Contents

INTRODUCTION

Chemistry is a natural science dealing with statements about different materials, their structure and their material changes in reactions with other materials.

Note: Chemistry deals with the materials and the material changes in chemical processes.

In contrast: Physics deals with the states and the state changes of the materials without changing their composition.

Definition of substance and material properties

Materials exist in the form of objects or substances. These materials consist of **mass-carrying particles** occupying a space (**volume**) and they have a **weight**.

Note: Different substances differ at least in one of their properties.

Some examples of material properties:

- Colour
- Melting or boiling point
- Density
- Conductivity (of heat and electricity)
- Solubility
- Hardness, strength, elasticity
- State of matter (solid, liquid, gaseous) etc.

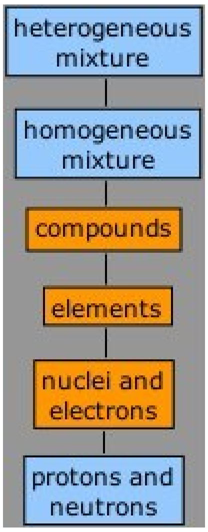
Pure substances and mixtures

Note: Homogeneous materials have the same composition and the same properties at all points. A heterogeneous substance is composed of different homogeneous material, and the characteristics may vary from point to point within the material.

Substances which may be broken down further by physical methods are called mixtures. The individual mixture components are the pure substances.

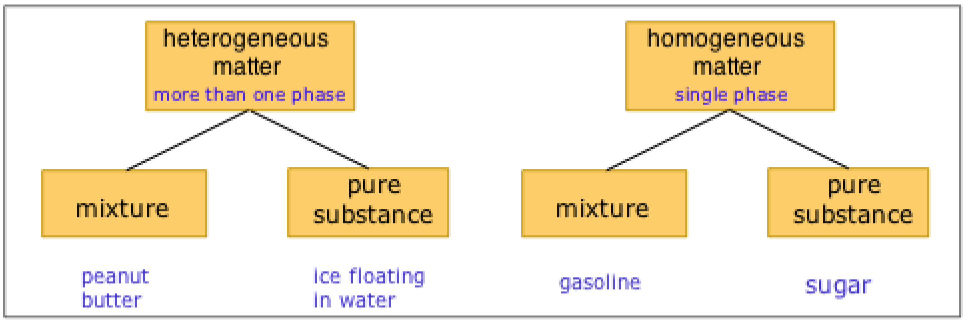
Pure substances that are made up of several substances can be separated only by chemical methods.

One useful way of organizing our understanding of matter is to think of a hierarchy that extends down from the most general and complex to the simplest and most fundamental. The orange-coloured boxes represent the central realm of chemistry, which deals ultimately with specific chemical substances, but in practice, chemical science extends both above and below this region.

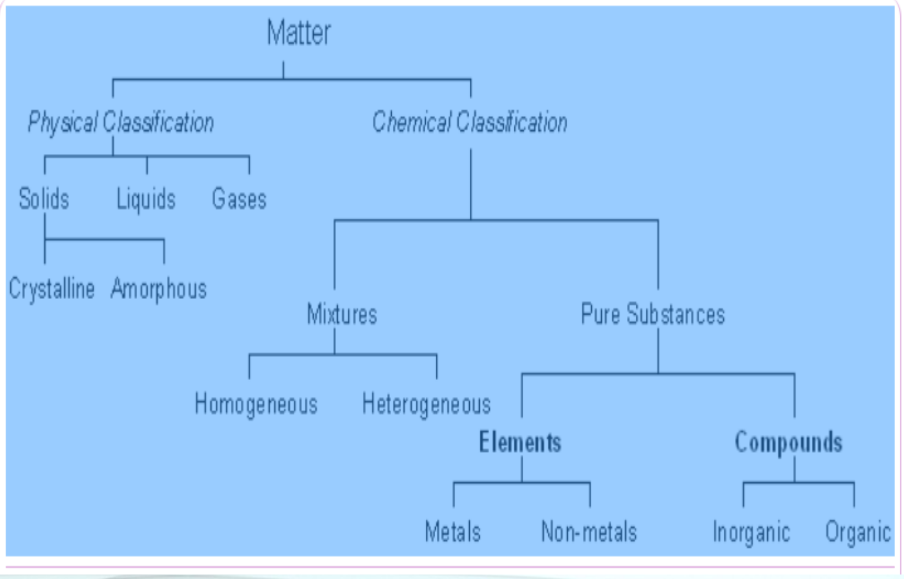


Alternatively, it is sometimes more useful to split our classification into two dimensions:

- Homogeneous *vs.* heterogeneous
- Pure substance *vs.* mixture



Two major categories of classification of matter are **physical classification** and **chemical classification** depicts the classification of matter into the two major categories, and the sub-classification therein.



To understand all the above and the following issues in more detail, it is necessary to be familiar with some fundamental concepts that form the basis of chemistry.

Atomic Model—Atomic Theory

Atoms are everywhere! The atomic model has taken years and years to build up. Scientists have constructed numerous models of the atom over the years and finally they realized that atoms are composed mainly of empty space. Awesome isn't it?

In the fifth century (460 – 371 before the Common Era) Democritus (Aristotle's "competition") thought about the composition and structure of matter, but at the time his model of the atom was not accepted. Today we know he was on the right track.

He said that all things are made up of tiny particles called atoms (atomos, "indivisible").

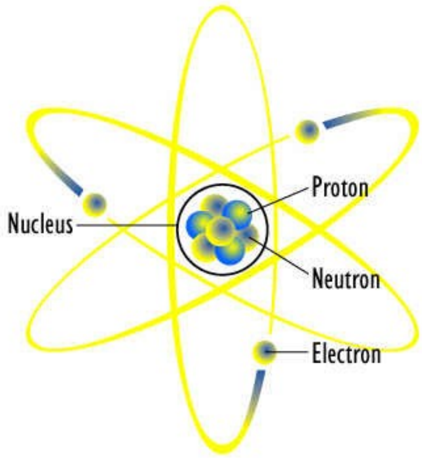
All atoms are made up of the same components but each atom had a different size, shape and number of “ingredients”.

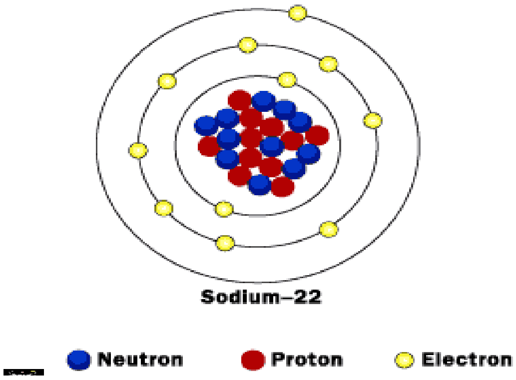
He also believed that atoms could not be broken down.

Most of what he said was correct except for his statement about atoms not being able to be broken down. Less than 100 years later his theory would be overshadowed by that of Aristotle.

Bohr was one of the first scientists to propose the model of an atom with a nucleus and an electron in a fixed orbit. Each electron has a fixed amount of energy. This energy keeps the electron in orbit. Bohr had worked under Rutherford and had taken parts of his observations to formulate his atomic model

Neils Bohr's atomic model





The atom is a basic unit of matter that 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-1, which is the only stable nuclide with no neutrons). The electrons of an atom are bound to the nucleus by the electromagnetic force. Likewise, a group of atoms can remain bound to each other, forming a molecule. An atom containing an equal number of protons and electrons is electrically neutral. If not, it has either a positive charge if there are fewer electrons (electron deficiency), or a negative charge if there are more electrons (electron excess). A positively or negatively charged atom is known as an i**on**. An atom is classified according to the number of protons and neutrons in its nucleus: the number of protons determines the chemical element, and the number of neutrons determines the isotope of the element.

1. ATOMIC STRUCTURE

Matter is made up of atoms. It has proven to be very convenient to work with the atoms as building units of matter, because the properties of atoms correspond very well with the properties of matter. The general word matter is rarely used in chemistry, the chemist prefers to speak of compounds, or even better of substances.

A substance is composed of atoms. But you cannot say that atoms are the smallest particles of a substance, because atoms themselves are not compact and uniform, but they are in turn composed of smaller particles known as elementary particles.

