# *What is matter made of?*

## *How can matter change?*

### Some basics from physics and chemistry

Salad coral, Sulawesi, B. Jäckli

A tutorial for independent study by BMS bili students

Barbara Jäckli, “Technology & Environment“, wkvw
2016/2021

## *Introduction*

The things around us – rocks, trees, skyscrapers, water, salt, iron, air - are all *subject to change*. In everyday life you can observe two basic processes. Changes and processes in "matter" [die Materie] lead into the topic of <u>*chemistry*</u> as well as into <u>*physics*</u>:

Many processes that we continually observe all around us – in a lake, in the soil, or in living organisms, such as photosynthesis in a plant or the digestion of food in humans – are based on *the transformation of one substance into another* [Stoffumwandlungen], or ***chemical reactions***.

<u>Examples of chemical reactions</u>: The hot *burning* of solid candle wax, using the gas *oxygen* [Sauerstoff] from the air, turns both wax and oxygen into other materials: *carbon dioxide* [Kohlendioxid], an invisible gas, and *water vapour* [Wasserdampf] and some solid black flakes of half-burnt *soot* [Russ].

Brownish rust [Rost] forms on the shiny metal iron nail using oxygen from the air when it gets moist. It forms a new substance, iron oxide.

The decay [Zerfall, Abbau] of food by bacteria and the transformation of the sugar in grape juice to alcohol in wine are also chemical reactions.

Digestive juices [Verdauungssäfte] in our body change pasta, salad, meat or oil into smaller nutrients [Nahrungsbausteine] which the body can absorb into the blood. The substances [Stoffe] have all changed considerably, their *properties* [Eigenschaften] *have changed*; we speak of *chemical reactions*. Because many processes in nature depend on chemical reactions, it is important to have some basic knowledge!

<u>*A completely different process*</u> can be shown by heating up ice and liquid water: as you know, the substance called "water" exists in three forms or "physical states" [physikalische Zustände]: solid [fest] as ice, liquid [flüssig] and gaseous [gasförmig] as water vapour [Wasserdampf].

The conversion [Umwandlung] from one state or form into another, e.g. by melting, freezing or evaporating [verdunsten], is *not* a chemical transformation of materials but a **physical change**! The water particles that make up the substance called "water" remain unchanged; *water always remains water*! The three states of matter are described in more detail below.

### 1) The three "states of matter" [Aggregatszustände, physikalische Zustände]

The substances around us are made of tiny particles [Teilchen] which are in continuous motion [ständige Bewegung].

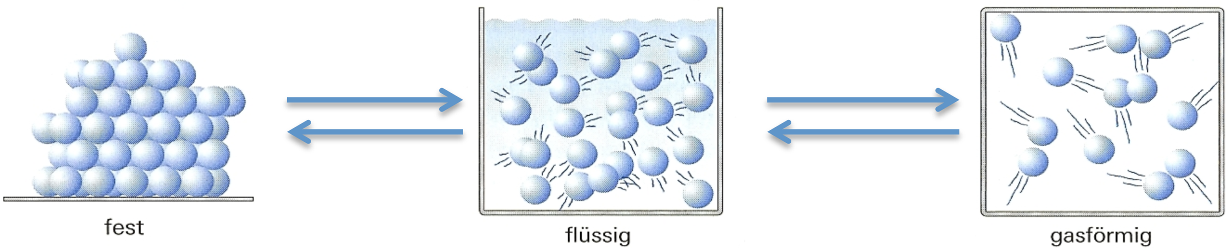
a. In a <u>*solid*</u> (or a solid substance [festen Stoff]) the particles are very densely packed and lie close to eachother: the forces of attraction [Anziehungskräfte] between them are very strong. The only movement they show is a kind of "vibration". Solid substances usually have a *high density* [hohe Dichte], e.g. gold or lead [Blei], which are both solid at room temperature. Water is an exception: There are small spaces between the water particles in the ice; this is why ice takes up 1/10 more space and is also less dense than liquid water and floats on water (also Question 7, in 4.2). When heat is applied to this solid the particles leave their fixed positions: the solid substance "ice" *melts* and becomes a liquid at temperatures over $0^{\circ}$C, it melts [schmilzt].

b. In a <u>*liquid*</u> (or a liquid substance [flüssigen Stoff]) the particles move much more than in the solid; the forces of attraction between particles are still quite strong. They are able to move and slide around but cannot move away from eachother. When heat is applied to the liquid the particles move faster and faster. Finally they leave the liquid and the substance becomes *gaseous* [gasförmig], it *evaporates* [verdampft]. Water boils at > 100° C.

The particles in a liquid do not all move at the same speed and some leave the liquid before reaching the boiling temperature [Siedetemperatur]: the liquid just *evaporates*. The remaining liquid then cools off. Your body uses the "evaporative cooling" [Verdunstungskälte] effect when you sweat!

c. Gases neither have a definite *form* nor a definite *volume*. The particles in a gas move independently of eachother, occupying the entire available space and distributing themselves evenly, the average distance between them being equal. The gas of a substance has a much lower density than the liquid or the solid. If a gas (or mixture of gases) is heated the particles move even faster in all directions: the gas expands [dehnt sich aus], becoming even less dense. This is the physics behind a hot air balloon! http://www.eballoon.org/balloon/how-it-works.html

When water boils and evaporates you first see "fog" [Nebel]: It still consists of small water droplets and so isn't yet a gas! Only when the droplets evaporate completely and the particles become invisible it becomes a gas.




solid liquid gas

Watch this short video on the 3 states of matter: http://youtube.com/watch?v=s-KvoVzukHo

Text and helpful illustrations in German: http://www.seilnacht.com/Lexikon/aggreg.html

Animations and video (in German): http://www.zum.de/dwu/depotan/apwl101.htm
http://www.youtube.com/watch?v=PTQicV7sg7Q&feature=related

The states of matter, and heating and cooling:
http://www.bbc.co.uk/education/guides/zccmn39/revision (see 1 and 2!)

☞ 1.) Name the changes in state shown above (wite your answer above or below the arrows).
*Please note your answers to the questions before checking them! The answers to all the questions in the text are at the end of this tutorial.*

Water vapour dissolves [löst sich] in the air. In dry climates there is less water, in humid climates there is more. Usually humidity is expressed in % [Prozent Feuchtigkeit].

