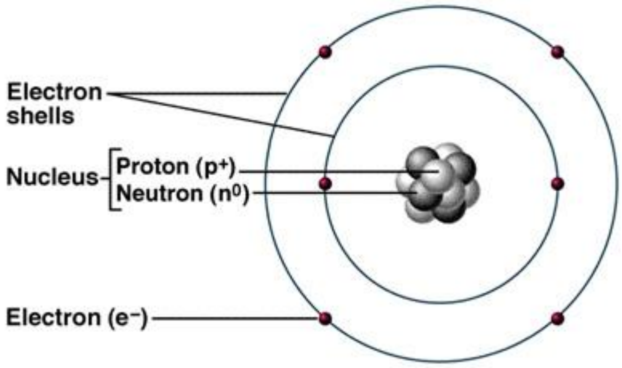
Learning Objective
Distinguish the parts of an atom

Key Terms
Proton, neutron, electron, nucleus, electron shell

What is an atom?

An atom is the smallest component of an element having the chemical properties of the element.

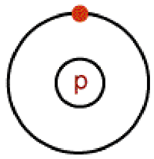
Basic Structure of an Atom



- An atom has a nucleus at the center containing neutrons and protons with one or more electrons circulating around the nucleus in *electron shells* which are different *energy levels*.
- Protons are positively charged.
- Neutrons have no charge.
- Electrons are negatively charged.
- The electrons are held by an electrostatic force of attraction by its negative charge and positive charge of protons.
- An atom is electrically neutral because the same proton number (positive charge) in the nucleus is balanced by the electron number (negative charge) in the shells.

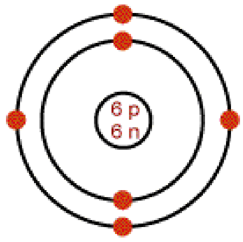
How to identify atoms of different elements

- Proton number also called atomic number.
- The atomic number (proton number) determines the identity of an element.
- Each element has different proton number and no two different elements have the same proton number.
- For examples, hydrogen has one proton number, carbon has six proton number and chlorine has seventeen proton number (see image below).



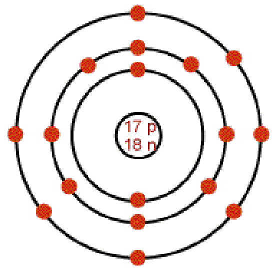
Hydrogen has one proton

The atomic number is 1



Carbon has six protons

The atomic number is 6

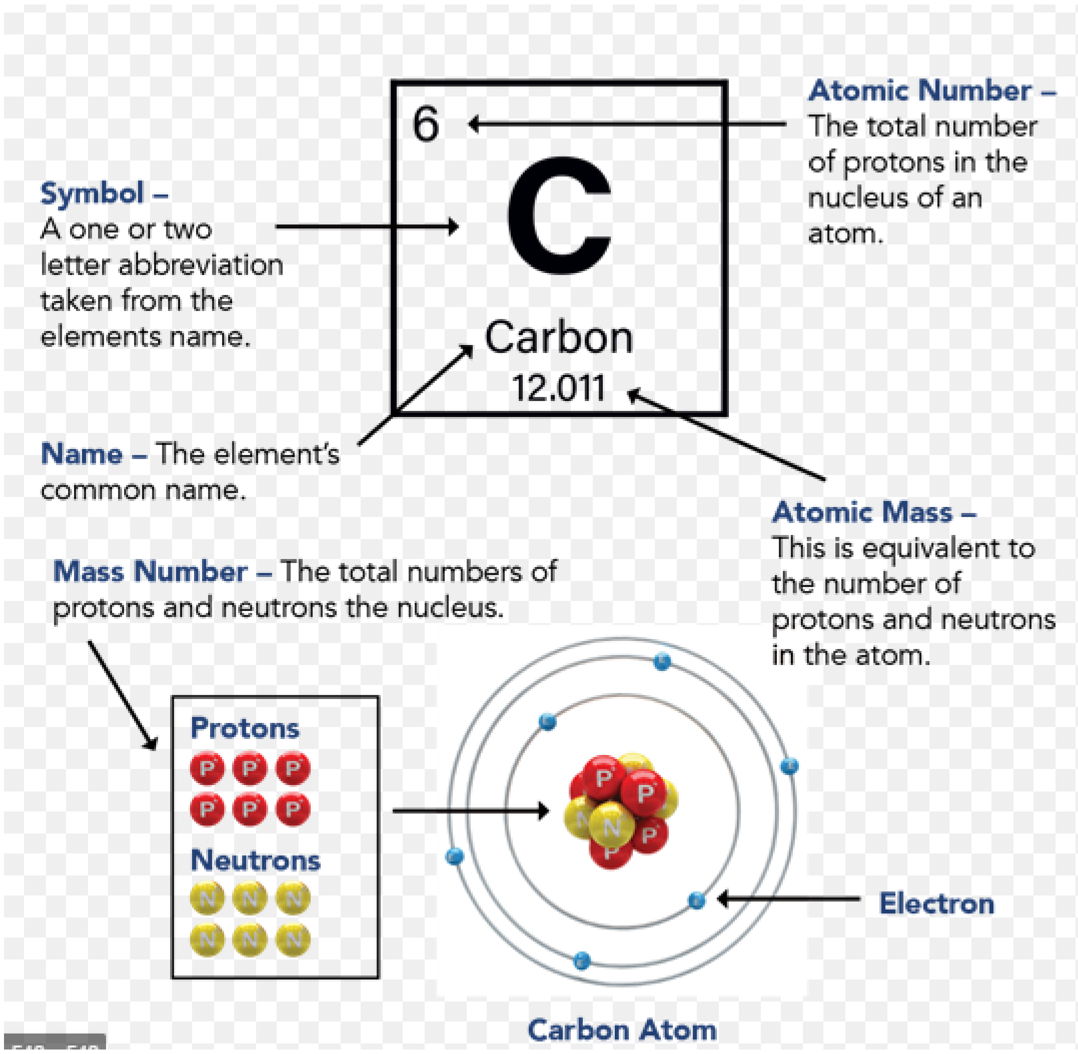


Chlorine has 17 protons

The atomic number is 17

N.B. In the Periodic Table, the elements are arranged in order of increasing atomic number.

The atom of Carbon



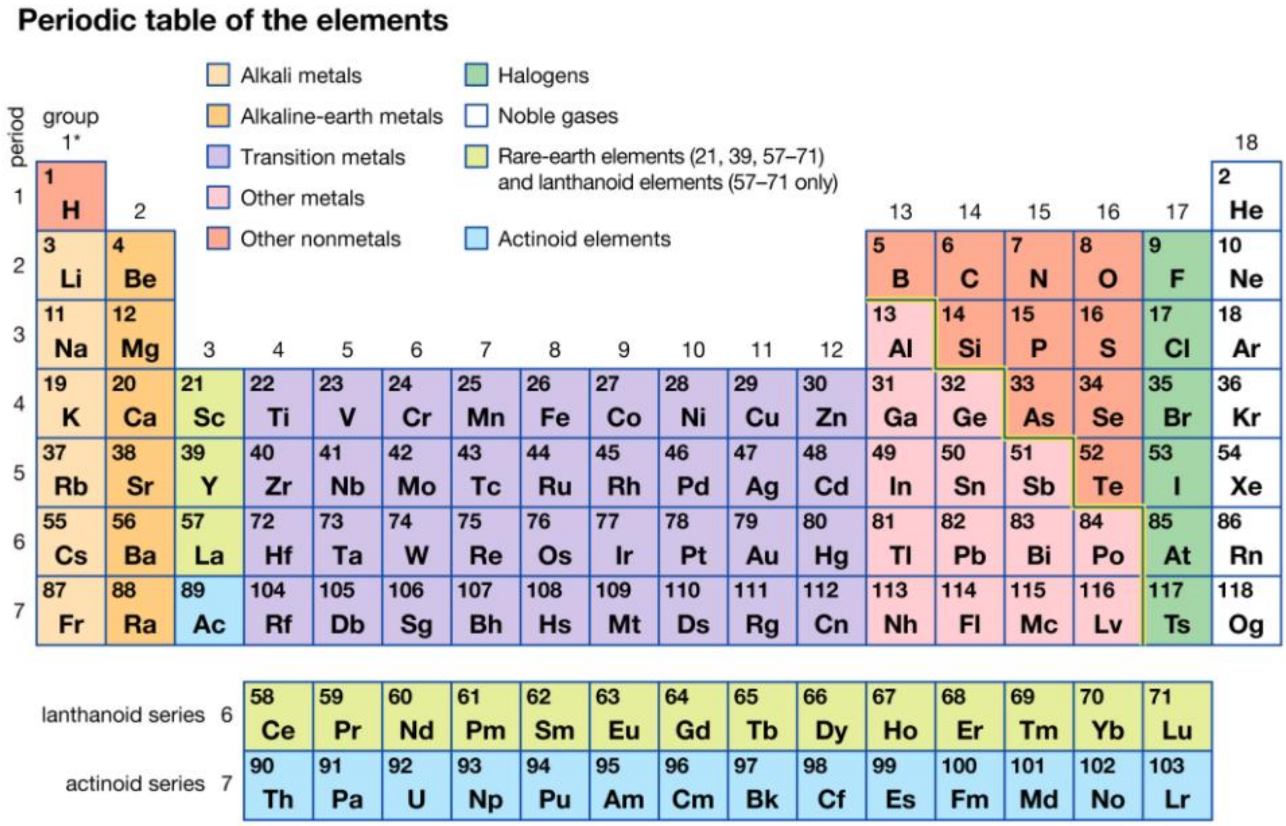
2. PERIODIC TABLE

Learning Objective
Distinguish the parts of the periodic table
Recognize the atomic number and the atomic mass

Key Terms
Period, group, element, metal, non-metal, atomic number, atomic mass

Arranged by Mendeleev in 1869, the periodic table of elements shows all the chemical elements in order of increasing atomic number and allow to easily find electron configuration, and recurring chemical properties. The structure of the table shows periodic trends.