For the needs of chemists – and usually doctors too – it is sufficient to deal with three elementary particles:

- Protons
- Neutrons
- Electrons

These three elementary particles can be characterized by their mass and electric charge.

1.1 The mass of elementary particles

Protons and neutrons have approximately the same mass. The electron in comparison to the proton and neutron has a negligibly small mass.

If the mass of elementary particles were indicated in the unit grams, then you would have to handle inconveniently small numbers which you could hardly remember. For example the proton would then have a mass of $1.6725 \bullet 10^{-24}$ g, which is the same as 0.000 000 000 000 000 000 000 001 6275 g. This is the reason why we use a smaller unit at the atomic level, the so-called atomic mass unit, abbreviated as **amu** or simply just **u** for atomic mass unit. The definition of this unit of mass is not discussed at full length here. You just should remember:

The "unified atomic mass unit" u is defined as:

1 u = $\mathrm{m_u}$ = $\mathrm{m(^{12}C)/12}$

Protons and neutrons have roughly the mass of 1 amu. The electron has roughly the mass of $5 \bullet 10^{-4}$ amu.

Compared to each other, the masses of the three elementary particles are then:

Proton	neutron	electron
1 :	1 :	$5 * 10^{-4}$

If you want to know the masses of the elementary particles exactly, they are:

Proton:	1.007276 amu
Neutron:	1.008665 amu
Electron:	0.0005486 amu

Amount of a substance – mole concept

The **mole** is a unit of measurement used in chemistry to express amounts of a chemical substance. It is defined as the amount of a substance that contains as many elementary entities (e.g., atoms, molecules, ions, electrons) as there are atoms in 12 grams of pure carbon $-12(^{12}C)$,

a) The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12; its symbol is "mol".
b) When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The definition of the mole also determines the value of the universal constant that relates the number of entities to amount of substance for any sample. This constant is called the **Avogadro constant**, which is equal to 6.02214129(27) $\bullet 10^{23}$ entities per mole. As a symbol $\mathrm{N_A}$ or L are commonly used.
The **molecular mass** M of a substance corresponds to the numerical value of the relative atomic mass $\mathrm{A_r}$ or relative molecular mass $\mathrm{M_r}$ of the substance together with the unit of g / mol.

Example:

the relative molar Mass of water $\mathrm{H_2O}$ and $\mathrm{CO_2}$:

$\mathrm{M_r}$ $\mathrm{(H_2O)}$ = 2 • $\mathrm{A_r(H)}$ + 1 • $\mathrm{A_r(O)}$ = 2 • 1g + 1 • 16g = 2g + 16g = 18 g/mol

$\mathrm{M_r}$ $\mathrm{(CO_2)}$ = 1 • $\mathrm{A_r(C)}$ + 2 • $\mathrm{A_r(O)}$ = 1 • 12g + 2 • 16g = 12g + 32g = 44 g/mol

The **standard molar volume**, i.e. the volume of gases at standard conditions (T = 273.15 K and p = 1.01325 bar) for all gases equals 22.4 L / mol. Symbol: $\mathrm{V_m}$

The same amounts (moles) of different gases at the same pressure and temperature have identical volume. V = n • $\mathrm{V_m}$

n: number of moles

Example:

What is the volume of 2 moles of Hydrogen?
Relative atomic mass of hydrogen (6.02214129(27) • 10^{23} H-atoms) = 1 g
Hydrogen exists as H_2 molecules
→ mol-weight of H_2 = 2 • 1g → mol weight H_2 = 2 g/mol
→ 2 moles Hydrogen 2g H_2H_2 → H_2H_2

1.2 The elementary charge

The three elementary particles Proton, Neutron and Electron differ in their electrical charge:
The proton has a positive charge.
The neutron is electrically neutral.
The electron has a negative charge.

Protons and electrons have one elementary electric charge. The term "elementary electric charge" means that all charges must be experimentally measurable integer multiples of this amount of elementary electric charge. In other words, experimentally you cannot find any smaller amount of charge other than the electron charge.
Thus the proton carries the charge +1
The neutron carries the charge 0
The electron carries the charge -1
For clarity the data of the three particles are shown in Table 1.

Elementary Particle	Mass (rounded down)	Charge
Proton	1 amu	+1
Neutron	1 amu	0
Electron	$5*10^{-4}$ amu	-1

Table 1: mass and charge of elementary particles

1.3 Distribution / Arrangement of elementary particles in the Atom

How are the elementary particles, protons, neutrons and electrons distributed in the atom? According to the most widely accepted **atomic model, that of Niels Bohr,** the atom is composed of a small nucleus containing protons and neutrons in the centre. The electrons around the nucleus form a wide loose electron shell.

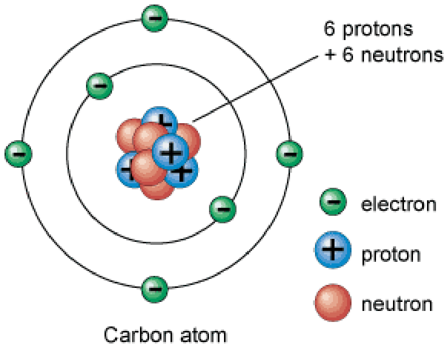
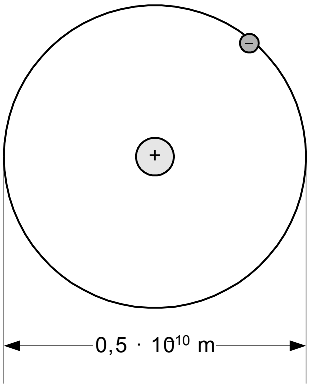


Figure: Bohr model of the Carbon atom



Size of the hydrogen atom

If you look at the charge and mass of elementary particles, it can be concluded for the nucleus and electron shell:

The nucleus must be positively charged, because in addition to the electrically neutral neutrons, it contains the positively charged protons.

The electron shell has to be negatively charged, because it contains the negatively charged electrons. The nucleus contains practically the entire mass of the atom, because both neutrons and protons are heavier by a factor of about $5 * 10^4$ compared to an electron. For example an atom, that is composed of 20 protons, 20 neutrons and 20 electrons, has a nucleus with mass 40 amu and an electron shell with the mass 0.01 amu. In this case the mass of the atomic shell has only a share of 0.025% of the atomic mass.

The nucleus occupies only a tiny fraction of the atomic volume. The neutrons and protons in the nucleus are very tightly packed, while the electrons form a very loose electron shell.

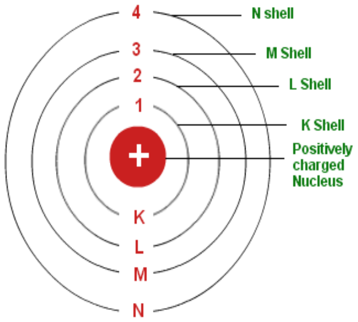
1.4 Elements and Compounds

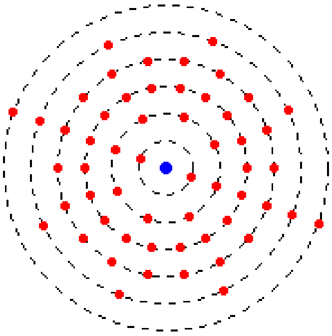
Note: Elements (basic or elementary substances) are substances that are not further separable by chemical methods.

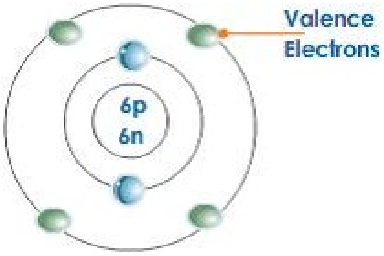
Compounds are substances which are composed of elements.
The smallest assemblies of chemical compounds are called molecules. Molecules are compounds of at least two identical or different atoms.
The chemical formula of a compound gives information about which substance it is, but also the elements which are used to build up the substance and how many atoms of each element are included in a molecule of the compound.
Creating a compound is called synthesis.
The dismantling of a compound into its elements is called analysis or decomposition.

2. ATOMIC NUCLEUS

The nucleus is not treated in detail, because for chemistry, the electron shell is the most important part of the atom. The **outermost** shell, called **valence shell** is especially significantly involved in chemical interactions and compound formation. The innermost shell, called the K-shell can hold only two electrons, whereas the outermost shell (called L, M, N, O, P or Q) (valence shell) is most stable and energetically significantly saturated when holding its maximum 8 **valence electrons**.