The "fog" [Nebel] on concert stages is a result of the direct evaporation of "dry ice" [Trockeneis] or frozen carbon dioxide [Kohlendioxid]; this process is called "sublimation". In winter, on glaciers or in polar regions you can see the *sublimation* of ice as the sun shines on it.

"Dry ice" sublimating: http://www.youtube.com/watch?v=Re9l9IIxYqo

☞ 2.) Cold air can absorb and contain less water than warm air. Explain why a cold aluminum can [Getränkedose] or a glass bottle taken out of a fridge will become wet on the outside. What process has taken place?

**The "particle model" [Teilchenmodell] in physics and chemistry**

The particle model describes our basic concept of the nature of substances:

- Substances are made up of tiny particles which are in continuous motion.
- Forces of attraction and repulsion [*Anziehungs- und Abstossungskräfte*] act upon the particles. The forces depend on the type of particle and the distances between eachother.

The particles never stop moving. The higher the temperature, the more they move. And the more the particles move the higher becomes their temperature. We feel this when the particles push against our skin. (This is called "Brownian motion" after Robert Brown who discovered it in 1827.)

Siehe: https://www.youtube.com/watch?v=R5t-oA796to (Random movement of tiny pollen grains [Pollenkörner] under the microscope) Sizes: http://www-saps.plantsci.cam.ac.uk/pollen/index2.htm

## 2) The smallest particles in chemistry: "*atoms*"

Over 2500 years ago the ancient Greeks already thought that matter consisted of tiny indivisible [unteilbare] particles: we still call these *atoms*. The concept has become a theory which is supported by experimental evidence.

The tiny atoms, only $10^{-10}$m (= 1 Å) in size, are themselves made up of even smaller particles, the so-called *subatomic* or "***elementary particles***" [Elementarteilchen]. Three of these are important:

***protons*** ***neutrons*** ***electrons***

These differ in *mass* [Masse] (= weight on Earth) and *electrical charge* [elektrische Ladung].

• *Protons* are part of the inner *nucleus* [Kern] of an atom and are the heaviest elementary particle. They have a single positive electrical charge (+1).

• *Neutrons* (also in the nucleus) are almost as heavy as the protons but are not electrically charged; they are neutral (uncharged).

• *Electrons* exist in a kind of "cloud" in the outer shells [Schalen, Aussenhüllen] of an atom and are much smaller and 2000x lighter than protons. They are negatively charged (-1).

Electric charge:

- There are two kinds of electric charge, positive (+) and negative (-).
- Particles with opposite charge attract eachother.
- Particles with identical charge repel eachother.

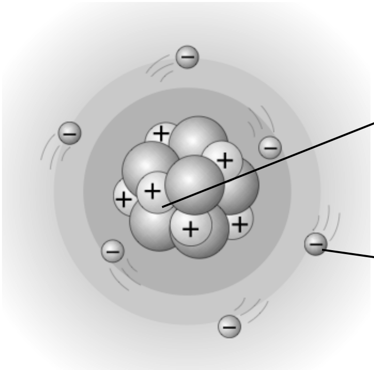
The number of electrons in an atom is the same as the number of protons. This is why an *atom as a whole is uncharged* (neutral).

*It is not possible to split an atom or change it into another type of atom by using the methods of chemistry* (chemical reactions). (In atomic physics [Atomphysik] atoms can be split, e.g. for releasing nuclear energy).

*Each type of atom has a certain number of protons.  Atoms differ by the number of their protons.*

For example, carbon atoms [Kohlenstoff-Atome] have 6 protons and helium atoms 2 protons.

**Model of a carbon atom (C)**

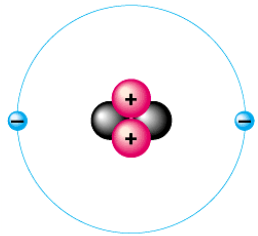


The **nucleus** (*Kern*) of the atom is **positively charged (+)** *(positiv elektrisch geladen)***.**

Carbon: 6 protons (+) (*Protonen*) and 6 neutrons (0) (*Neutronen*, *ungeladen)*

6 **negatively charged electrons (-)** (Elektronen) in a cloud around the nucleus in the outer shell. Several shells lie around the nucleus like onion skins.

The electric charge of an atom as a whole is 0; an atom is *neutral (uncharged).*
Carbon:   (+6) + (-6) = 0



**The Helium Atom (H)** is much smaller than the carbon atom. It  has only 2 protons, 2 neutrons and 2 electrons.

☞ 3) Draw (or describe) a Lithium atom, which has 3 protons!
How is it structured? Name the elementary particles as well as their location in the atom, their number and respective electrical charges.

***Elements** are pure substances which are made up of only one type of atom,*
for example iron or oxygen.

*Element symbols*: Every element has a name and a symbol consisting of a capital letter [Grossbuchstaben] (C, N, O) or a capital letter followed by a lower case letter (Si = Silicon; Fe = „ferrum“, Latin for iron).

*Atomic symbols = element symbols: the symbols are used both for the substance as well as its atoms.* Fe stands for the element (substance) “iron“ as well as an iron atom.

Today over 100 *elements are known*, 92 of which occur naturally; 25 of these are found in living things.

Wasserstoff-Atom

All elements (types of atoms) are arranged in a table [Tabelle] called the **periodic table** [Periodensystem] according to *atomic number* [Atomzahl] (= number of protons) and structure of its electron shells. These determine its properties when reacting with other elements.

The very first atom (element) in this table - and the smallest - is H or *hydrogen* [Wasserstoff]. This means it is also the lightest element. It is the most common element in the universe and is the basic matter which stars are made of. In a brightly burning star hydrogen exists in a state of matter called “plasma“; in a star, the H atoms are changed into helium atoms by nuclear fusion, releasing an extremely high amount of energy (including heat and light). Helium (H) is the 2nd atom in the periodic table and has 2 protons, 2 neutrons and therefore 2 electrons.