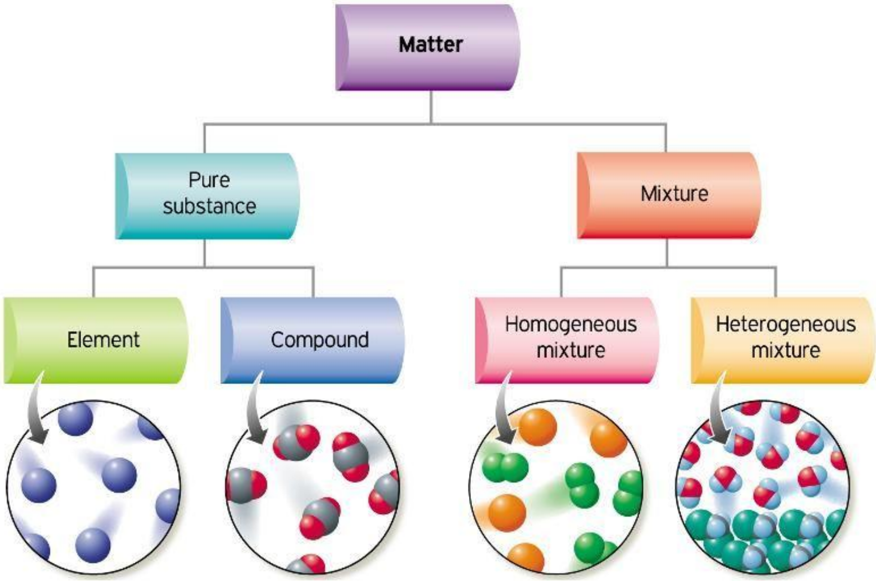
The seven rows of the table are called <u>periods</u>. The columns, called <u>groups</u>, contain elements with similar chemical behaviours. Six groups have accepted names as well as assigned numbers: for example, group 1 are alkali metals, group 17 elements are the halogens; and group 18 are the noble gases.
Metals are on the left and nonmetals on the right, divided by the yellow line



3. PURE SUBSTANCES AND MIXTURES

Learning Objective
Understand the difference among elements, compounds and mixtures

Key Terms
Matter, element, compound, homogeneous mixture, etherogeneous mixture



Chemical Substances

In chemistry, a pure substance is a form of matter that has constant chemical composition and characteristic properties. It cannot be separated into components without breaking chemical bonds. Chemical substances can be solids, liquids, gases, or plasma. Changes in temperature or pressure can cause substances to shift between the different phases of matter.

An element is a chemical substance that is made up of a particular kind of atom and hence cannot be broken down or transformed by a chemical reaction into a different element. All atoms of an element have the same number of protons, though they may have different numbers of neutrons and electrons.

A pure chemical compound is a chemical substance that is composed of a particular set of molecules or ions that are chemically bonded. Two or more elements combined into one substance through a chemical reaction, such as water, form a chemical compound.

All compounds are pure substances, but not all pure substances are compounds.

A chemical compound can be either atoms bonded together in molecules or crystals in which atoms, molecules or ions form a crystalline lattice. Compounds made primarily of carbon and hydrogen atoms are called organic compounds, and all others are called inorganic compounds.

Chemical Mixtures

A mixture is a material system made up of two or more different substances, which are mixed but not combined with chemical bonds. A mixture refers to the physical combination of two or more substances in which the identities of the individual substances are retained.

Distinguishing between homogeneous and heterogeneous mixtures is a matter of the scale of sampling.

Heterogeneous Mixtures

A heterogeneous mixture is a mixture of two or more chemical substances (elements or compounds), where the different components can be distinguished visually or with an optical microscope. The components can be easily separated by physical means.

Blood can be considered a heterogeneous mixture, because at the microscope red and white cells can be distinguished. It’s a suspension.

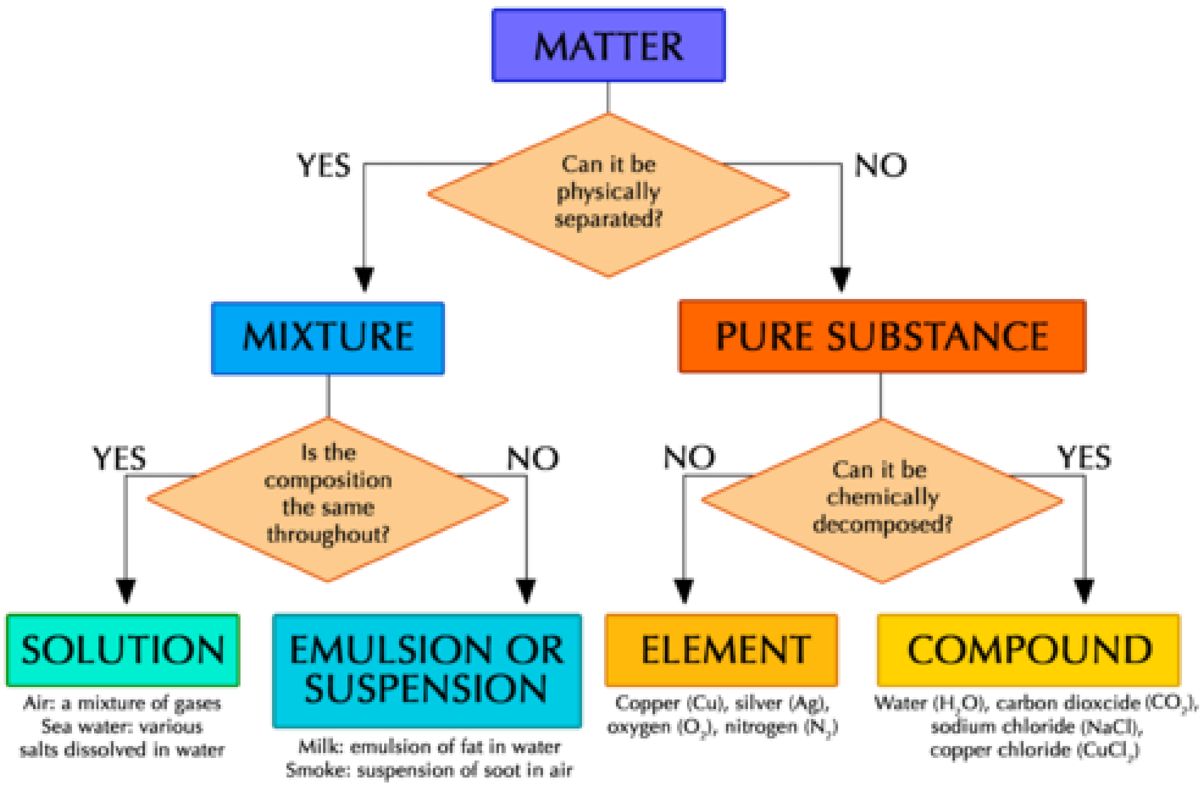
Even milk belongs to heterogeneous mixtures, because fat can be easily separated. It’s an example of colloids, as clouds and smoke (two types of aerosol or nebulizer).

Homogenous Mixtures

A homogeneous mixture is a mixture of two or more chemical substances (elements or compounds), where the different components cannot be visually distinguished, even at the microscope. The composition of homogeneous mixtures is constant.

They are also called solutions (solvent * solute). For example: water and salt, alloys.

SUMMING UP



In brief...

- Matter can be broken down into two categories: pure substances and mixtures. Pure substances are further broken down into elements and compounds. Mixtures are physically combined structures that can be separated into their original components.
- A chemical substance is composed of one type of atom or molecule.
- A mixture is composed of different types of atoms or molecules that are not chemically bonded.
- A heterogeneous mixture is a mixture of two or more chemical substances where the various components can be visually distinguished.
- A homogeneous mixture is a type of mixture in which the composition is uniform and every part of the solution has the same properties.
- Various separation techniques exist in order to separate matter, including include distillation, filtration, evaporation and chromatography. Matter can be in the same phase or in two different phases for this separation to take place.

4. MIXTURE SEPARATION TECHNIQUES

Learning Objective
Distinguish the different methods to separate mixtures

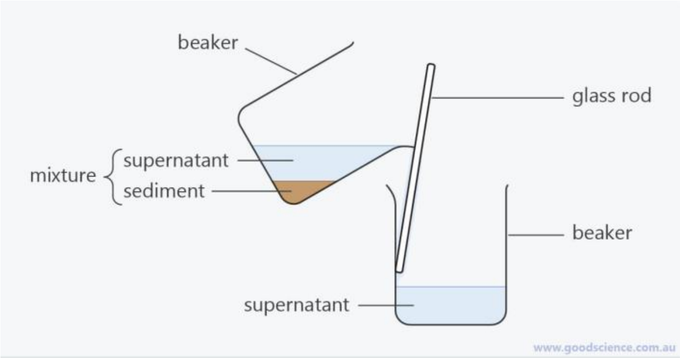
Key Terms
Decanting, sieving, filtration, separating funnel, centrifugation, Magnetism, evaporation, distillation, chromatography

Since mixtures are formed by the physical combining of substances, they can also be physically separated.
The most appropriate technique for separating a mixture depends on the type of mixture and the physical properties of the components, such as: melting and boiling point, size of fragments, solubility, density, magnetism and other forms of attraction.