Shell number n and Shell ID	Number of possible electrons on shell n: $2n^2$	
$n = 1$: K-shell	$2n^2 = 2 \bullet 1^2 = 2 \bullet 1 = 2$	**These figures are maximum numbers (fully occupied shell). But also partially filled inner shells can be present!**
$n = 2$: L-shell	$2n^2 = 2 \bullet 2^2 = 2 \bullet 4 = 8$	
$n = 3$: M-shell	$2n^2 = 2 \bullet 3^2 = 2 \bullet 9 = 18$	
$n = 4$: N-shell	$2n^2 = 2 \bullet 4^2 = 2 \bullet 16 = 32$	
$n = 5$: O-shell	$2n^2 = 2 \bullet 5^2 = 2 \bullet 25 = 50$	
$n = 6$: P-shell	$2n^2 = 2 \bullet 6^2 = 2 \bullet 36 = 72$	
$n = 7$: Q-shell	$2n^2 = 2 \bullet 7^2 = 2 \bullet 49 = 98$	

Note: The number of electrons in the outer shell is crucial for the chemical behaviour of the materials. These outer shells (valence shells) can be occupied with a maximum of 2 electrons in the K shell and a maximum of 8 electrons for the other shells.

In case, the outer shell is fully occupied by $2n^2$ or filled with 8 electrons, then a very stable behaviour of the situation is observed (see noble gas configuration – noble gases [monoatomic gases with very low chemical reactivity]).

The nucleus itself and all the issues surrounding it are part of nuclear physics. Here we only discuss a few important concepts.

2.1 Proton number

The nucleus is always positively charged. The number of positive charges in the core is determined by the number of protons. We call this number the **atomic number** or **reference number** of the atom.

2.2 Element concept

By using the atomic number, each element can be clearly defined: An **element** contains only atoms with the same atomic number, i.e. with the same number of protons in their nuclei.

2.3 Atomic number

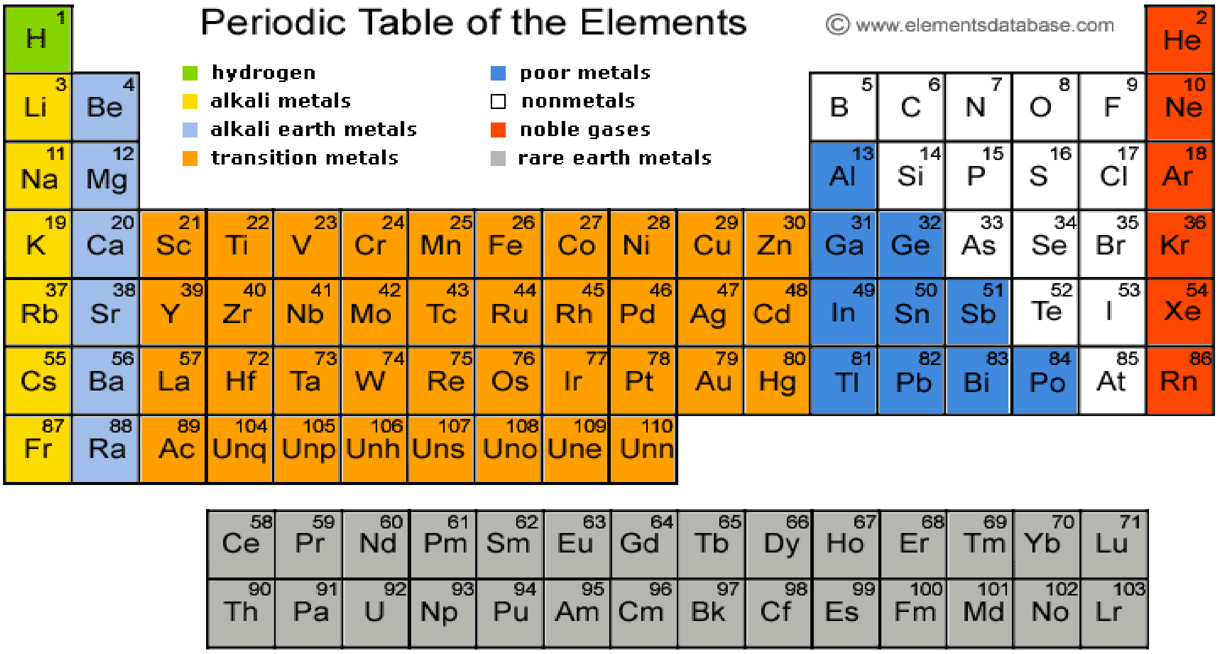
The number of protons is also known as the atomic number. The atomic number can serve as a label for an element. For example the atomic number 1 is characteristic for the element hydrogen, the atomic number 6 for the element carbon and so on. Number of protons = atomic number = reference number. You can arrange the elements in this order.

Periodic Table of the Elements

All the elements are arranged in the Periodic Table of the Elements

In the Periodic Table of Elements, all elements with the same number of shells are combined in horizontal rows (= period). Elements with the same number of outer electrons are grouped in a vertical row (= group). The position of the elements is determined by the reference number (= atomic number).

Exceptional case: Only hydrogen – a typical non-metal element – has no chemical similarity with the elements below it (all metals). This is due to the unique situation with a maximum of 2 electrons at the outermost (valence) shell.



Periodic Table of the Elements

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🟩 hydrogen
🟨 alkali metals
🟦 alkali earth metals
🟧 transition metals
🟦 poor metals
☐ nonmetals
🟥 noble gases
⬜ rare earth metals

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn								
			58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
			90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

2.4 Mass number

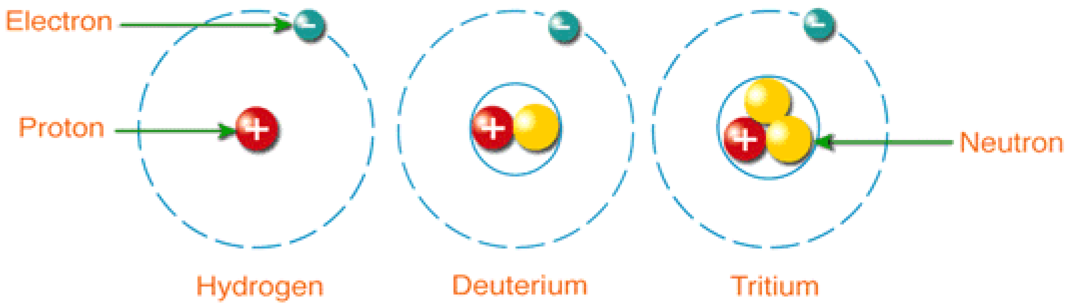
Another key code number for an atom is the mass number. This is the sum of protons and neutrons in the nuclei.

Number of protons + neutrons = mass number
To avoid misunderstandings, it should be emphasized that the mass number does not indicate the real mass of the nucleus, but only the number of mass particles (protons and neutrons). The mass number therefore always is an integer number, however, since both protons and neutrons have approximately the mass of 1 amu the core mass, indicated in amu is very similar to the mass number.

To consider the masses of atoms measured in grams, for example, would be to deal with inconveniently small numbers. Thus the real mass of the atoms is not discussed further. Rather, the mass of an atom is compared with that of an atom of carbon-12. The relative atomic mass of carbon-12 is taken to be 12. Relative masses have no units because they have been cancelled in their calculation.

2.5 Isotopes

As discussed in the previous text, an element is characterized by a certain number of protons in the core. In contrast, atoms of the same element may have different number of neutrons in the nucleus. All atoms of an element have the same atomic number, but they can have different mass numbers.
We call such atoms of an element having the same number of protons but a different number of neutrons, **isotopes**.
Isotopes are atoms with the same atomic number but different mass numbers.
This aspect is clearly represented in the following diagram for the three isotopes of hydrogen:



For the element chlorine with atomic number 17, two isotopes exist, and they have the mass numbers 35 and 37. The numbers of neutrons for those chlorine isotopes are 18 and 20 respectively.