The number of neutrons in the nucleus of an atom can sometimes be higher than the number of protons. Atoms with the same number of protons (= the same type of atom) but with a different number of neutrons are called ***isotopes*** of this type of atom, e.g. Carbon $^{12}C$, $^{13}C$, $^{14}C$ in:

*Interactive periodic table* of the elements: http://www.rsc.org/periodic-table

http://www.ptable.com/?lang=de

Scroll through the interactive table of the elements in German: e.g. look through the page on C (carbon, Kohlenstoff) http://www.seilnacht.com/Lexikon/psframe.htm

(☞ *More information is in the separate file “**The periodic table of the elements**“*. Read and study this chapter to understand how it is constructed according to the properties of the elements.)

During a chemical reaction, two things can happen to the atoms:

- Atoms can become charged particles called “*ions“ [Ionen]* by losing or gaining electrons,
- Atoms can combine to form larger groups called “molecules“ [Moleküle]:

### 3) “Ions“ [Ionen]: electrically charged atoms

Atoms are electrically uncharged or neutral, having an equal number of protons and electrons. In a chemical reaction some atoms can lose or gain electrons: they become *charged particles* called *ions.*

An ion’s electrical charge is written to the right above the symbol of the element: for example, the ion of the element Aluminum (Al) with a positve charge of 3 is written as $Al^{3+}$.

In ions having a charge of 1+ or 1- the number “1“ is not written. Example: $Na^{+}$ and $Cl^{-}$.

Ions with negative and positive charges attract eachother, like the two poles of a magnet. Ions with the same charge repel eachother.

Substances made of ions are called *ionic compounds*. They can form huge “lattices“ [Gitter] and are also called “salts“ as they have properties similar to common table salt [Kochsalz] (more in 4.1)

The formation of ions (loss or gain of electrons) is determined by physical laws concerning the arrangement of the electron shells around the nucleus.

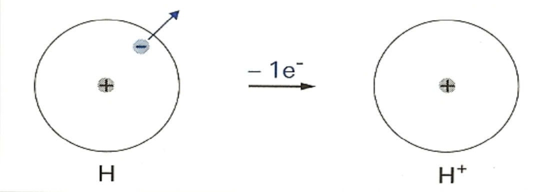
(The “readiness“ of an atom to combine with another particle through a chemical reaction, depends on the tendency of that particle to gain or lose electrons ($e^{-}$) which is shown by its position in the periodic table of the elements).

Look at the three examples shown below, then answer the following questions.

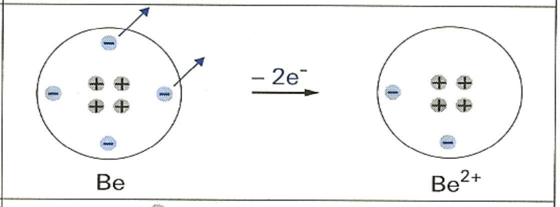
☞ 4.) What ions (show symbols) are formed when:

- a Calcium atom (Ca) loses two electrons.
- a Selenium atom (Se) gains two electrons.
- a Bromine atom (Br) gains an electron.

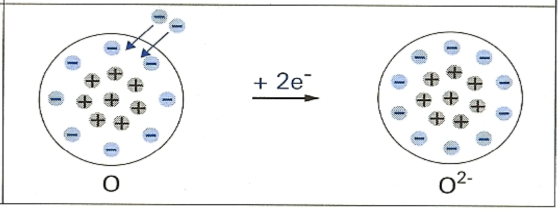
Wenn ein Wasserstoff-Atom sein einziges Elektron abgibt, entsteht ein Wasserstoff-Ion mit der Ladung 1+.




Wenn ein Beryllium-Atom zwei Elektronen abgibt, entsteht ein Beryllium-Ion mit der Ladung 2+.




Wenn ein Sauerstoff-Atom zwei Elektronen aufnimmt, entsteht ein Ion mit der Ladung 2–.




## 4) Chemical compounds [Verbindungen] (of atoms)

*Compounds* are combinations of atoms formed through chemical reactions of two or more *elements.* Theoretically they can be changed back into the original indivisible [unzerlegbaren] *elements* if enough energy is available.

The formation of a compound from elements is called *chemical synthesis* [Synthese]. The opposite decomposition [Zerlegung] to form elements is called *chemical analysis* [Analyse]:

| | | |
|---|---|---|
| | → *synthesis* → | |
| *elements* | chemical reaction | *compounds* |
| | ← *analysis* ← | |

Elements or *basic substances* such as gold, aluminum or oxygen are *pure substances* which cannot be separated into further substances.

To date [bis heute] over *10 million chemical compounds* are known. They can be assigned to different kinds of groups according to different criteria. Some of these are discussed later. They may be grouped:

- according to the type of particle which they consist of: *molecular compounds* [Molekülverbindungen] and *ionic compounds* [Ionenverbindungen] (see 4.1)
- according to their occurence in nature: *organic* and *inorganic compounds (see 7.)*
- as *classes of substances* [Stoffklassen]: based on their properties and the structures of their molecules organic compounds can be divided into classes such as alcohols, amino acids, fats, carbohydrates [Kohlenhydrate], proteins, etc. (see 6.).
- according to their *chemical behaviour* compounds can be placed into groups such as acids [Säuren] and bases [Basen].

### 4.1 Ionic compounds or salts

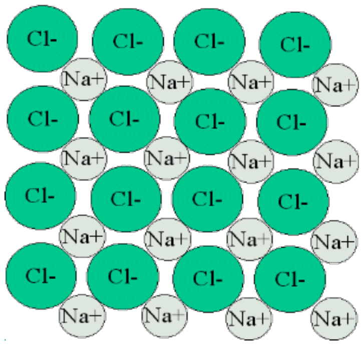
*Ionic compounds* or *salts* are compounds whose particles are ions. They show properties similar to our table salt [Kochsalz]. At room temperature salts exist as solid crystals in a lattice [Gitter] made of ions, a ionic lattice. Most of them have a high melting point (temperature) and a high boiling point as the ions in the lattice are held together by the ions which attract eachother strongly. They can conduct an electrical current. Many salts can dissolve themselves [sich auflösen] in water, each ion becomes surrounded by water (see also "water" in 7. below).