Techniques for Separating Heterogeneous Mixtures	Techniques for Separating Homogeneous Mixtures
Decanting	Evaporation
Sieving	Distillation
Filtration	Chromatography
Separating funnel	
Centrifugation	
Magnetic separation	

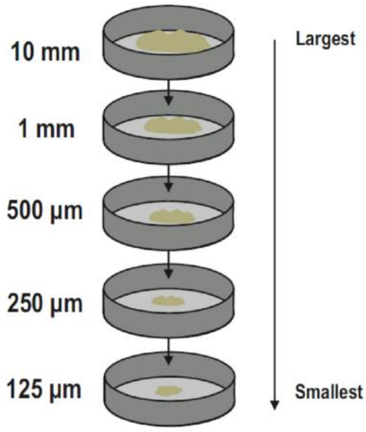
- Decanting involves separating a liquid from a solid by gently pouring off the liquid.
- Sieving involves separating a mixture based on different sizes of components, where smaller fragments pass through holes in the sieve but large fragments do not.
- Filtration is a special form of sieving where filter paper is used to trap very fine solid particles (residue) from the rest of a liquid or gas mixture (filtrate).
- Separating funnels or used for separating liquids with different densities.
- Centrifugation separates heterogeneous mixtures by spinning them at very high speeds, which forces components to separate into layers.
- Magnetism can be used for separating magnetic materials from non-magnetic materials.
- Evaporation is used for recovering dissolved substances from solutions by evaporating the solvent and crystallising the solute.
- Distillation involves the evaporation of a liquid (distillate), which is then cooled and condensed back into a liquid, to be collected separately.
- Chromatography separates mixtures based on their differing levels of attraction to two different substances, known as the mobile phase and the stationary phase.

Decanting involves separating a dense, insoluble substance from a heterogeneous mixture.
For example, if we mixed sand with water in a beaker, the sand would not dissolve, but would settle to the bottom, forming a sediment layer.
By gently pouring off the water (the supernatant), we could separate the sand from it.
Decanting is only a useful method if the solid particles readily settle to the bottom.
It would not be useful, for example, in separating fine silt particles from water, as they often remain suspended in the water.



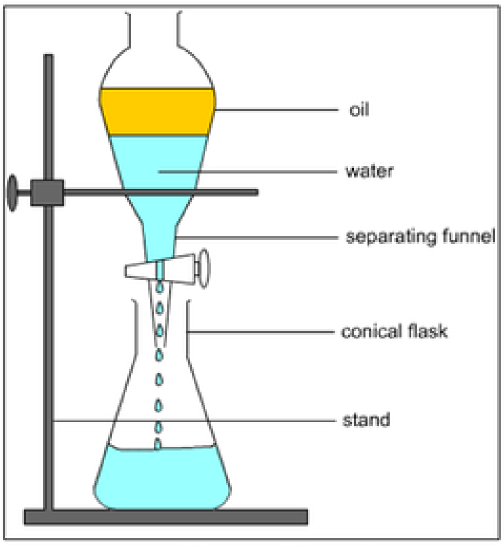
Decanting

Sieving involves separating a mixture based on different sizes of components.
For example, small rocks can be separated from sand by sieving the mixture. The smaller sand grains will pass through the holes in the sieve, whereas the rocks will not pass through.

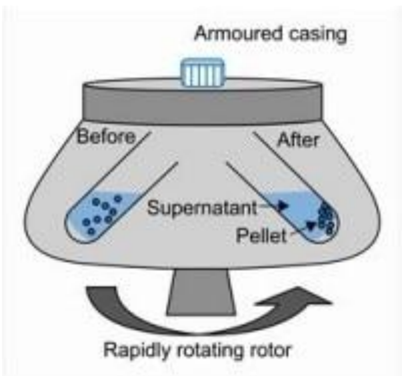


Filtration is a special form of sieving that separates very fine solid particles from liquid or gas mixtures. Filter paper (or a similar substance with very fine pores) is used as a sieve.
In a laboratory, filtration is often carried out by placing filter paper in a funnel, pouring the mixture into the funnel and collecting the filtered liquid in a beaker.
The liquid that passes through the filter is called the filtrate and the solid that gets trapped in the filter is called the residue.

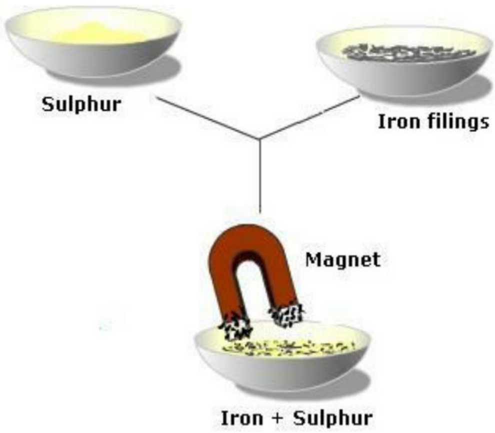
A separating funnel can be used to separate a mixture of two non-miscible liquids – that is, liquids that do not mix together to form a homogeneous solution.
This technique is mostly used to separate liquids that are miscible in water from liquids that are non-miscible in water. An oil-water mixture would be an example of this.



Centrifugation involves spinning tubes of heterogeneous mixtures at very high speeds, which forces part of the mixture to settle at the bottom of the tube.
It can be used for separating solid particles from liquids, or for separating non-miscible liquids. Examples include the separation of fat from milk and the separation of different components in blood (red blood cells, white blood cells and plasma).

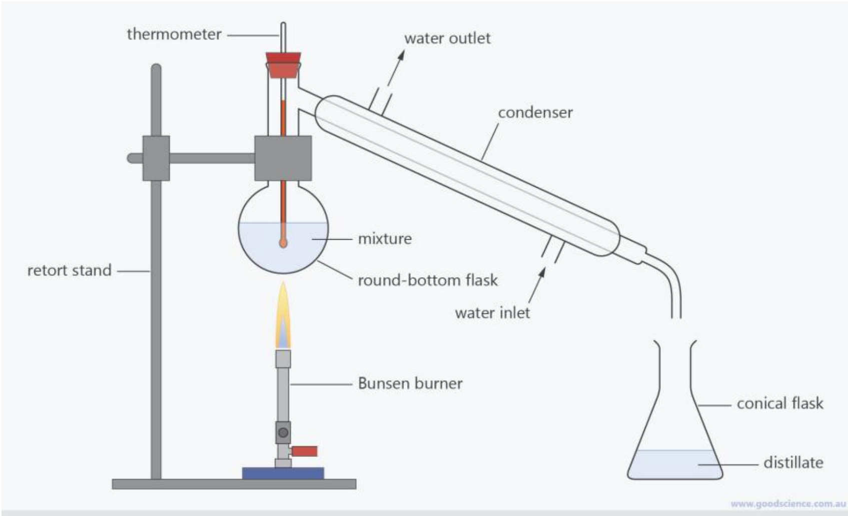


Magnetic separation is a specialised method specifically used for separating magnetic materials, such as iron, from non-magnetic materials, such as soil and plastic.
It is commonly used in the mining and recycling industries.



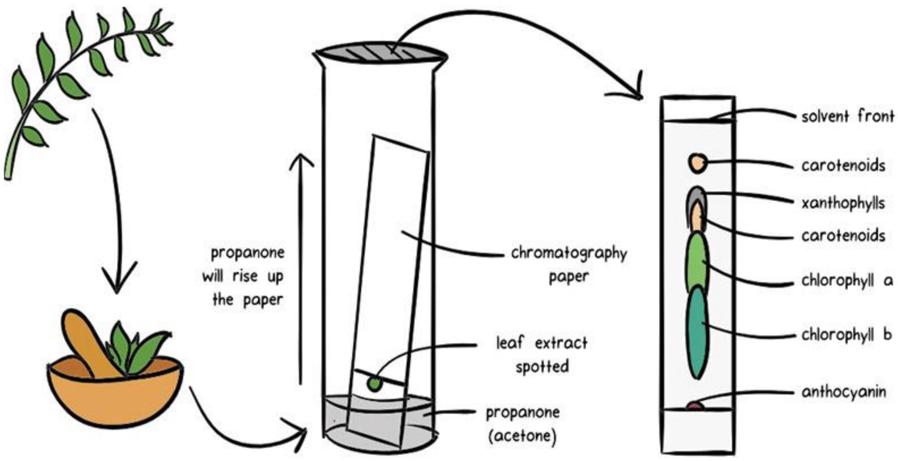
Evaporation is used for recovering dissolved solids from solutions.
The solution is either boiled or simply left uncovered, resulting in the evaporation of water and the crystallisation of solutes. For example, sea salt is recovered by the evaporation of sea water.