In calculating the relative atomic mass of chlorine, the relative mass and proportion of each is taken into account. For example, naturally occurring chlorine consists of atoms of *relative isotopic masses* 35 (75%) and 37 (25%). Its relative atomic mass is 35.5.
A_t = (75/100 x 35) + (25/100 x 37) = 35.5

That’s the reason for odd relative atom mass numbers in the Periodic Table of the Elements.
A **pure element** or anisotopic element is a chemical element with only one isotope. All these atoms contain of the same number of protons and neutrons in the nucleus. All other elements are **mixed isotopes elements**.

3. CHEMICAL BONDING

3.1 Covalent Bonding = Atomic Bonding

Note: **When** molecules are formed, the atoms involved seek the lowest energy state. This is the electron configuration of the so called noble gases, which show fully occupied outer shell with 8 electrons in their valence shell.

In order that a combination of two non-metal atoms can take place, they must first get very close together. If they get so close that the atomic shells interpenetrate each other under the influence of the atomic nucleus, then the merger of the two atoms can proceed. The approach described represents the overlapping of both electron shells, which can be thought of as an "electron cloud". The overlapping of two hydrogen atoms is shown as an example below.
Atomic bonds are only possible with bonds of non-metals. In this type of bonding, the atoms share common electron pairs so that each atom achieves the very low-energy noble gas state.

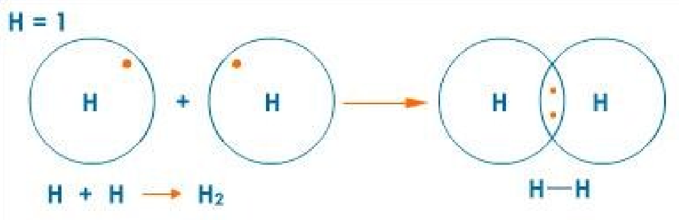
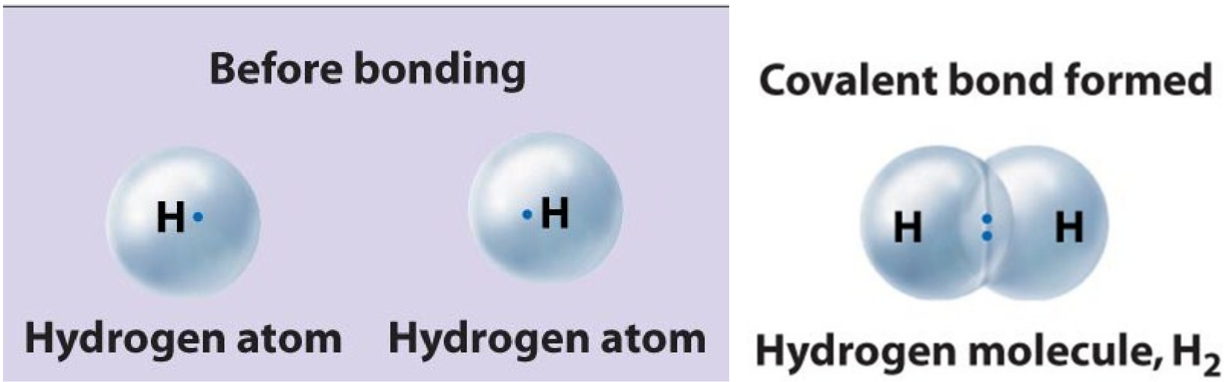
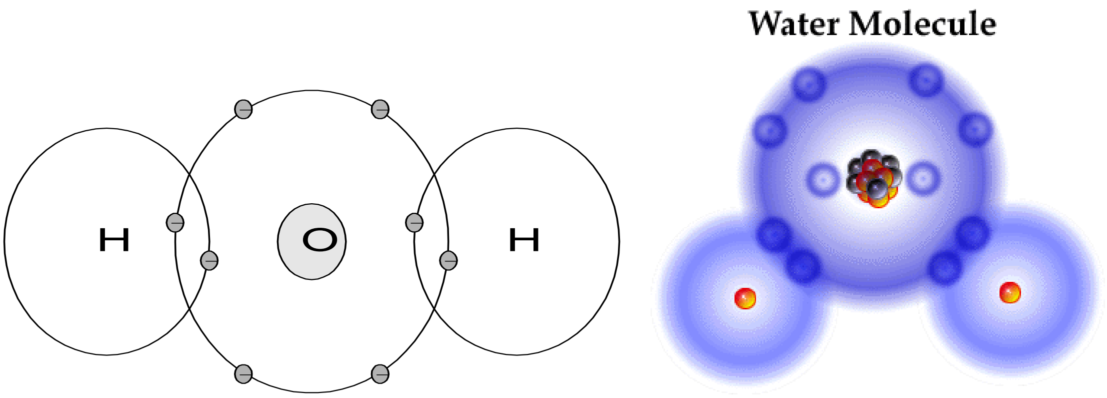


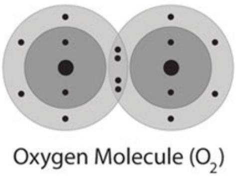
Fig. 3.4 Formation of molecule of hydrogen

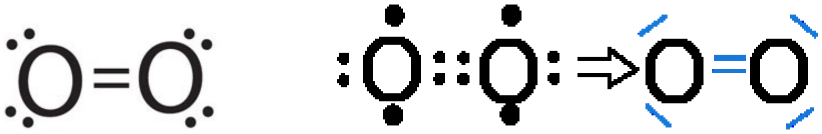




Atomic bonding situation in case of the water, H_2O molecule.

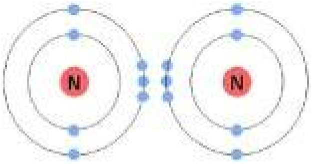
Oxygen bonding

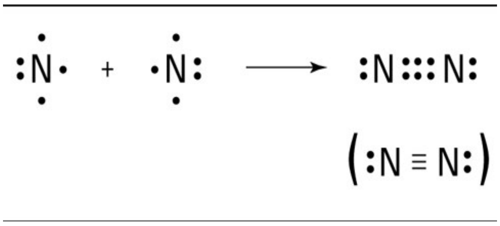


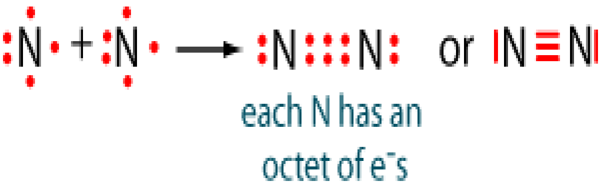


Double bond

Nitrogen bonding

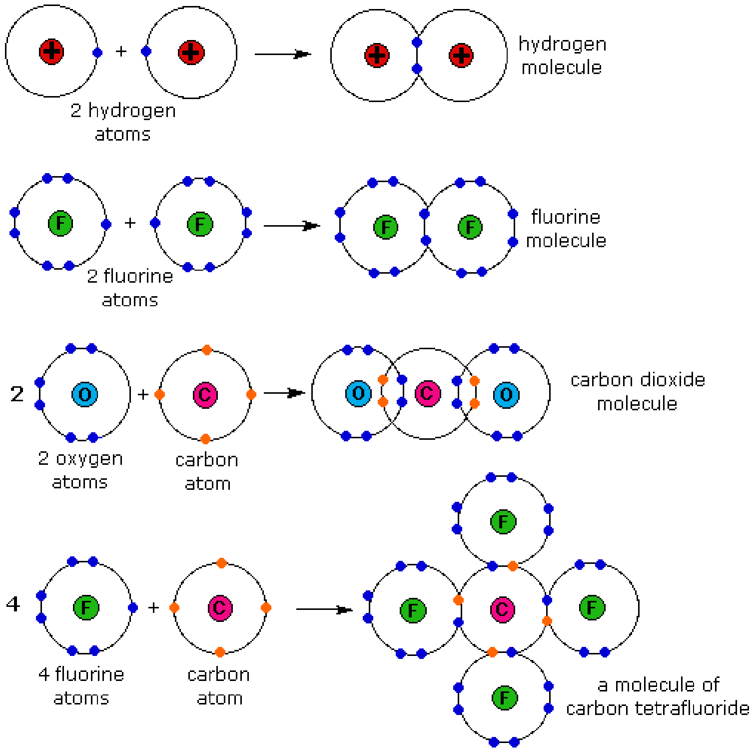


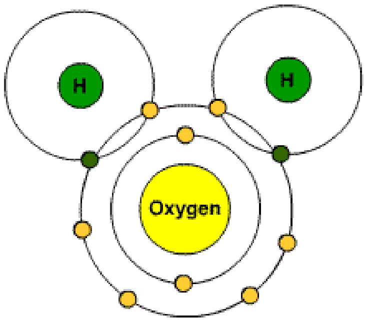




Triple bond

Some examples of different covalent (atomic) element bonding





3.2 Ionic Bonding

Metal atoms react by releasing the valence electrons of the outer shell. In this case positive charged atoms (positive ions = cations) are generated.