Every salt consists of positively and negatively charged ions. In table salt NaCl the ions are arranged in a lattice with alternating *positive* and *negative ions*. Similar to a collection of tiny magnets the positive and negative particles are drawn [angezogen] to eachother. This results in a regularly formed salt crystal which theoretically can become huge, as the pattern keeps repeating itself.

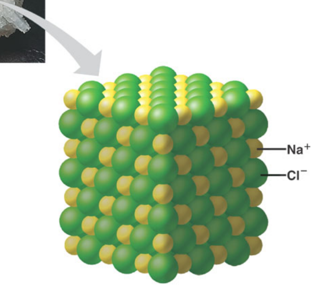
In a crystal of table salt the number of $Na^+$ and $Cl^-$ ions are the same, so that the crystal as a whole is neutrally charged. In the formula for table salt (NaCl) the numbers indicate the relative numbers of the two different ions.

| | |
|---|---|
| Formula of table salt: | NaCl |
| Numerical ratio: | $1Na^+ : 1Cl^-$ |

Two models and photos of NaCl crystals showing the ionic lattice structure:




Halite (rock salt) crystal


seilnacht.com

☞ 5.) Look at some rock salt (= table salt) crystals (Halite) in a dish under the microscope. The cube structure of the lattice is repeated from the smallest units of a few ions to the visible crystal!

6.) Why can't a crystal consist of only one kind of ion?

### 4.2 Molecular compounds [Molekülverbindungen]

A *molecular compound* is a compound in which several atoms are held together in a stable new particle, the "**molecule**" [Molekül]. It is usually so stable [stabil] that a very high amount of energy would be needed to separate it back into its atoms!

*The "**formula**" of a compound* is a form used for writing a compound showing the number of atoms of each element present in the compound as symbols.
For example CO consists of 1 carbon atom (C) and 1 oxygen atom (O).

But carbon dioxide $CO_2$ consists of one carbon atom and two oxygen atoms:

If there is more than one type of atom in a molecule, the number of atoms is written as an index *after* and *below* the symbol of each element.

Water molecule: $H_2O$ means that the water molecule consists of two H atoms and one O atom.

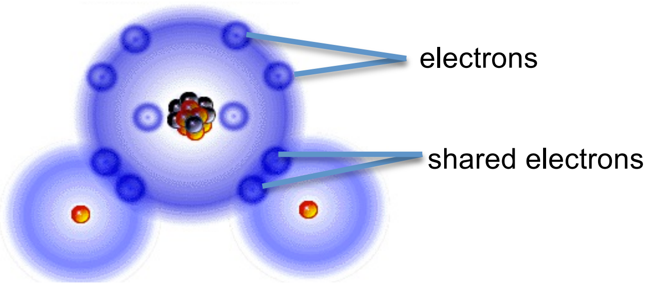
Oxygen molecule: $O_2$ means that an oxygen molecule consists of two oxygen atoms. It exists in this form as a gas in the air – which we need to breathe!

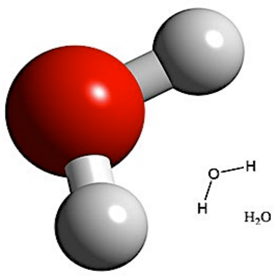
Typical properties of a molecular compound:

The atoms in a molecule such as water are held together by so-called "covalent bonds": atoms here do not gain or lose electrons, they *share electrons* (see the picture of the models below).

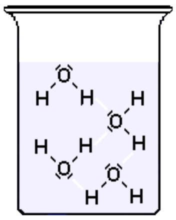
☞ Find "oxygen" in the periodic table (element number 8). Two elements after oxygen is neon Ne (10) with a full outer shell of 8 electrons (and 2 electrons in the first inner shell). Oxygen still needs 2 electrons to complete its outer shell. Hydrogen has only 1 electron; it would need a second one for a stable outer shell. When the two nonmetals oxygen and hydrogen form a bond they do not gain or lose the electrons they "crave", they share them so that both can form their full outer shells.

**Two different models of a water molecule $H_2O$**




*The two H atoms, or hydrogen [Wasserstoff] atoms share their electrons with the single O or oxygen atom in this stable molecule.* The two H atoms lie to one side at an angle [Winkel] of about 104° with the O atom. The O atom "pulls" the electrons of the H atom towards its side. Thus the side of the molecule with the H atoms acts rather *positively charged*, with less electrons, and the side with the O atom with the many electrons acts more negative: The molecule is **polar** with two sides, **+** and **-** .



In the substance "water" the postive and negative sides of the molecules approach eachother and form groups which are always moving and breaking up.

Here the formation of tiny "bridges" between the molecules of water is explained (in German):

http://www.youtube.com/watch?v=RNdXegV-dK4 [ -> *More about water* later in 7.! ]

☞ 7.) Watch the video on ice tea! Explain to someone why an ice crystal is *lighter* than water.

https://www.youtube.com/watch?v=UukRgqzk-KE

*Small molecular compounds made of a few atoms such as* $H_2O$ (water), $CO_2$ (carbon dioxide) and $CH_4$ (methane) normally exist as a gas or a liquid. *Large molecular compounds* such as glucose [Traubenzucker] $C_6H_{12}O_6$ can be solids. (They dissolve in water – if at all - as whole molecules, and do not separate into charged ions like *salt crystals* do. The solutions [Lösungen] of these compounds in water do not conduct electricity – as opposed to salt solutions.)

☞ 8) Oxygen can be found dissolved [*gelöst*] in the water in lakes and rivers, the molecules move and spread out between the water molecules. There is usually enough $O_2$ for fish and other organisms but in warm summers bacteria often use up a lot of oxygen.
Why is there in summer often not enough oxygen for the fish although the water molecule $H_2O$ itself contains oxygen?