Distillation is similar to evaporation, except that the evaporated substance, known as the distillate, is collected. The evaporated substance is passed through a tube known as a condenser, which is surrounded by cold water. The evaporated substance is cooled, causing it to condense back to a liquid so that it can be collected.
Distillation can be used to separate liquids based on their differing boiling point.
It is commonly used in producing petrol, alcohol and perfumes.



Distillation

Chromatography, in particular a type of chromatography called paper chromatography. uses the principle of different solubility.
It separates inks, dyes and clhorophyll according to the size and the solubility of the particles in the solvent. As the solvent (water) rises through the paper, it dissolves the sample mixture, which will then travel up to the paper. Small particles travel further than larger particles, due to the difference of solubility and their attraction with the paper
The pigment particles are attracted to both the paper and the water, but by different degrees. Particles that are more attracted to the water will migrate faster; particles that are more attracted to the paper will migrate slower.



5. PHYSICAL VS CHEMICAL TRANSFORMATION

Learning Objective
Distinguish a chemical reaction from a physical transformation

Key Terms
Indicator, precipitation,chemical change, color change, temperature change, gas production, sparkles

Tips to understands if it’s a chemical reaction

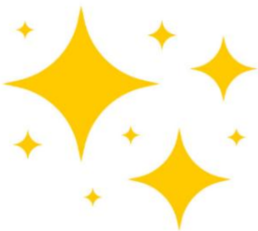
- Evidence!

There are 4 major indicators of chemical change.

1. Temperature change

2. Color change
3. Gas production (odor, bubbles)
4. Solid formation
   (precipitation)

and don’t forget: sparkles or explosions!



6. LEWIS SYMBOLS

Learning Objective
Learn how to draw an atom’s electrons

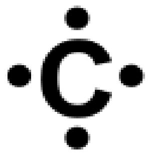
Key Terms
Energy level, valence elecrons

Lewis symbols (also known as electron dot diagrams) represent the valence electrons of an atom.

Chemical reactivity of all of the different elements in the periodic table depends on the number of electrons in that last, outermost level, called the valence level or valence shell.

Atoms gain, lose, or share electrons in their valence level in order to achieve greater stability, or a lower energy state.

In the Lewis symbol for an atom, the chemical symbol of the element (as found on the periodic table) is written, and the valence electrons (corresponding at the group it belongs) are represented as dots surrounding it.



Octect rule

- The noble gases (VIII group) are chemically stable and have a full valence level of electrons.
- Other elements react in order to achieve the same stability as the noble gases.
- Lewis symbols represent the valence electrons as dots surrounding the elemental symbol for the atom.

Determining the Number of Valence Electrons

Each group (A) of the periodic table contains elements that have the same number of valence electrons. Furthermore, the number of the group tells us the exact number of valence electrons for that element.

The middle part of the periodic table that contains the transition metals is *skipped* in this process for reasons having to do with the electronic configuration of these elements.

Recall that any valence level can have up to eight electrons, except for the first principal energy level, which can only have two.

Some periodic tables list the group numbers in Arabic numbers instead of Roman numerals. In that case, the transition metal groups are included in the counting and the groups indicated at the top of the periodic table have numbers 1, 2, 13, 14, 15, 16, 17, 18. The corresponding roman numerals used are I, II, III, IV, V, VI, VII, VIII.

The eighth and final column, in which the most stable elements are listed. These are all gaseous under normal conditions of temperature and pressure, and are called ‘noble gases.’ Neon (Ne), argon (Ar), krypton (Kr), etc., each contain eight electrons in their valence level. Therefore, these elements have a full valence level that has the *maximum* number of electrons possible. Helium (He), at the very top of this column is an exception because it has two valence electrons; its valence level is the first principal energy level which can only have two electrons, so it has the maximum number of electrons in its valence level as well.

The noble gases represent elements of such stability that they are not chemically reactive, so they can be called *inert*. In other words, they don’t need to bond with any other elements in order to attain a lower energy configuration. We explain this phenomenon by attributing their stability to having a ‘full’ valence level.

The significance in understanding the nature of the stability of noble gases is that it guides us in predicting how other elements will react in order to achieve the same electronic configuration as the noble gases by having a full valence level.

The Octet Rule

Noble gases like He, Ne, Ar, Kr, etc., are stable because their valence level is filled with as many electrons as possible. *Eight* electrons fill the valence level for all noble gases, except helium, which has *two* electrons in its full valence level. Other elements in the periodic table react to form bonds in which *valence electrons are exchanged or shared* in order to achieve a valence level which is filled, just like in the noble gases. We refer to this chemical tendency of atoms as ‘the octet rule,’ and it guides us in predicting how atoms combine to form molecules and compounds.

Key Points

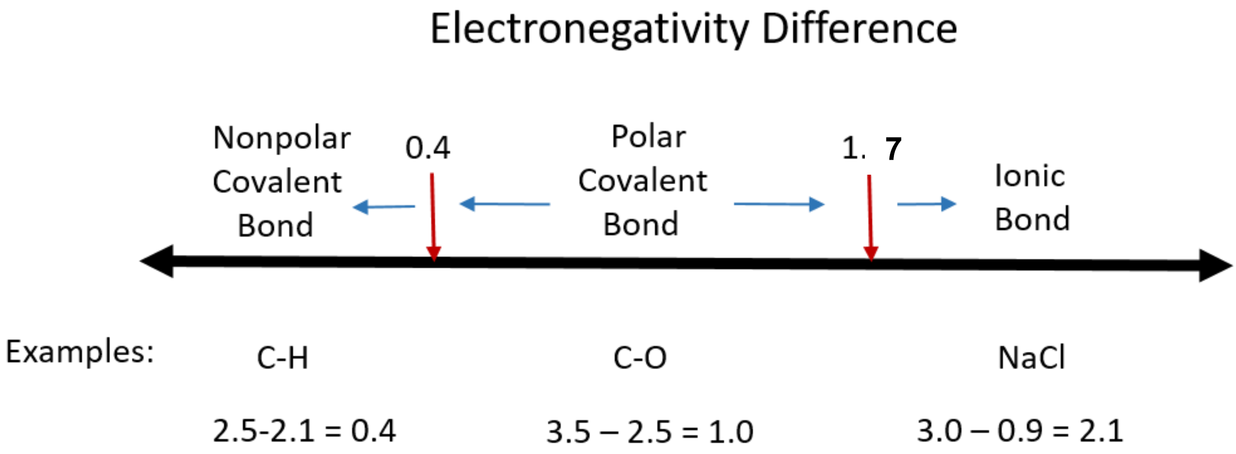
- The octet rule says that the noble gas electronic configuration is a particularly favorable one that can be achieved through formation of electron pair bonds between atoms.
- In many atoms, not all of the electron pairs comprising the octet are shared between atoms. These unshared, non-bonding electrons are called ‘ lone pairs ‘ of electrons.
- Although lone pairs are not directly involved in bond formation, they should always be shown in Lewis structures.
- There is a logical procedure that can be followed to draw the Lewis structure of a molecule or compound.

Key Terms

- **octet rule**: Atoms try to achieve the electronic configuration of the noble gas nearest to them in the periodic table by achieving a full valence level with eight electrons.
- **exceptions to the octet rule**: Hydrogen (H) and helium (He) only need two electrons to have a full valence level.
- **covalent bond**: Two atoms share valence electrons in order to achieve a noble gas electronic configuration.
- **Lewis structure**: Formalism used to show the structure of a molecule or compound, in which shared electrons pairs between atoms are indicated by dashes. Non-bonding, lone pairs of electrons must also be shown.

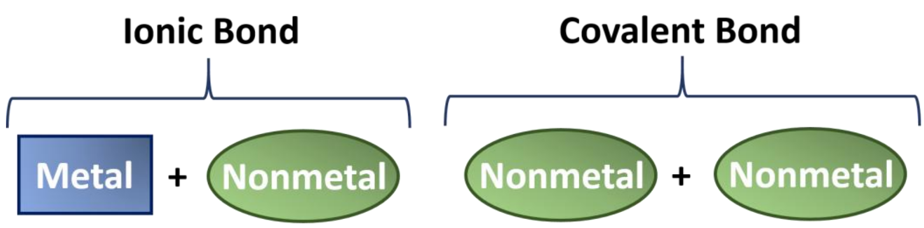
7. ELECTRONEGATIVITY

- Electronegativity is an atom's tendency to attract electrons to itself in a chemical bond.
- The most electronegative element is fluorine. The least electronegative or most electropositive element is francium.
- The greater the difference between atom electronegativity values, the more polar the chemical bond formed between them.



Electronegativity Difference Diagram. The diagram above is a guide for discerning what type of bond forms between two different atoms. By taking the difference between the electronegativity values for each of the atoms involved in the bond, the bond type and polarity can be predicted. Note that full ionic character is rarely reached, however when metals and nonmetals form bonds, they are named using the rules for ionic bonding.

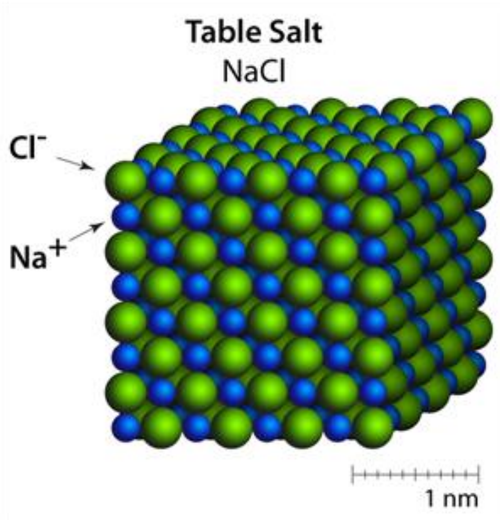
Electronegativity difference and type of bonds.