Non-metal elements with a lack of electrons in the valence shell easily absorb electrons to receive the very low-energy noble gas state.

Electrically charged atoms are called ions. There are two types of ions; cations (electrically positive) with more protons than electrons and anions (negatively electrically) with more electrons than protons.

An ionic bond is formed when a metal atom reacts with a non-metal atom. The metals form the positive ions (**cations**). They provide electrons from their outer shell to the non-metallic atoms. By *accepting* these electrons the non-metallic atoms turn into negative ions (**anions**).

Because of the electric charge formed by the ions, an electric field, which causes electrostatic forces, is generated and binds the ions.

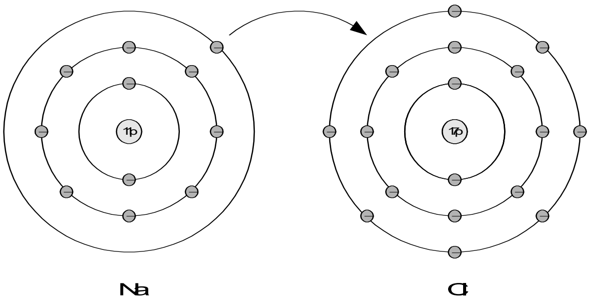
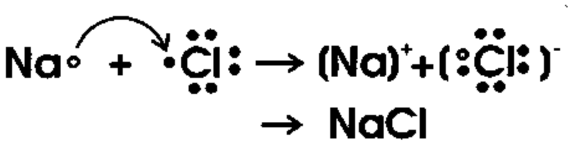
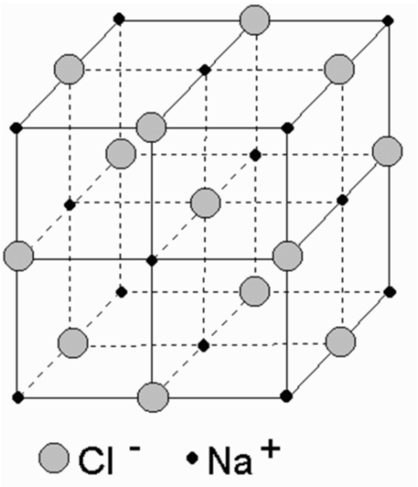


Illustration of “electron migration” between metal-atom and non-metal atom to form ions with electrostatic forces



Compounds with ionic bonds occur only as salts or oxides. Salts form lattice structures and thus occur as crystals, just as table salt (sodium chloride) NaCl does. Such a simple crystal lattice is shown below:



Crystal lattice (ionic lattice) of the salt NaCl

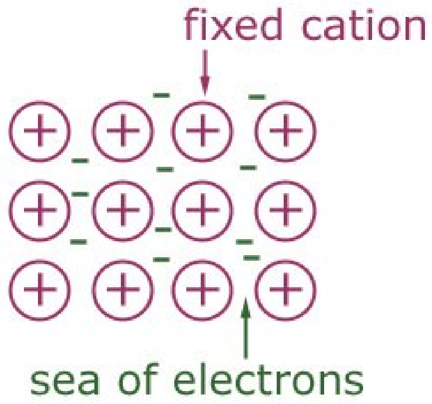
In ionic crystals, the ions are bound by electrostatic forces. This results in regular spatial arrangements.

The valency of non-metals indicates how many electrons can be accommodated. The valency of the metals indicates how many electrons can be emitted.

3.3 Metal Bonding

As the name suggests, this type of bonding occurs between metals. In this type of bonding many positive metal ions occupy a fixed position in a lattice (a bit like ionic bonding). Their outer electron energy levels become delocalised, creating what is known as a sea of electrons since they are not fixed and free to move throughout the lattice.

It is well known that metals can form positive ions when they donate electrons to other reaction partners. This is also the case when metal atoms react with each other.
In order not to repel the positively charged metal ions, such as Na^+ or Al^{3+}, the negatively charged electrons are located between the positive metal ions. Thus electrostatic attraction forces between these negative and positive particles manage the cohesion. The electrons can form a mobile "**free-moving electron gas**" between the metal ions.



4. CHEMICAL REACTIONS

Instead of an equal sign in an equation, an arrow is used, which is also referred to as a reaction-arrow. It symbolizes – like an equal sign a mathematical equation – the equality of both sides. Moreover, it makes reference to the direction of the chemical reaction.
The generation of a new compound consisting of two or more other substances is called **synthesis**.
Analysis refers to the decomposition of a compound into its constituent parts.

4.1 Oxidation

Reactions with oxygen appear in daily life, such as work processes, particularly frequently. For example, oxygen is necessary for all types of combustion processes, especially in engines, in ovens or in our body. These combustion processes deliver energy, in the form of heat and partly in the form of light.

Note: Chemical reactions in which energy is delivered are called **exothermic** reactions.
e.g.: $2\ H_2 + O_2 \rightarrow 2\ H_2O$ + Energy (exothermic)
Chemical reactions in which energy must be supplied are called **endothermic** reactions.
e.g.: $2\ H_2O$ + Energy $\rightarrow 2\ H_2 + O_2$ (endothermic)

Chemical reactions with oxygen are called oxidation.
The oxides may be solid, liquid or gaseous products, depending on which element is oxidized by the oxygen.

Carbon C and oxygen O_2 burn exothermically to form carbon dioxide CO_2:
$C + O_2 \rightarrow CO_2$ + Energy

The mine gas methane (CH_4) burns at a certain mixing ratio with air in an explosive manner:
$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ + Energy
1 mol CH_4 + 2 mol O_2 → 1 mol CO_2 + 2 mol water + Energy

CO_2: $M_r = 12 + 4 \bullet 1 = 16$ → $M = \underline{16\ g/mol}$
O_2: $M_r = 2 \bullet 16 = 32$ → $M = \underline{32\ g/mol}$
CO_2: $M_r = 12 + 2 \bullet 16 = 44$ → $M = \underline{44\ g/mol}$
H_2O: $M_r = 2 \bullet 1 + 16 = 18$ → $M = \underline{18\ g/mol}$

Equations for reaction and masses (**Stoichiometry**):
1 mol CH_4 •16 g/mol + 2 mol O_2•32 g/mol → 1 mol CO_2 •44 g/mol + 2 mol H_2O •18 g/mol
16 g CH_4 + 64 g O_2 → 44 g CO_2 + 36 g H_2O
$\underline{80\ g} \rightarrow \underline{80\ g}$

Law of Conservation of Mass

In chemical reactions, the total mass of the starting materials (educts, reactants or starting materials) is equal to the total mass of the reaction products.

4.2 Reduction

Reduction refers to the extraction of oxygen from a chemical compound. Reduction consumes heat (endothermic).

In the blast furnace, iron oxide FE_2O_3 is reduced by carbon in the form of coke C with a supply of heat.
3 mol of C and 2 mol of FE_2O_3 result in 4 mol Fe and 3 moles of CO_2:

2 FE_2O_3 + 3 C + heat → 4 Fe + 3 CO_2

5. OXIDATION AND REDUCTION OPERATIONS IN WORKING PROCESS

5.1 Oxidation processes in technology

5.1.1 Combustion

Heat is generated by the combustion of solid, liquid or gaseous substances, called fuels. The combustible components of all fuels are:

- Carbon C,
  Hydrogen H_2,
  Sulphur S

Sulphur however is an unwanted component because the resulting combustion reaction product – sulphur dioxide SO_2 – reacts forming sulphurous acid in combination with water vapour (moisture). This acid easily attacks metals, leading to corrosion.

The combustion of a substance is an oxidation reaction because the combustible elements of a fuel react with the oxygen (from the air). Heat is released in this case.