### 4.2 Metallic compounds

In a metal the atoms exist as ions (in the solid state) in a lattice not unlike that of a salt. The bonds are strong but he electrons are free to move about in the lattice: this means they can *conduct electricity*.

http://www.bbc.co.uk/education/guides/zfsk7ty/revision

☞ 9) Order the following symbols according to the type of particle into 3 groups; name the 3 groups:

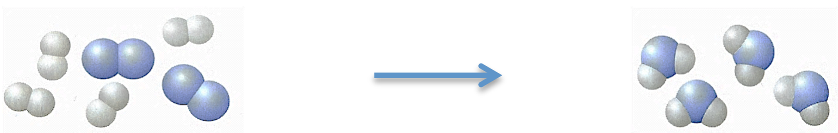
$O^{2-}$, $O_2$, Fe, $N_2$, C, HF, Hf, $NH_3$, $K^+$

## 5) Chemical reactions

If you bring the two gases hydrogen [Wasserstoff] ($H_2$) and oxygen [Sauerstoff] ($O_2$) together in a closed space they only mix as molecules moving around. A small spark, however, is enough to trigger a reaction: the molecules split into atoms and quickly combine to a completely new substance with new properties! A large amount of heat is set free in this *explosive reaction* – like the fire in the Zeppelin airship disaster of 1937; it was filled with the extremely light $H_2$ :

https://www.youtube.com/watch?v=-vgkvUxxZFg

The reaction (grey = hydrogen molecules, blue = oxygen molecules):



hydrogen and oxygen (2 gases)  react (explosively) to form  water (liquid from 0° - 100° C)

After the catastrophe which destroyed the airship in Lakehurst, USA, in 1937, *water* was also formed, most of which however evaporated in the heat of the fire!

The reasons why some substances react and others do not (or only under certain circumstances) go largely beyond this introductory unit. For example the stable nitrogen molecules normally do not react with the oxygen molecules in the air. However, when lightning [Blitze] occurs, enough energy is released into the air nearby for so-called “nitrous oxides“ to form. These can be washed down into the ground with rain and form salts called nitrates, which plants can soak up, dissolved in water. Nitrates are also added as fertilizer [Dünger] to plants for growth.

**The chemical equation [chemische Gleichung]**

Every chemical process (chemical reaction) can be written or represented in a short symbolic form as a chemical equation. For this purpose the formulae of the substances are used. The substances which are brought together, the *reactants* [Ausgangsstoffe], are given on the left-hand side of the arrow, the *products* [Endstoffe] on the right-hand side. Here the *synthesis* [Herstellung] of water is shown in a chemical equation:

hydrogen and oxygen react to form water

$$2H_2 + O_2 \longrightarrow 2H_2O$$

or

$$H_2 + H_2 + O_2 \longrightarrow H_2O + H_2O$$

2 molecules of hydrogen react with 1 molecule of oxygen to 2 molecules of water ($H_2O$).
(The opposite reaction is also possible but only if a large amount of energy is added. Some living things, the green plants, can "break up" water molecules for photosynthesis, using a trick to lower the amount of energy needed.)

Here the *synthesis* of carbon dioxide is shown in a chemical equation:

carbon reacts with oxygen to carbon dioxide

$$C + O_2 \longrightarrow CO_2$$

1 atom of carbon reacts with 1 molecule of oxygen ($O_2$) to form carbon dioxide $CO_2$.

The numbers in front of the symbols indicate the proportions [Mengenverhältnisse] of the various molecules in the reaction.
*Like in a mathematical equation (with an "equal sign" (=) instead of an arrow), the same number of atoms or particles are to the left and to the right of the arrow.* In the synthesis of water 4 H atoms and 2 O atoms are both to the left and to the right of the arrow.
*The equation or the formulas of molecules cannot be simplified or shortened further* (not like mathematical equations) because *whole molecules* are needed to come together as reactants.
If the relative amounts of reactants are not available in the correct proportion to form the products, a part of them will be left over as shown in the following example.

In this chemical reaction electrons are transferred and a salt is formed (see 4.1) by bringing a *metal and chlorine (a so-called "halogen")* together, forming an ionic compound:

*Chlorine* [Chlor] is a corrosive [ätzend] gas ("swimming pool smell"). It exists as the molecule $Cl_2$ with a covalent bond between the two atoms. *Sodium* [Natrium] Na is a silvery soft metal. Together they react to form the white crystals of table salt, an ionic compound of a completely different nature! The reaction of chlorine with sodium to "sodium cloride" [Kochsalz] or NaCl:

$$Na + Na + Cl_2 \longrightarrow NaCl + NaCl$$

or

$$2Na + Cl_2 \longrightarrow 2NaCl$$

https://www.chemie-interaktiv.net/html5_flash/nacl_synthese_5.html

☞ 10.) Why are some Na atoms left over in this chemical reaction?

## 6) *Organic* and *inorganic* substances or compounds

*Organic compounds are without exception carbon compounds, their molecules always contain carbon (C) atoms.* Almost all carbon compounds [*Kohlenstoffverbindungen]* are organic. There are, however, some exceptions: very small molecules such as the gas CO (carbon monoxide, [Kohlenmonoxid]) and $CO_2$. These are considered to be *inorganic* compounds.

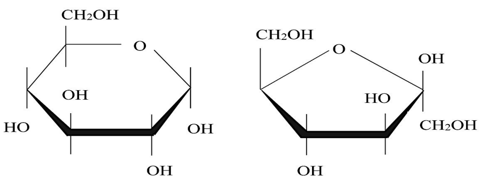
*The formation of organic compounds out of inorganic compounds only occurs naturally in living things.*

Many organic substances are not heat stable [hitzestabil]. They disintegrate when heated and finally turn black and carbonize [*verkohle*n]. The black coloration indicates the presence of carbon. Many organic compounds are combustible [brennbar].

| | **organic substances** | **inorganic substances** |
|---|---|---|
| natural formation | ***in living things*** | can be found everywhere |
| How many are carbon compounds? | ***all*** | a few: carbon dioxide $CO_2$, CO, carbonates |
| synthesis in the lab | possible | possible |
| behaviour in heat? | usually carbonize (verkohlen) | most melt and boil/ evaporate |
| examples | sugar, starch, fat, protein | water, ammonia, table salt |

*Little helpers*: Living things depend on many chemical reactions in their bodies, for example, they need to digest the food they eat and break it down into small molecules which they then can absorb from the intestine [Darm] into the blood stream. These may be energy-rich molecules such as sugar or building blocks for their bodies such as amino acids [Aminosäuren]. Such reactions, breaking down materials, would take place very slowly - we would starve! For this reason living things had to develop a way to speed up and optimize the chemical reactions in their metabolism [Stoffwechsel]. For this purpose they "invented" *biocatalysts* [*Bio-Katalysatoren]*, enzymes. Like a catalyst in a motor which optimizes the burning process, enzymes can break down large starch molecules in pasta into small sugar molecules which the body can easily absorb.