8. CHEMICAL BONDS

IONIC BONDS

Ionic bonds are formed between a metal and non-metal, for example sodium chloride.
An atom of sodium will lose an electron and form a positive ion.
An atom of chlorine will gain an electron and form a negative ion.
The ionic bond is the electrostatic force of attraction between a positively charged metal ion and a negatively charged non-metal ion.
Metals form positive ions because they lose electrons to become stable.
Example: Magnesium (Mg) has the electron arrangement 2,8,2.
To become stable it must lose its two outer electrons to obtain a full outer energy level.
Atoms are neutral because they have equal numbers of protons and electrons however, when they lose two electrons they are no longer neutral. They change into ions with a two positive charge.
Non-metals form negative ions because they gain electrons to become stable.
Chlorine (Cl) has an electron arrangement 2,8,7.
To become stable it must gain an electron to obtain a full outer energy level.
When these two charged particles come together they form an ionic bond because the positive magnesium ion is attracted to the negatively charged chloride ion.
Ionic compounds form what is known as a lattice structure. This is a regular repeating arrangement of metal and non-metal ions which creates compounds with very high melting points which conduct when molten or in solution but never when solid.



A cube of tightly packed alternate metal and non-metal ions.

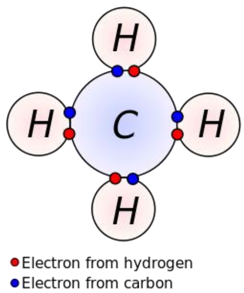
Ionic compounds dissolve in water easily, when they do this their lattice breaks up completely and water molecules surround the seperated ions. Therefore they can conduct as their ions are free to move.

Covalent Bonds and Lewis Diagrams of Simple Molecules

The simplest example to consider is hydrogen (H), which is the smallest element in the periodic table with one proton and one electron. Hydrogen can become stable if it achieves a full valence level like the noble gas that is closest to it in the periodic table, helium (He). These are exceptions to the octet rule because they only require 2 electrons to have a full valence level.

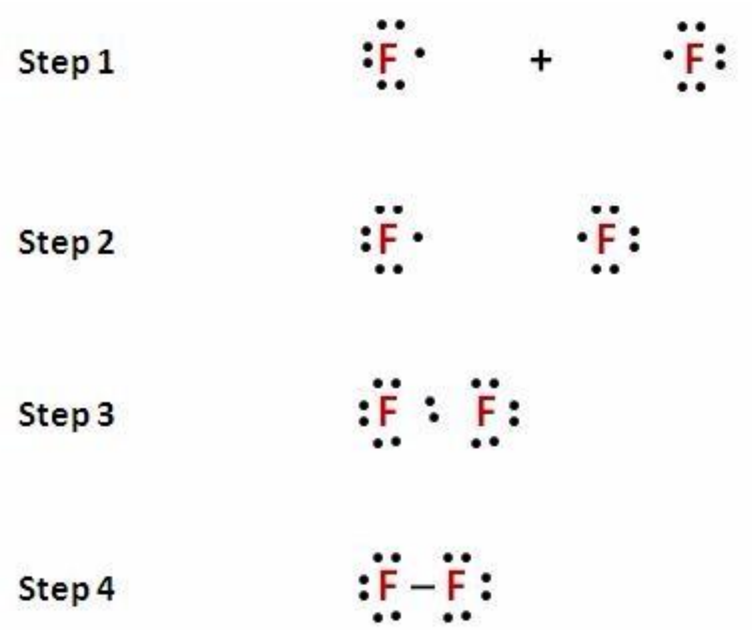
Two H atoms can come together and *share* each of their electrons to create a 'covalent bond.' The shared pair of electrons can be thought of as belonging to either atom, and thus each atom now has two electrons in its valence level, like He. The molecule that results is H_2, and it is the most abundant molecule in the universe.

The Lewis formalism used for the H_2 molecule is H:H or H—H. The former, known as a 'Lewis dot diagram,' indicates a pair of shared electrons between the atomic symbols, while the latter, known as a 'Lewis structure,' uses a dash to indicate the pair of shared electrons that form a covalent bond.



Lewis dot dragram for methane: Methane, with molecular formula CH_4, is shown. The electrons are color-coded to indicate which atoms they belonged to before the covalent bonds formed, with red representing hydrogen and blue representing carbon. Four covalent bonds are formed so that C has an octet of valence electrons, and each H has two valence electrons—one from the carbon atom and one from one of the hydrogen atoms.

Now consider the case of fluorine (F), which is found in group VII (or 17) of the periodic table. It therefore has 7 valence electrons and only needs 1 more in order to have an octet. One way that this can happen is if two F atoms make a bond, in which *each* atom provides one electron that can be shared between the two atoms. The resulting molecule that is formed is F_2, and its Lewis structure is F—F.



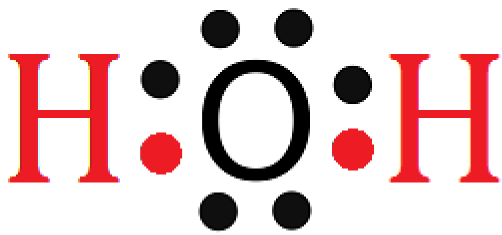
Achieving an octet of valence electrons: Two fluorine atoms are able to share an electron pair, which becomes a covalent bond. Notice that only the outer (valence level) electrons are involved, and that in each F atom, 6 valence electrons do not participate in bonding. These are 'lone pairs' of electrons.

After a bond has formed, each F atom has 6 electrons in its valence level which are not used to form a bond. These non-bonding valence electrons are called 'lone pairs' of electrons and should *always* be indicated in Lewis diagrams.

Procedure for Drawing Simple Lewis Structures

We have looked at how to determine Lewis structures for simple molecules. The procedure is as follows:

1. Write a structural diagram of the molecule to clearly show which atom is connected to which (although many possibilities exist, we usually pick the element with the most number of possible bonds to be the central atom).
2. Draw Lewis symbols of the individual atoms in the molecule.
3. Bring the atoms together in a way that places eight electrons around each atom (or two electrons for H, hydrogen) wherever possible.
4. Each pair of shared electrons is a covalent bond which can be represented by a dash.



Alternate view of lewis dot structure of water: This arrangement of shared electrons between O and H results in the oxygen atom having an octet of electrons, and each H atom having two valence electrons.

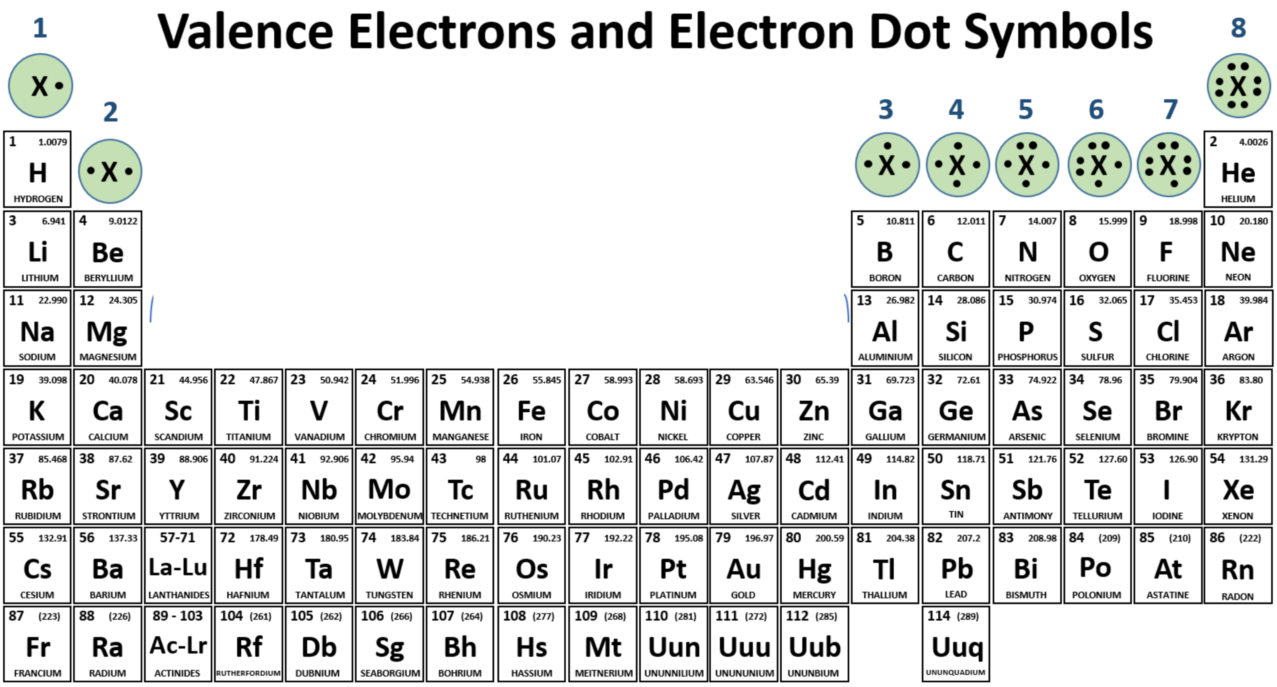
Multiple bonds can also form between elements when two or three pairs of electrons are shared to produce double or triple bonds, respectively. The Lewis structure for carbon dioxide, CO_2, is a good example of this.