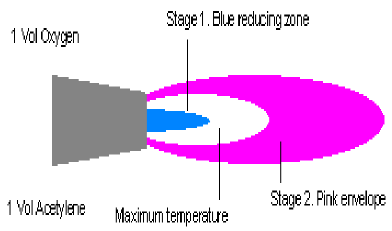
Consequently combustion is an exothermic reaction. It may be complete or incomplete. In complete combustion, all the chemical energy possible is released. In imperfect combustion processes, sometimes combustion-gases (such as CO) are generated which can develop also more heat in further combustion reactions (e.g., to form CO_2).

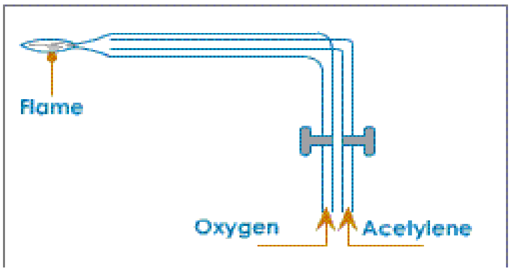
For technical firing equipment complete combustion is desired.

Normally the combustion products are gaseous. But liquid or solid combustion residues can occur as well.
Combustible materials (fuels) are only those materials, which can combine (react) with oxygen, such as carbon, hydrogen, or methane gas. Consequently, substances that have already reacted with oxygen – like oxides – are considered to be non-combustible material.

If fuel is dispersed and intimately mixed with oxygen, then the oxidation can quickly propagate through the entire fuel, without being slowed down by the subsequent flow of oxygen required. This results a **deflagration** or **explosion**.

Even in the application of gas welding – usually with an oxyacetylene flame – a good mixture formation is very important.





2 $C_2H_2 + 5\ O_2 \rightarrow 4\ CO_2 + 2\ H_2O$ + Heat (work zone temperature about 3100 °C)

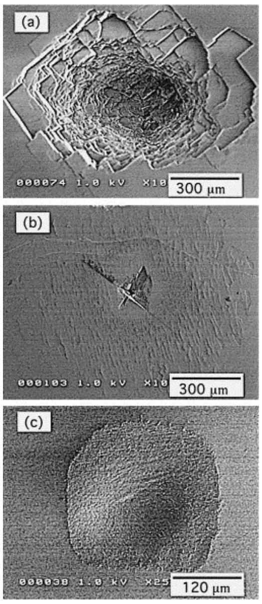
5.1.2 Corrosion and preventing corrosion

Corrosion is the structural change of a material starting from the surface, which is caused by unintentional chemical or electrochemical attack.

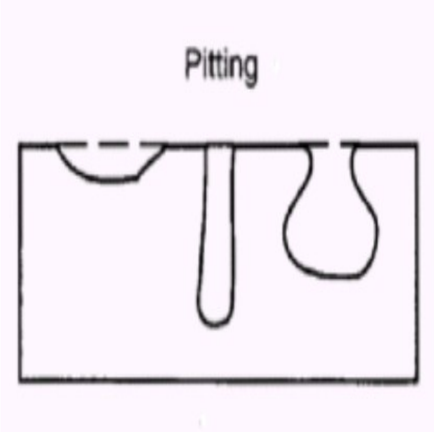
Although non-metals (e.g., glass or concrete) can corrode, it is an especially common and important reaction for metals, so we only consider the corrosion of metals here.

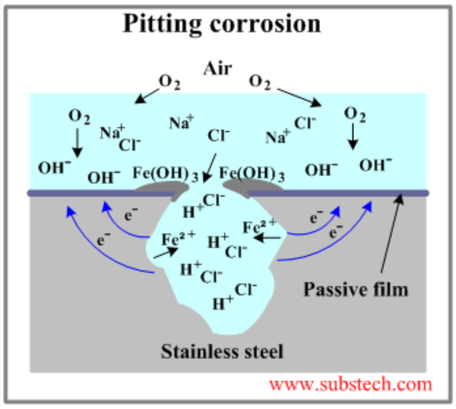
The appearance of corrosion can be very varied. The most “harmless” kind is the uniform ablation. Pitting is more critical. In this case, the chemical or electrochemical attack on some points of the surface are more concentrated, thus pit formation can occur and finally result in local perforation. A more dangerous form is intergranular corrosion.

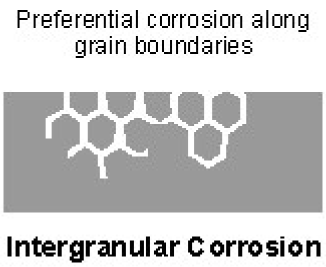
But in any case, all corrosion results in the complete destruction of the metal in the end!

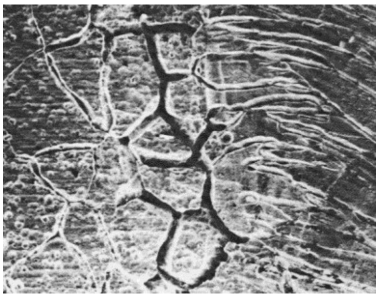


Uniform Ablation









5.1.2.1 Chemical Corrosion

Metal surfaces can undergo a chemical reaction, e.g. to form a metal oxide. Especially some base metals (for example, aluminium, iron and zinc) have a high tendency to react with oxygen.

Note: The rate of a chemical reaction doubles to quadruples with an increase in temperature of 10°C.

2 Al + $\frac{3}{2} O_2 \rightarrow Al_2O_3$; ΔH = -1,677 $\frac{kJ}{mol}$
4 Al + 3 $O_2 \rightarrow$ 2 Al_2O_3

The aluminothermic reaction is highly exothermic, with temperatures up to 2450°C, hence the entire reaction mixture is present as a melt.

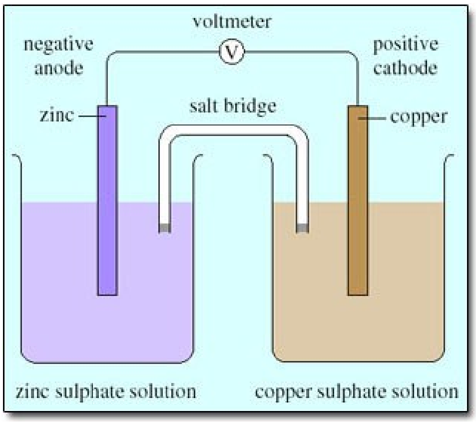
Thermite (Al and Fe_2O)

5.1.2.2 Electrochemical Corrosion

Electrochemical corrosion is the most common form of corrosion. It looks like chemical corrosion. However in contrast to chemical corrosion, electro-chemical corrosion is characterized by the presence of an ion-conductive liquid, called the electrolyte.

Two different metals, in combination with an electrolyte result in a galvanic element. In case of corrosion it is called the **corrosion element**. Corrosion elements cause corrosive damage. Galvanic cells are used to generate an electric voltage.

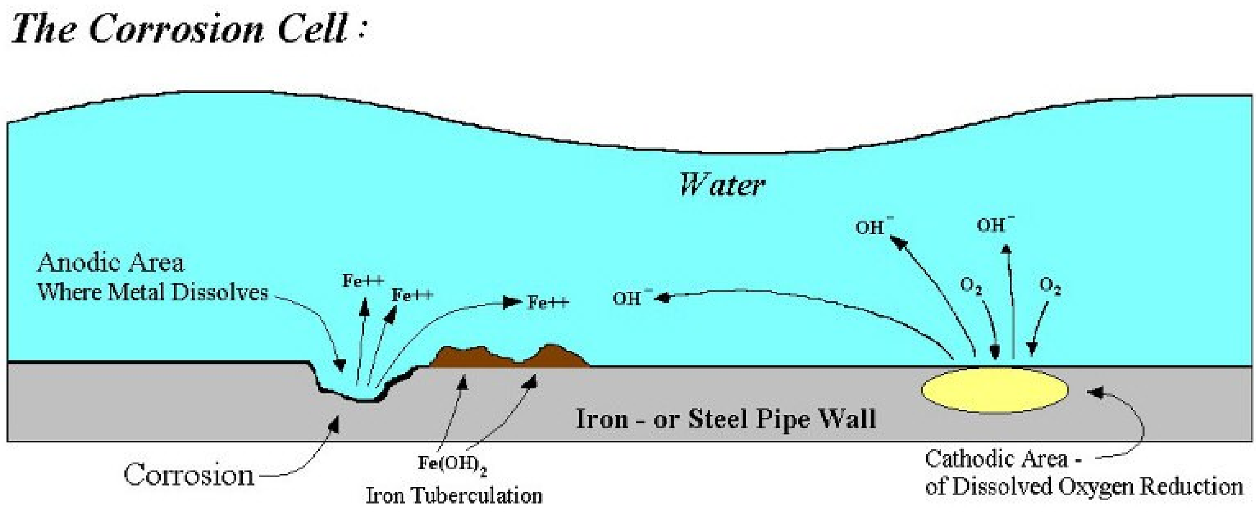
The figure below shows the structure of a galvanic element, known as a Daniell cell:



A galvanic element is a chemical system which converts most of the chemical energy into electrical energy and provides this energy as electric current.