The *structure of an organic molecule is important for an organism* in order to be able to utilize the substance. This is true for the sugars: The numerical formula of a galactose sugar molecule is the same as that of the sugar molecule glucose, the most important fuel source for a living cell, but their 3-D structures are different! Because a molecule needs to react with others in the body, its structure needs to fit, it needs to be "recognized". Glucose, Galactose (and also fructose) all have the formula $C_6H_{12}O_6$!



Glucose Fructose Galactose

## 7) Some especially important elements in nature

### The 6 main elements that make up living things

About 25 common elements make up living things but only 6 of these make up 99% of their mass:

carbon [Kohlenstoff] **C**, oxygen [Sauerstoff] **O**, hydrogen [Wasserstoff] **H**, nitrogen [Stickstoff] **N**, sulfur [Schwefel] **S** and phosphorus [Phosphor] **P**.

(☞ See the separate file: "*Six main elements in living things*")

In addition, Calcium Ca, potassium [Kalium] K and Magnesium Mg are important. These elements are used by the organism to form proteins [Eiweisse], hormones, vitamins, fats, carbohydrates [Kohlenhydrate], bones, etc.

*Amounts of the most common elements in %*

| **Earth's crust** | | **human body** | | **melon** | |
|---|---|---|---|---|---|
| Oxygen | 49 | Oxygen | 65 | Oxygen | 85 |
| Silicon | 26 | Carbon | 18 | Hydrogen | 11 |
| Aluminum | 7 | Hydrogen | 10 | Carbon | 3 |
| Iron | 5 | Nitrogen | 3 | Potassium [Kalium] | 0.3 |
| Calcium | 4 | Calcium | 2 | Nitrogen | 0.2 |
| Sodium [Natrium] | 3 | Phosphorus | 1 | Phosphorus | 0.05 |
| Potassium [Kalium] | 2 | Potassium [Kalium] | 0.04 | Calcium | 0.02 |
| Magnesium | 2 | Sulfur [Schwefel] | 0.3 | Magnesium | 0.01 |

## The "air" or atmosphere

The Earth is enveloped in a gaseous layer, the *atmosphere*. Its 3 major roles for life on earth are:

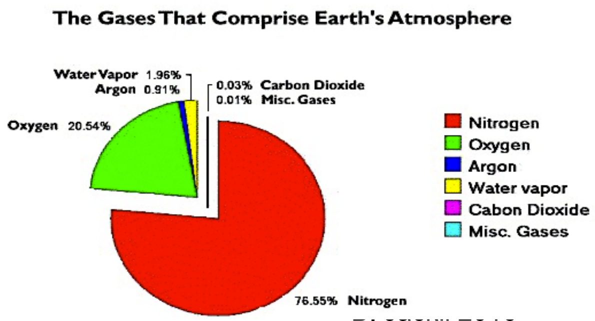
- It protects living things from dangerous radiation. (The earth's magnetic field is also crucial as it deflects the charged particles streaming in from the sun – the "solar wind" – and so protects the Earth's surface. The interaction between the these particles and the molecules of the upper atmosphere cause the "northern lights": https://www.youtube.com/watch?v=xl_qG0DuuMU)
- It influences and regulates the heat balance of the earth; its gases, especially water vapour and $CO_2$, absorb the rays of the sun (= natural greenhouse effect). (This is why the earth has an average temperature of +15°C instead of -17°C!) https://scentofpine.files.wordpress.com/2011/05/greenhouse_effect2.jpg
- It distributes gases, e.g. oxygen ($O_2$), which almost all organisms need to breathe, and carbon dioxide ($CO_2$), which green plants and other one-celled small green organisms with chlorophyll need in order to make photosynthesis in order to make sugar (food).

### *"Air" is a mixture of many different gases!*

The air or atmosphere contains the following gases:

nitrogen [Stickstoff] *(about 78%)*, the most abundant, exists as molecules of $N_2$, *oxygen* [Sauerstoff] *(20.9%)*, exists as molecules of $O_2$, "noble" gases [Edelgase] *(0.9%)* such as argon Ar, krypton Kr and xenon Xe exist as atoms ("noble" meaning they do not react naturally with other elements) and carbon dioxide [Kohlendioxid] *(0.035%) as $CO_2$.* The rest, a mixture of other gases, is only 0.006%.

About 1.96% is also water vapour, which is usually not counted as a gas as it falls back onto the earth and evaporates again into the atmosphere.



**Water, the strangest chemical on earth**

Without water, life on earth as we know it would not be possible! Water has some strange properties making it *the most unique and special liquid of life*!

Water, the “strangest chemical on earth“ is explained in this lively video:

https://www.theguardian.com/science/video/2015/may/28/water-strangest-chemical-universe-explainer-video

An organism’s chemical processes, its “metabolism“ [Stoffwechsel], all take place in the *watery inside, the “milieu“* of the body. Salt and many other substances are taken into an organism dissolved in water, they are transported around the organism and are then excreted [ausgeschieden] from it *dissolved in water*. This means that an organism has to drink or take in a lot of water. An adult human needs about 2 litres a day and is *60 - 70% water*. The amount of water in organisms ranges from *50* to *90%.*

*Amount of water* in % of total weight

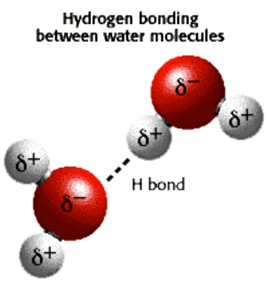
| | | | | |
|---|---|---|---|---|
| food | flour 7 | butter 10 | meat 55 | salad 90 |
| organism | beetle 50 | human 60 | fish 80 | plants 90 |
| parts of organisms | seeds 15 | wood 50 | bones 30 | skin 70 |

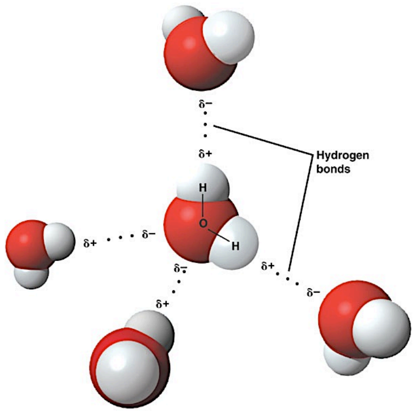
There are some exceptions when animals have very little access to water, for example desert mice, which can utilize the water produced when the energy in their food is released during cellular respiration. This is called “metabolic water“ [“Stoffwechsel-Wasser“].