Lewis structure of carbon dioxide: This figure explains the bonding in a CO_2 molecule. Each O atom starts out with six (red) electrons and C with four (black) electrons, and each bond behind an O atom and the C atom consists of two electrons from the O and two of the four electrons from the C.

In order to achieve an octet for all three atoms in CO_2, two pairs of electrons must be shared between the carbon and each oxygen. Since four electrons are involved in each bond, a double covalent bond is formed. You can see that this is how the octet rule is satisfied for all atoms in this case. When a double bond is formed, you still need to show all electrons, so double dashes between the atoms show that four electrons are shared.

$$:\ddot{O}=C=\ddot{O}:$$

Final Lewis structure for carbon dioxide: Covalent bonds are indicated as dashes and lone pairs of electrons are shown as pairs of dots. in carbon dioxide, each oxygen atom has two lone pairs of electrons remaining; the covalent bonds between the oxygen and carbon atoms each use two electrons from the oxygen atom and two from the carbon



9. NOMENCLATURE

Practice Writing Correct Formulas

To predict and write correct chemical formulas, the key fundamental steps that are required, are (1) knowing the charge states of the ions and (2) using basic math to help you determine how many cations and anions are needed to reach a zero charge state, (3) writing the chemical formulas with the cation first followed by the anion, and (4) writing the formula with the lowest ratio of Metals (cations) and Non-metals (anions) to create a net neutral compound.

Ionic bonding occurs between a metal (electron donor) and a non metal (electron acceptor) to form a Ionic compound that has a neutral net charge.

Covalent bonding occurs most commonly between two nonmetals, or between a nonmetal and a semimetal (metalloid). A covalent bond makes a MOLECULE!

So, say we want to write the correct chemical formula for a molecule that contains the metal Fe^{3+} , and the non-metal Cl^{-} . What is the correct ionic formula?

To begin this type of problem, I recommend drawing out a charge box or a charge table to help you keep track of the number of ions used, the charges of those ions, and the overall positive and negative charges on the molecule. Drawing out the electron dot symbols can also be helpful. Here is an example of a generic charge box

	CATION	ANION	
CHARGE of ION			
# ATOMS			Total Charge (on the Molecule)
TOTAL ION CHARGE			

Let's try it out for our example of Fe^{3+} and Cl^{-}. First, let's fill in what we know about each element and it's ionic state:

	Fe	Cl	
CHARGE of ION	+3	-1	
# ATOMS			Total Charge (on the Molecule)
TOTAL ION CHARGE			

So now we have our charge box set up with our known information. Now we need to figure out how many atoms of the cation and the anion are required to cancel out the overall positive and negative charge on the resulting molecule. To do this, it is often useful to use the cross-multiplication strategy, where you try using the charge number for the cations, as the number of atoms of anion required, and the charge number for the anion as the number of atoms of the cation required. Multiply each of the ion charges by the number of atoms to calculate the total ion charges of the ions present and then add these numbers together to find the total charge on the compound. This will usually get you to the stable ionic formula that has a net neutral charge of zero.

	Fe	Cl	
CHARGE of ION	+3	-1	
# ATOMS	1	3	Total Charge (on the Molecule)
TOTAL ION CHARGE	+3	-3	= 0

The # of atoms column then becomes the subscripts that you need to use to construct the correct ionic formula. In this case 1 atom of iron (Fe) with 3 atoms of chlorine (Cl) for a formula of $FeCl_3$.

What would the correct ionic formula be for aluminum sulfide? First, identify the two atoms involved (Aluminum and Sulfur) and start building your charge box with what you know from the periodic table. From the periodic table you can see that aluminum forms a cation with a +3 charge whereas sulfur forms an anion with a -2 charge state.

	Al	S	
CHARGE of ION	+3	-2	
# ATOMS	2	3	Total Charge (on the Molecule)
TOTAL ION CHARGE	+6	-6	= 0

For step 1: Add in the correct charge, in this case +3 for Al and -2 for S.

For Step 2: Use the cross multiply rule to predict how many atoms will be needed from each type and multiply through the total ion charge for both the cation and anion.

For Step 3: Add the products together to be sure that your compound is stable and the net charge on the formula is zero.

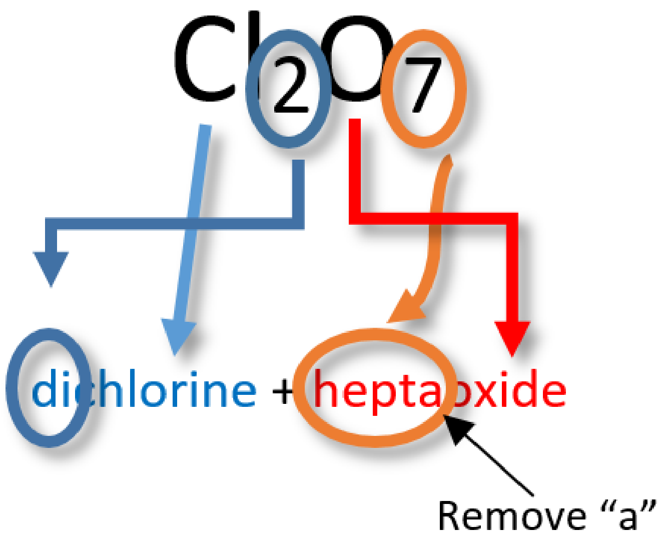
Step 4: Use the # Atoms value to create the subscripts for your chemical formula: Al_2S_3

Examples of Naming Covalent Molecules

Formula	Name
NO	nitrogen monoxide
N_2O	dinitrogen monoxide
S_2Cl_2	disulfur dichloride
Cl_2O_7	dichlorine heptoxide

Prefixes are used in the names of binary molecular compounds to identify the number of atoms of each element. The table below shows the prefixes up to ten.

Number of Atoms	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-



dichlorine heptoxide

TRICKY FAQ (*Frequently Asked Questions)*

WHAT IS A MOLECULE?

A molecule is defined as two or more atoms (of the same element or different elements) that are bound together by covalent bonds.

WHICH IS THE SMALLEST PARTICLE: ATOM OR MOLECULE?

An atom is the smallest particle of an element, that retains the properties of that element,

a molecule is the smallest particle of a compound, that retains the properties of that compound.

TYPES OF MOLECULES

Monoatomic Molecules A molecule may be monoatomic, which means that it consists of atoms of only one chemical element, as the gases: Hydrogen (H_2), Nitrogen (N_2), Oxygen (O_2), Fluorine (F_2), Chlorine (Cl_2), Iodine ((I_2) and Bromine (Br_2);

Polyatomic Molecules Molecules may also be diatomic or polyatomic, that means that they are a chemical compound composed of more than one element, as water (H_2O) which is diatomic or sugar ($C_6H_{12}O_6$) which is polyatomic.

WHAT IS THE DIFFERENCE BETWEEN A MOLECULE AND A COMPOUND?

Compounds are molecules when the atoms are linked by covalent bonds (they can be otherwise ionic compounds).

Molecules are compounds, when they are polyatomic molecules (formed by more than one element).

Not all molecules are compounds, because molecules can be monoatomic (formed by only one element).

A molecule is formed when two or more atoms of an element chemically join together with a covalent bond. If the types of atoms are different from each other, a compound is formed.

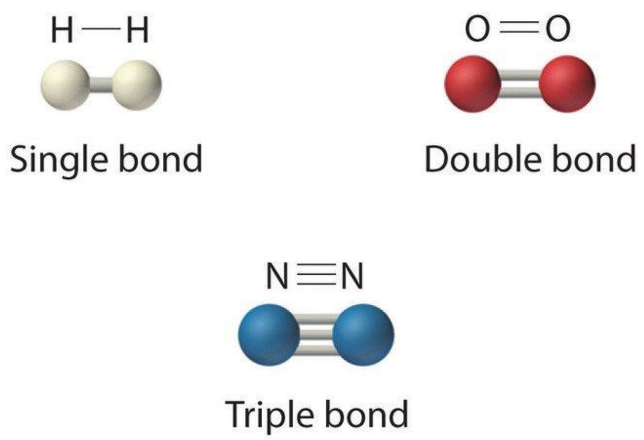
Not all molecules are compounds, since some molecules, such as oxygen gas (above image of molecule of-O_2) or ozone (O_3), consist only of one element or type of atom.

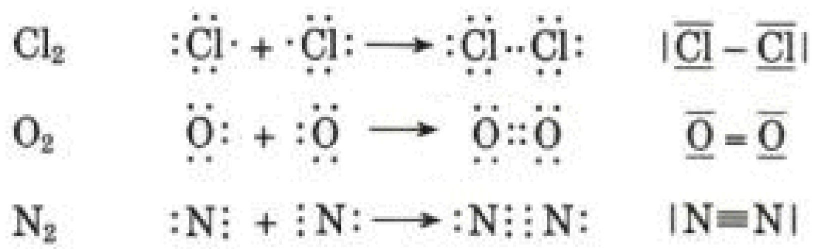
Water is a molecule because it is made from atoms that have been chemically combined by polar covalent bonds. But water is also a compound since the atoms that make water are not all the same: it is formed by one oxygen atom and two hydrogen atoms.