A **beneficial** effect is that the chemical energy is not converted completely into thermal energy, only a small fraction warms the electrolyte caused by ion-motion (conversion of kinetic energy into thermal energy).

This process is also involved in electrochemical corrosion. The galvanic cell simply consists of what are known as metal-electrodes and a surrounding electrolyte. In the cases of corrosion for example, water can pass to the construction parts (metals), either as rain or condensation. This water frequently contains ions or it takes up ions from the surrounding materials and becomes an electrolyte.



Metal atom can discharge electrons and become an ion.

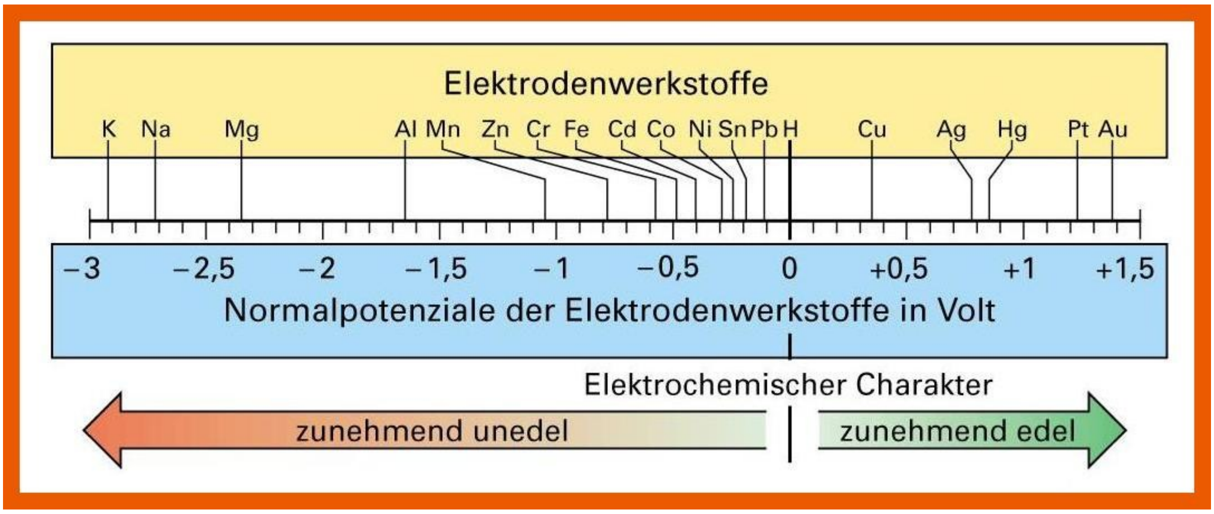
For Example: $Fe \rightarrow Fe^{2+} + 2e^{-}$

$Zn \rightarrow Zn^{2+} + 2e^{-}$

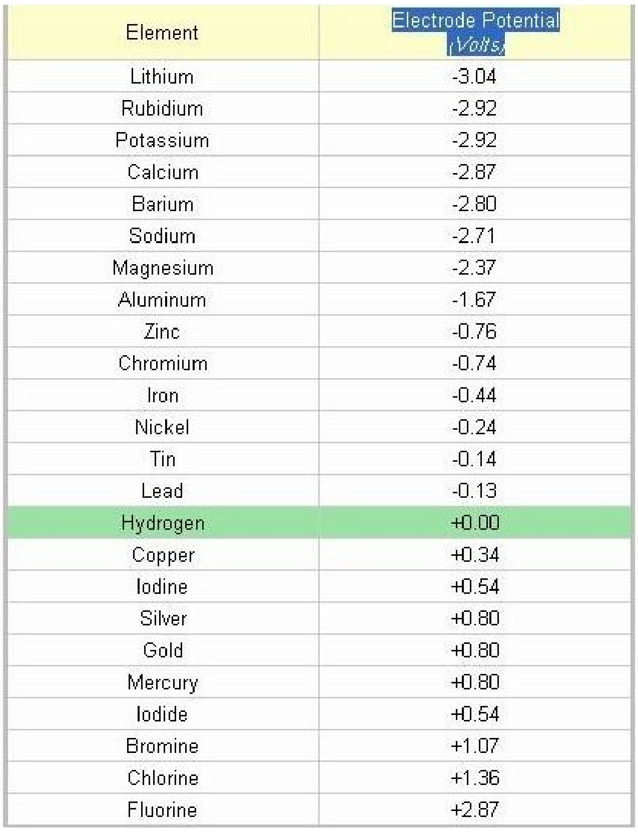
Different metals have different behaviour in their tendency to be converted into ions. This can be measured by the potential generated in reference to a standard electrode. We can see this difference can be seen in the **electropotential series.**

The ability of metals to resist corrosion is to some extent dependent upon their position in the electropotential series.

Element	**Na**	**Mg**	**Al**	**Zn**	**Cr**	**Fe**	**Sn**	**Pb**	**H**	**Cu**	**Ag**	**Au**
voltage	–2.7	–2.4	–1.7	–0.76	–0.56	–0.44	–0.14	–0.12	0	+0.34	+0.8	+1.36
	← base Metals →									← noble Metals →		
	← Cathode behaviour (negative pole)									Anode behaviour (positive pole) →		



[XXX Electrode material / Potential of the electrode in Volts / Electrical character / more base; more noble]
Metals become more noble as we co from left to right, because their potential increases (decreasing the tendency to convert into an ionic state). Hydrogen is used as reference material at 0 volts.



Element	Electrode Potential (Volts)
Lithium	-3.04
Rubidium	-2.92
Potassium	-2.92
Calcium	-2.87
Barium	-2.80
Sodium	-2.71
Magnesium	-2.37
Aluminum	-1.67
Zinc	-0.76
Chromium	-0.74
Iron	-0.44
Nickel	-0.24
Tin	-0.14
Lead	-0.13
Hydrogen	+0.00
Copper	+0.34
Iodine	+0.54
Silver	+0.80
Gold	+0.80
Mercury	+0.80
Iodide	+0.54
Bromine	+1.07
Chlorine	+1.36
Fluorine	+2.87

The electrical voltage of a galvanic element is obtained from the "distance" between the normal potentials of the individual materials and is calculated according to the formula:

U = electrical potential positive pole — electrical potential negative pole

For example:
Calculation of the voltage of a galvanic element with an Al-anode (ignoble) and a copper cathode (noble).
$U = U_{CU} - U_{Al}$
U = 0.34 V – (-1.67 V) = 0.34 V + 1.67 V = 2.01 V

5.1.2.3 Corrosion protection

There are a number of ways to avoid or at least limit the most negative effects on the material properties due to corrosion. There are several ways of distinguishing types of corrosion protection:

active corrosion protection	Intervention in reactions. This includes, for example, cathodic protection by deliberately using base metals as a sacrificial anode to protect expensive components. Using other materials or changing the corrosive agents are also possible. Furthermore the reaction conditions, e.g. the temperature can be changed.
Passive corrosion protection	Separation of material and corrosive agent by a separating layer, which can be applied by various methods. a) Coat metals with oil, paint, grease or varnish because it can prevent corrosion. b) Plating, painting, and the application of enamel are the most common anti-corrosion treatments.