*“Bridges“ between molecules or “**hydrogen bonds**“* [Wasserstoffbrücken]

The attraction between the partly positve H atom and the partly negative O atom in molecules with shared electrons such as in water with its covalent bonds can lead to the formation of “bridges“ between the molecules or *hydrogen bonds*.

Do you remember the water molecule in section 4.2?.
You may want to check it again.

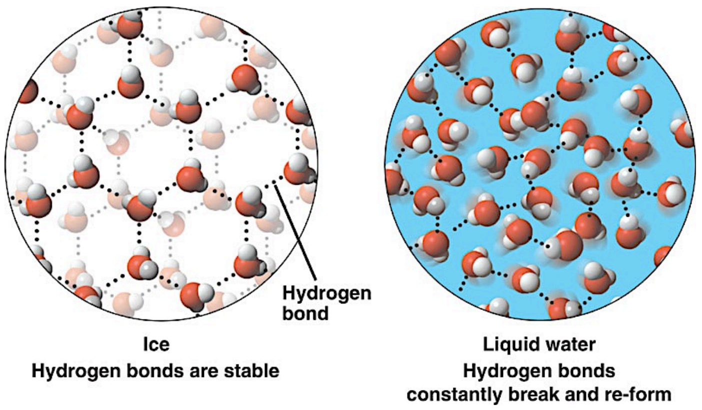



Strong bonds between water molecules means that they show a strong *cohesion* [Zusammenhalt]; this strong “sticking together“ creates a strong surface tension at the “edge“ where water ends and air begins, e.g. in a water drop or at the bulging surface of an overfull water glass:

☞ <u>"Sticky water"</u> You can try this *experiment* in class or at home to demonstrate how strongly the water molecules attract eachother and stick together:
http://www.exploratorium.edu/ronh/bubbles/sticky_water.html

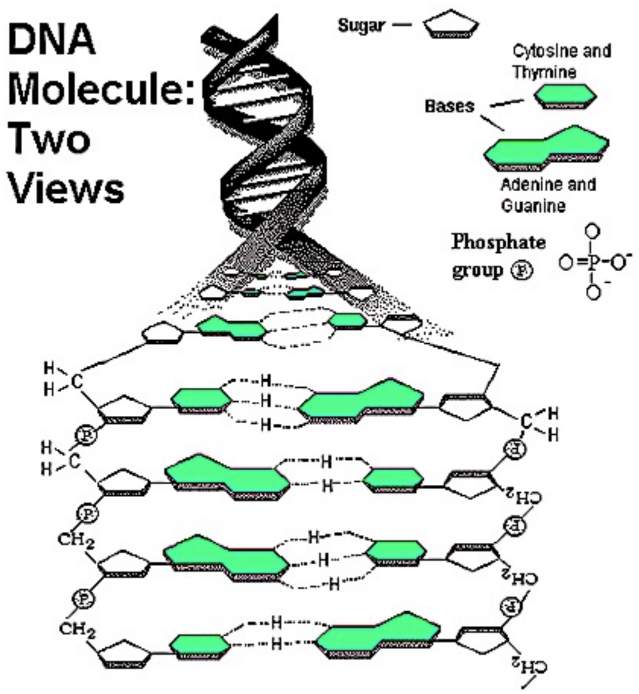
☞ 11). Explain to someone why the special way that *ice forms* in lakes and rivers as it freezes is favourable for life in water. See https://www.youtube.com/watch?v=UukRgqzk-KE




<u>Hydrogen bonds not only form between water molecules – "the example of DNA"</u>

As you may know, DNA is the molecule which carries the genetic information of humans, animals and plants. You may have seen a model of the "staircase"- like DNA molecule in class.

*Hydrogen bonds* enable the two strands of DNA to stay together until they need to be separated when the information in the DNA needs to be accessed.

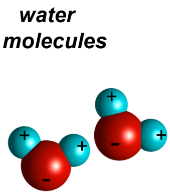


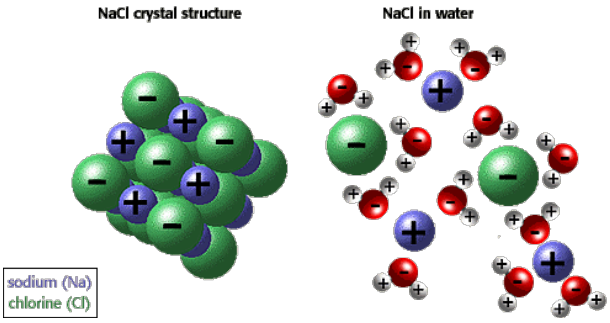

The hydrogen bonds between the two stands of DNA are useful to keep them in place. But they can also easily be disconnected when necessary, for example when the strands need to be accessed for information or in making new copies.

Water, the most important ***solvent*** [Lösungsmittel] in nature

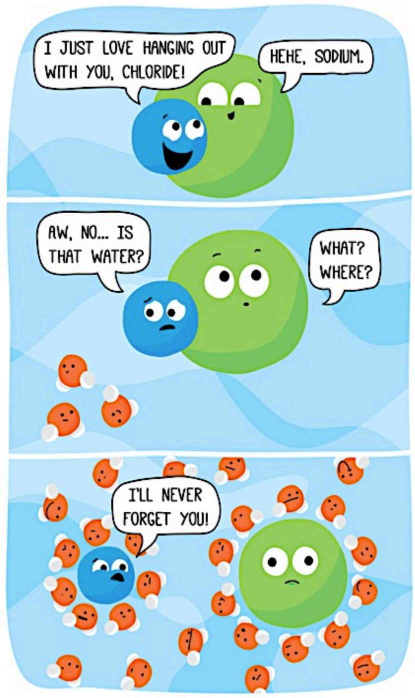
Water is the most important solvent for those molecules and salts which need to be taken up and be excreted from an organism!