HOW ARE MOLECULES REPRESENTED?

Molecules can be represented with a **chemical formula** which shows the types of atoms in the molecule, and how many of each type of atom is present.

WHAT IS THE DIFFERENCE AMONG SINGLE, DOUBLE AND TRIPLE BONDS?





SINGLE BOND

It forms when an atom shares only one electron with another atom in a single covalent bond (denoted by single dash joining the atoms). The elements with single bonds are halogens and hydrogen.

DOUBLE BOND

When two atoms share two electron pairs between each other (to reach the octect), they are said to be bonded by double covalent bond, denoted by double dash joining the atoms. E.g.: O_2, CO_2 etc.

TRIPLE BOND

When two atoms share three electron pairs between each other, they are said to be bonded by triple covalent bond. Triple bond is denoted by three dashes joining the atoms.

E.g.: N_2 that belongs to the group V and needs 3 electrons to ‘feel like’ a noble gas.

Most important types of compounds

Compounds can be binary if formed by only two elements, or ternary if they contain three elements, usually one metal (or H), one nonmetal and oxigen.

Legend

M metal

NM nonmetal

BINARY COMPOUNDS

OXIDES **M/NM + O^{-2}** Examples:

An element + oxygen

Oxygen charge -2 Metal + oxygen CaO calcium oxide

Nonmetal + oxygen CO_2 carbon dioxide

HYDRIDES **M + H^{-1}**

Metal + hydrogen

Hydrogen is more electronegative so it takes charge -1 and goes on the right

NaH sodium hydride

CaH_2 calcium dihydride

BINARY ACIDS **H^{+1}+ NM**

Hydrogen + halogen

Since H is less electronegative it goes on the left and it has positive charge +1

HCl hydrogen chloride or hydrochloric acid

HBr hydrogen bromide

BINARY SALTS **M +NM** **<u>name ending in -ide</u>**

A metal replaces the hydrogen of the binary acid.

NaCl sodium chloride

$CaBr_2$ calcium bromide

TERNARY COMPOUNDS

HYDROXIDES **M $(OH)^-$** **they are <u>bases</u> (opposite of acids in the pH scale)**

A metal + the polyatomic group $(OH)^-$

NaOH sodium hydroxide

$Ca(OH)_2$ calcium hydroxide

TERNARY ACIDS H NM O

or **oxygenated acids**

Only some exemple:

HNO_3 nitric acid

H_2SO_4 solforic acid

H_2CO_3 carbonic acid

TERNARY SALTS M NM O **name ending in -ate**

or **oxygenated salts**

Only some exemple:

$NaNO_3$ sodium nitrate

$CuSO_4$ copper sulftate

$CaCO_3$ calcium carbonate

REMEMBER THE RULES TO BUILD A COMPOUND

1. CHECK THE ELECRONEGATIVITY (in the periodic table, usually above the symbol)

2. WRITE ON THE LEFT THE ELEMENT LESS ELECTRONEGATIVE WITH CHARGE **+**

(choose it in the periodic table, usually below the symbol; when there are more charges it means that more than one compound can be created, so it will be the exercise to specify which is the right charge to make the compound)

3. WRITE ON THE RIGHT THE ELEMENT MORE ELECTRONEGATIVE WITH CHARGE **–**

4. WITH THE CRISS CROSS RULE, EXCHENGE THE CHARGES IN ATOM NUMBERS (in the subscripts)

5. SEMPLIFY NUMBERS (in case there are multiples)

N. B.

Nonmetal gases are molecules (covalent bonds) so they must be written with the subscript 2 !

Metals or solid nonmetal (ex. S) just the symbol!!

CHEMICAL NOMENCLATURE

The nomenclature of inorganic compounds is based on the oxidation states of elements.

The oxidation state is the hypothetical charge that an atom would have if all bonds to atoms of different elements were 100% ionic. Oxidation states can be positive, negative, or zero.

It should be remembered that the oxidation state of an atom does not represent the "real" charge on that atom.

Oxides

Naming oxides

Oxides are binary compounds with oxygen where the oxidation state of oxygen is O-II.

Oxides of metals are named as if they were salts.

The name is composed of the cation name and the word oxide.

E.g. Na_2O sodium oxide

CaO calcium oxide

SnO tin (II) oxide or stannous oxide

SnO_2 tin (IV) oxide or stannic oxide

Cu_2O copper(I) oxide or cuprous oxide

CuO copper (II) oxide or cupric oxide

Oxides of non-metals are named by stating the name of the element first, followed by the word oxide. Numeral prefixes are used where necessary:

E.g. SO_2 sulphur dioxide

SO_3 sulphur trioxide

NO nitrogen oxide or nitrogen monoxide

N_2O_5 dinitrogen pentoxide

Cl_2O dichlorine oxide

Cl_2O_5 dichlorine pentoxide

Cl_2O_7 dichlorine heptoxide

P_2O_3 diphosphorus trioxide

P_2O_5 diphosphorus pentoxide Some elements form only one type of oxide.

In these cases, the use of numerical prefixes is not necessary:

E.g. Al_2O_3 aluminum oxide SiO_2 silicon oxide

Hydroxides

Hydroxides are compounds which have an OH^- group in their molecules.

Since the oxidation state of oxygen is –II and the oxidation state of hydrogen is I, the formal oxidation state of the hydroxide group is –I, (OH)-I.

In the nomenclature of hydroxides the metal ion is named first, followed by the word hydroxide.

If the oxidation state of the metal is > I, we have to put the OH group into brackets.

E.g. sodium hydroxide NaI (OH)-I NaOH

calcium hydroxide II I Ca OH – 2 ( ) $Ca(OH)_2$, not $CaOH_2$

aluminum hydroxide III I Al OH – 3 ( ) $Al(OH)_3$, not $AlOH_3$

Binary acids

Binary acids are compounds of hydrogen with non-metal.

The oxidation state of hydrogen in acids is always +I.

These acids are actually aqueous solutions of gaseous binary compounds that have the same formula.

The most common binary acids are summarised in the following table:

Formula Name of Pure Compound Name of Aqueous Solution

HF hydrogen fluoride hydrofluoric acid

HCl hydrogen chloride hydrochloric acid

HBr hydrogen bromide hydrobromic acid

HI hydrogen iodide hydroiodic acid

H2S hydrogen sulphide sulphane hydrosulphuric acid

Salts

The name of a salt consists of the name of its cation followed by that of its anion.

An anion is always formed by splitting one or more hydrogen atoms from an acid. S

ome hydrogen atoms may stay fixed in the anion part, which is expressed by the prefix hydrogen- and, if necessary, a numerical prefix.

HCl H+ + Cl– chloride

Salts of binary acids

In the case of salts derived from binary acids the name of the anion consists of the stem of the central atom plus the suffix – ide.

Binary acid

Anion Formula

Name Formula Name

HF hydrofluoric acid F-I fluoride

HCl hydrochloric acid Cl-I chloride

HBr hydrobromic acid Br-I bromide

HI hydroiodic acid I -I iodide S-II sulphide

H2S hydrosulphuric acid (HS)-I hydrogensulphide

E.g. SnI4 IV I Sn I – 4 tin (IV) iodide or stannic iodide (NH4)2S I II NH S – 4 2 ( ) ammonium sulphide Ca(HS)2 II I Ca HS – 2 ( ) calcium hydrogensulphide

FeCl3 III I Fe Cl – 3 iron (III) chloride

Deriving formulas: the rules for deriving formulas for salts are similar to those used for the nomenclature of metal oxides.

Complex anions that consist of more than one atom must be enclosed in brackets if the numerical index is greater than one.

E.g. magnesium hydrogensulphide: $Mg(HS)_2$, not $MgHS_2$

10. CHEMICAL REACTIONS

Some types of reactions

NEUTRALIZATION REACTION

when an acid and a base react to form water and a salt

it involves the combination of H^+ ions and OH^- ions to generate water

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

A powerful acid + a powerful base become just drinkable water and salt

$$HCl + NaHCO_3 \longrightarrow NaCl + H_2O + CO_2$$

this very powerful acid is in our stomach to start digestion

If we take some baking soda (sodium bicarbonate) the result is water, salt and some carbon dioxide that makes us burp ;)

COMBINATION REACTION

is a reaction where two compounds (reactants) combine to form a single compound (product).

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

This is the reaction that occurs in sparkling water

Back to Lab we will do the combustion of magnesium (used for sparkler = handheld firework)

$$Mg + O_2 \rightarrow MgO$$

Then the combination with water that create the hydroxide, that is a base so it turns blu the pH indicator (while it turns red with acids and green with neutral substances)

$$MgO + H_2O \longrightarrow Mg(OH)_2$$

EXERCISES ON CHEMICAL EQUATIONS

1. Complete the equations (of synthesis reactions) with the correct compound and then balance them

$Si + O_2 \rightarrow$

$Zn + O_2 \rightarrow$

$Al + O_2 \rightarrow$

$Al + H_2 \rightarrow$

$Al + S \rightarrow$

$Al + Cl_2 \rightarrow$

$K + H_2 \rightarrow$

$Ca + H_2 \rightarrow$

$Cl_2 + H_2 \rightarrow$

2. Write the equations with elements in the reactants and the compound as product and then balance them

fluorine + hydrogen

.... + ... → ....

sodium + oxigen

.... + ... → ....

calcium + clorine

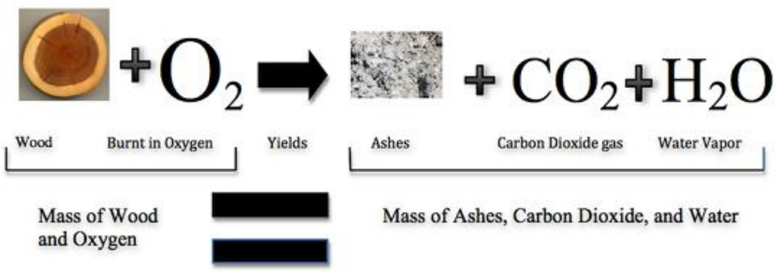
.... + ... → ....