5.2 Reduction processes in technology

Reduction refers to the extraction of oxygen from an oxygen containing chemical compound. Reduction has technical significance like oxidation. Special reduction furnaces have been developed for many special applications. These are industrial furnaces, in which the furnace gases have reduction effects and are controlled precisely in terms of their oxygen content by means of flow control of the combustion air supply. For example, this is the case in furnaces for metal recovery. Iron production is established using such blast furnaces for reducing oxidised iron ore with coke. In the blast furnace process the iron ore is reduced in what is known as the reducing zone mainly by carbon monoxide (CO), corresponding to the following reaction equations at different levels:

$3\ Fe_2O_3 + CO \rightarrow 2\ Fe_3O_4 + CO_2$ indirect reduction (by CO)
$Fe_3O_4 + CO \rightarrow 3\ FeO + CO_2$
$FeO + CO \rightarrow \mathbf{Fe} + CO_2$

In direct reduction hot coke reacts with iron ore:
$Fe_3O_4 + 4\ C \rightarrow 3\ Fe + 4\ CO$ direct reduction (by C)
$FeO + \rightarrow \mathbf{Fe} + CO$

6. ACIDS, BASES AND SALTS

6.1 Acids

There is a group of chemical compounds which behave very similarly in aqueous solutions. They colour litmus indicators red and have an acidic taste. These are the well-known compounds termed as acids.
There are two groups of acids, and indeed there are oxygenated acids and oxygen-free acids.

oxygenated acids		oxygen-free acids	
name	chemical notation	name	chemical notation
Sulphurous acid	H_2SO_3	Hydrochloric acid	HCl
Sulphuric acid	H_2SO_4	Hydrofluoric acid	HF
Nitric acid	HNO_3	Hydrosulphuric acid	H_2S
Phosphoric acid	H_3PO_4		
Carbonic acid	H_2CO_3		

Sulphuric acid H_2SO_4 → (H_2) + (SO_4)
Hydrochloric acid HCl → (H) + (Cl)
Carbonic acid H_2CO_3 → (H_2) + (CO_3)

Acids always are made up of hydrogen and the acid residue.

This above statement alone is not sufficient to describe an acid completely, because there are many compounds of hydrogen and non-metal atoms which are not acids, such as methane, CH_4, or ammonia, NH_3.

Chemically pure water, H_2O is an electric insulator.

An aqueous acid solution conducts electricity.

But this can only be the case when the acid particles, which are dissolved in water, are electrically charged. So ions must have been created. This can only mean:

Acid molecules partly decompose in water into ions: hydrogen ions (protons or most likely oxonium ions H_3O+ and acid residue anions.

For example: H_2SO_4 + 2 H_2O → $2\ H_3O + SO_4^{2-}$

This process is known as dissociation, and the aqueous solution with the dissolved ions is called an electrolyte, which conducts electricity.

The strength of acids is directly related to their degree of dissociation. The degree of dissociation therefore is a measure of the danger of an acid. Hydrochloric, sulphuric and nitric acid, in particular, should be handled with great care. These acids are highly corrosive because they dissociate completely.

Warning notices

- Acids attack the skin and eyes, they are caustic
- Acids eat away textiles
- Acids destroy base metals are corrosive
- Acids conduct electricity
- Acids turn litmus indicator paper red

6.2 Bases (alkalis)

Anhydrous alkalis are called bases.

name	chemical notation
Sodium hydroxide (caustic soda)	NaOH
potassium hydroxide (caustic potash)	KOH
calcium hydroxide (water-slaked lime)	$Ca(OH)_2$
ammonium hydroxide	NH_4OH

Overview of the main bases

Almost all bases consist of metal-ions and of the OH^- group, which is also called the hydroxide group. Bases conduct electricity when dissolved in water. Thus, also some degree of dissociation into ions must take place.

complete dissociation → strong base
low dissociation → weak base

When dealing with bases, extreme caution is necessary and appropriate precautions must be taken.

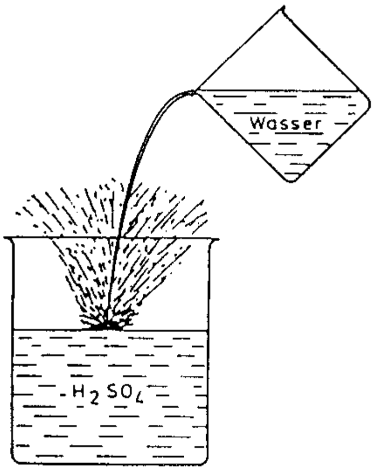
The dangers of acids and bases are related to the release of H^+ (H_3O^+ in aqueous solution) and OH^--ions and demand a particularly careful approach to these chemicals. The H^+- and OH^--ions are produced, due to the solution dissociation processes in water. But we must not draw the wrong conclusion that undissolved bases (solid ionic compounds) and concentrated acids are not dangerous. Remember that the human skin always humid, thus releasing the dangerous ions from these hazardous compounds. In addition, concentrated oxygen-containing acids (e.g. H_2SO_4) react as a very strong oxidizing agent.

All acids and bases are strong toxins. They destroy skin, mucous membranes and textiles, particularly when in concentrated form. Acids attack metals very strongly. Safety regulations should be noted strictly. In any case, you should:

- Wear safety goggles and rubber gloves
- Legible labels have to be attached to bottles – containing the name of the acid or base and its concentration.

Protect acids and bases from access by unauthorized persons (especially children).

When diluting acids or bases, always add the acids or bases to water while stirring. Never pour water into acids or bases. The reason for this is that when dilution occurs a lot of heat is released. Consequently the solution begins to boil and may cause dangerous spraying.



6.3 Salts

If hydrochloric acid (HCl) and the base sodium hydroxide (NaOH) react then sodium chloride (NaCl) and water are generated:

HCl	+	NaOH	→	NaCl	+	H_2O
↓		↓		↓		↓
Acid	+	Base	→	Salt	+	Water

Solid sodium chloride can be obtained by evaporating the resulting water. The example described above confirms a fundamental chemical statement:

Note: All substances which are formed by reactions between acids and bases are called salts.

Salts include positively charged metal ions and negatively charged acid residue ions. This can be clearly recognized when the equation is shown in ion notation:

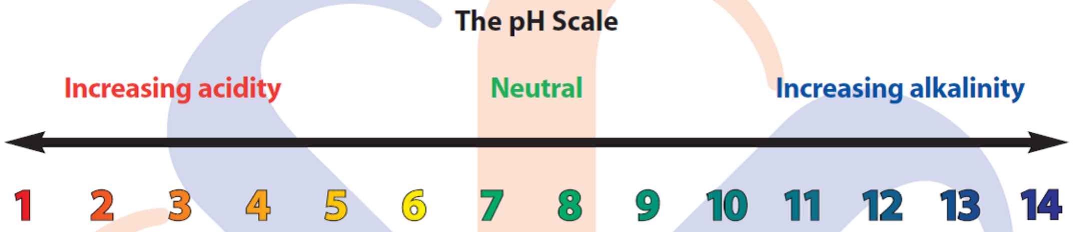
$$\mathrm{H}^+ + \mathrm{CI}^- + \mathrm{Na}^+ + \mathrm{OH}^- \quad \rightarrow \quad \mathrm{Na}^+ + \mathrm{CI}^- + \mathrm{H_2O}$$

It can easily be seen that the saline formation of NaCl resulted from a complete neutralization of hydrochloric acid and sodium hydroxide.

The pH-value indicates whether and how much acidity or alkalinity of a solution is present.

In case positive and negative ions in a solution (e.g., saline) are the same, then this is neutral. It has pH 7. However, if there is an excess of negative OH^--ions, then the solution is basic If there is an excess of positive H^+-ions the solution is more acidic. The pH-values vary between the limits 0 and 14.

Hydrochloric acid → *pH*-value = 0: *pH* 0
Sodium hydroxide → *pH*-value = 14: *pH* 14
Water → *pH*-value = 7: *pH* 7 (neutral)



The colours indicated on the chart are illustrative of the colours that would be indicated following a litmus test.

Base metals react with acids to form salts and hydrogen. It is the H^+ ions which destroy the metals in these processes.

$$\mathrm{Fe} + \mathrm{H_2SO_4} \quad \rightarrow \quad \mathrm{FeSO_4} + \mathrm{H_2} \uparrow$$

In this context, the expression of **water hardness** is discussed:
Water hardness is defined as the amount of dissolved calcium and magnesium salts in drinking and industrial water. Mainly $\mathrm{CaCO_3}$, $\mathrm{CaSO_4}$, $\mathrm{MgCO_3}$ and $\mathrm{MgSO_4}$ are involved

Hardness range	Total Hardness mmol / L
Nr. 1: Soft	Up to 1.3
Nr. 2: Moderately hard	1.3 to 2.5
Nr. 3: Hard	2.5 to 3.8
Nr. 4: Very hard	Above 3.8