When water molecules, having a more positively and a more negatively charged side, come into contact with the positive and negative charges of the outer ions of a salt crystal the attraction force of the water molecules on the ions is so strong that they are able to “pull away“ the outer ions and transport them off. This process of a *salt dissolving in water* continues until either all the salt is dissolved (distributed evenly in the solution) or stops because there are not enough water molecules to surround all the ions. In that case some of the salt remains (as crystals) in the solution.




*...or another view of this process:*




GETTING DISSOLVED CAN BE TRAUMATIZING.

Beatrice the Biologist

Here you can follow table salt (NaCl) being dissolved in water (in German):

https://www.youtube.com/watch?v=xdedxfhcpWo

*The substance “water“ and its special properties will continue to appear throughout this semester!*

.................................................................................................................................

**Answers** to the questions in the text

1.) **fest** / **solid** — *to melt (melting)* / *schmelzen* → **flüssig** / **liquid** — *to evaporate (vaporization)* / *verdampfen* → **gasförmig** / **gaseous** **(Zustand)** / **(state)**

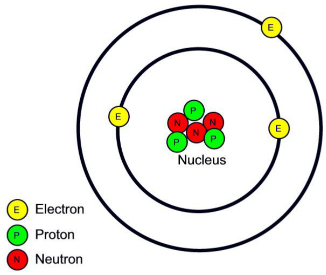
← *gefrieren/ erstarren* / *to freeze/ freezing (solidify/ solidification)* ← *kondensieren* / *to condense/ condensation*

*When vaporisation of a liquid takes place above boiling temperature it is called “boiling“.*
See also: http://www.bbc.co.uk/education/guides/zccmn39/revision/2

2.) The air around a cold aluminum can or glass bottle suddenly becomes colder; cold air can hold less water vapour than warm air. For this reason the excess water condenses as drops around the can or bottle.

3.) Lithium Atom:

nucleus (Kern) with 3 positively charged protons and neutrons, 3 electrons (negatively charged) in the shells [Schalen] around the nucleus
(number of protons = number of electrons)




4) $Ca^{2+}$ , $Se^{2-}$ , $Br^{-}$

6) One type of ion has only one type of charge, + or - (for example. $Na^{+}$). These would repel eachother (like the same magnetic poles). In order to get a solid lattice you need to bring + charged and – charged ions together which attract eachother (the same amount of + charges as - ones).

8) Fish cannot “crack open“ the stable water molecule ($H_2O$) to get at the oxygen in it. They have to take in the oxygen molecules ($O_2$) dissolved [gelöst] in the water through their gills [Kiemen] where they can be taken into the blood stream. Oxygen (molecules) continuously diffuse (or wander) in and out of the water and the air.

http://www.seilnacht.com/Lexikon/6Sauerst.htm#p

9) Atoms: Fe, C, Hf (Some atoms have a symbol with 2 letters: then the first letter is in capitals, the second is not).
Ions: $O^{2-}$, $K^{+}$ (The electrical charge [Ladung] is written above the letter)
Molecules: $O_2$, $N_2$, HF, $NH_3$ (The number of atoms is written below the letter)

10) Na ions are left over because there were too many of them. The proportion of Na ions to Cl ions needs to be 1:1 in order to form NaCl (or $Na^{+1}Cl^{-1}$).

11) Ice floats on water and enables organisms in a lake to survive in the liquid waters below the ice. Ice floats because there are spaces between the water molecules in the crystals. This is why ice is lighter than liquid water. Spaces form because the “bent“ water molecules try to lie next to eachother so that the positively charged sides (H atoms) lie next to the negative sides (O atoms). (See also 1).

....................................................................

☞ When you have finished the unit you can check some facts on this website:

http://www.rsc.org/Education/Teachers/Resources/cfb/basicchemistry.htm

You can revise (click on activity video) some of the topics here and take short tests!

For example “states of matter“: http://www.bbc.co.uk/education/topics/ztm6fg8

.........................................................................

Learning objectives

You can:

1. describe what kind of processes take place in chemistry and the difference between chemical reactions and physical changes in state.
2. describe what a chemical equation expresses, and explain why it is called an equation.
3. explain what atoms are, state their approximate size and describe how they are built (nucleus/ shells; subatomic particles, their place, charge and relative numbers in an atom). *Name parts in English*
4. state the *most important* difference between atoms of different elements.
5. explain what a molecule is, what an ion is, how an atom can become an ion and recognize the 3 particles according to their symbols.
6. explain the difference between and state an example of a molecular compound (what is a covalent bond) and an ionic compound (ionic bond).
7. explain how the periodic table is organized and what it shows (and state a typical property of each group: metals, nonmetals, halogene and noble gases); explain the tendency of halogens and metals to react,
8. explain the two main differences between organic and inorganic compounds.
9. describe the 3 main roles of the atmosphere (air) for life on Earth.
10. name the 4 main gases in the air (in English) state their amounts (in %, averages) and write their formulas ($N_2$, $O_2$, $CO_2$ and noble gases, e.g. Ne).
11. explain the importance of water for living things (incl. the formation of ice and hydrogen bonds).
12. name the 6 most common elements in living things, write their chemical symbols and describe their elemental properties in a few words (group in periodic table).
13. write the chemical formulas for the following molecules: water, oxygen, nitrogen, carbon dioxide and explain what the numbers mean.
14. name the three states of matter and the change from one state to another; you can choose correct satements on how the molecules can move in each state (for example water). (in English)
15. say what an "isotope" is and explain the difference between the isotopes of a given element.

...............................................................

This tutorial is based on *compendio Biologie: Grundlagen und Zellbiologie* by M. Bütikofer (2003) (compendio.ch)

Illustrations

compendio.ch

www.chemieunterricht.de/dc2/grundsch/versuche/gs-v-152.htm

www.seilnacht.com

(water molecules) http://foro.agricultularegenerativa.es/viewtopic.php?f=53&t=101

http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page3.html