11. PONDERAL LAWS

Law 1, by Lavoisier: The Conservation of Mass

The law of conservation of mass states that, in a reaction, the total mass of reactants is the same as the total mass of products.

The law of conservation of mass was formulated by Lavoisier as a result of his combustion experiment. He said "nothing is lost, nothing is created, everything is transformed".

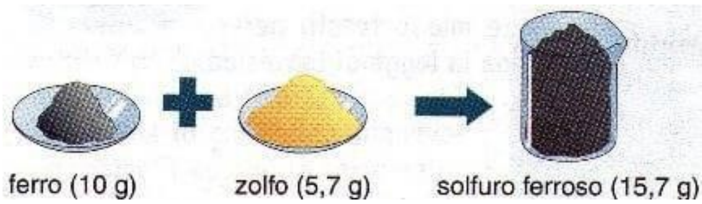


Law 2, by Proust: Definite Proportions

Joseph Proust (1754-1826) formulated the *law of definite proportions*.

This law states that the masses of the elements that form a compound combine always in the same proportions.

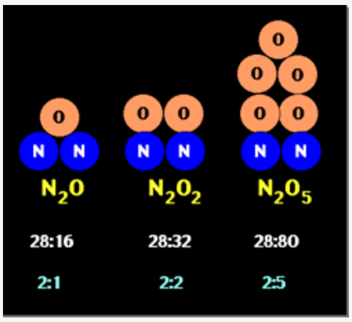
$$Fe + S \rightarrow FeS$$



Fe : S= 1 : 0,57

Law 3, by Dalton: Multiple Proportions

Two elements can react to form more than one compound. The law of multiple proportions states that when two elements form two or more compounds between them, the ratio of the masses of the second element in each compound can be expressed in the form of small whole numbers. For example, Nitrogen forms a very large number of oxides, 3 of which are shown in the picture. The ratio among the atoms of oxygen in the compounds is 1:2:5 (N is fixed at 2)



Dalton's Atomic Theory

The modern atomic theory was proposed about 1803 by the English chemist John Dalton, with six postulates:

1. All matter consists of indivisible particles called atoms.
2. Atoms of the same element are similar in shape and mass, but differ from the atoms of other elements.
3. Atoms cannot be created or destroyed. (1 law)
4. Atoms of different elements may combine with each other in a fixed, simple, whole number ratios to form compound atoms. (2 law)
5. Atoms of same element can combine in more than one ratio to form two or more compounds. (3 law)
6. The atom is the smallest unit of matter that can take part in a chemical reaction.

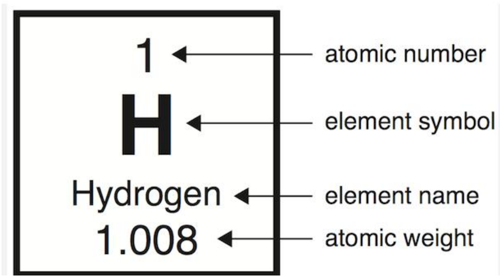
12. THE MOLE

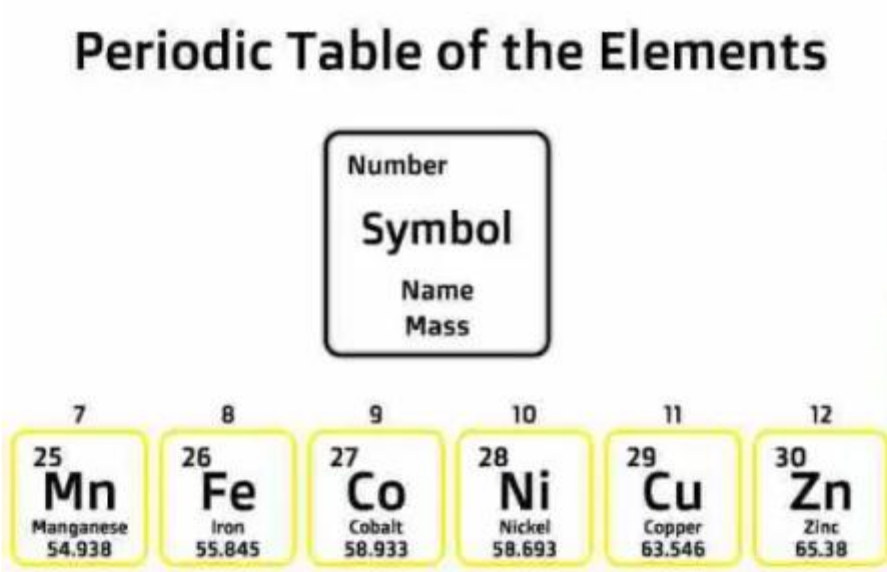
13. THE MOLE (symbol: ***mol***)

is the unit of measurement for amount of substance in the International system.

TO UNDERSTAND THE MOLE ……

WE MUST KNOW WHAT THE ATOMIC MASS IS, AND WHERE TO FIND IT, IN THE PERIODIC TABLE





IT REPRESENTS A DEFINED NUMBER OF PARTICLES, THE

AVOGRADO'S NUMBER !

= 602.000.000.000.000.000.000.000

$= 6.02 \times 10^{23}$

That can be read as:

a hundred sextillion

OR

a hundred thousand trillion

Number of zeros	U.S. & scientific community	Other countries
3	thousand	thousand
6	million	million
9	billion	1000 million (1 milliard)
12	trillion	billion
15	quadrillion	1000 billion
18	quintillion	trillion
21	sextillion	1000 trillion
24	septillion	quadrillion
27	octillion	1000 quadrillion
30	nonillion	quintillion
33	decillion	1000 quintillion
36	undecillion	sextillion
39	duodecillion	1000 sextillion
42	tredecillion	septillion
45	quattuordecillion	1000 septillion
48	quindecillion	octillion
51	sexdecillion	1000 octillion
54	septendecillion	nonillion
57	octodecillion	1000 nonillion
60	novemdecillion	decillion
63	vigintillion	1000 decillion
66 - 120		undecillion - vigintillion
303	centillion	
600		centillion

As we can measure with **PAIRS** like for shoes and we can have different weights….

Flip flops bunny booties sneakers ballerinas ski boots

or we can use **DOZEN** like for eggs, and they can be from…

hummingbird   ostrich   dinosaur

oooooooooooo   oooooooooooo   OOOOOOOOOOOOO



Chemists measure the amount of a substance in a unit called **MOLE**.

18g of water (H_2O)   58,5 g of salt (NaCl)   270 of sucrose ($C_{12}H_{22}O_{11}$)



It could be compared to a package of six candies …..if it didn’t have 23 zeroes after 😊



600.000.000.000.000.000.000.000

of ATOMS, MOLECULES, IONIC COMPOUNDS …

This is a convenient way of counting atoms and comparing masses of different elements or compounds.

It is a number but it’s also a ”bridge” between particles and mass! (Very useful in Lab!!)

It allows chemists to make predictions about the masses of different substances that are involved in reactions.

One mole is the **Avogadro number of particles** (atoms, molecules, ions or electrons) **in a substance**.

The Avogadro's number

One mole of atoms contains 6×10^{23} atoms, no matter what element it is. This is a very large number: it is 6 with 23 zeros after it. It is known as the **Avogadro number**.

This number is used in chemistry because if you could count out this many carbon atoms, the total mass of carbon you would have is 12 g. On the other hand, weighing out 12 g of carbon allows you to know how many atoms you have.

Moles of elements

One mole of any element has a mass in grams that is equal to its **atomic mass.**

One mole of iron has a mass of **55,85 g** because an atom of iron has an atomic mass =55,85. One mole of carbon atoms has a mass of exactly 12 g because the carbon mass is 12.

Moles of compounds

A mole of a molecular compound contains 6×10^{23} molecules.

It has a **mass that is equal to its** relative formula mass. So a mole of water (H_2O) has a mass of 18 g (2xH + 16xO). A mole of carbon dioxide (CO_2) has a mass of 44 g (12 + 16x2). This also works for ionic compounds, so a mole of sodium chloride (NaCl) has a mass of 58.5 g.

This approach can also be used for elements that are made from molecules. For example, oxygen gas O_2 is **diatomic** (each molecule contains two atoms) so its relative formula mass is 32. One mole of oxygen molecules would therefore have a mass of 32 g. One mole of oxygen **atoms** (if you could ever isolate them) would have a mass of 16 g.

the **MOLE** is

an AVOGADRO’S NUMBER of particles

6.02×10^{23}

a “bridge” between

PARTICLES and **MASS** (in grams)

COEFFICIENT IN CHEMICAL REACTIONS

$4Al + 3O_2 \rightarrow 2Al_2O_3$

Lab equipment