General Chemistry - Lecture 1
Fundamentals I

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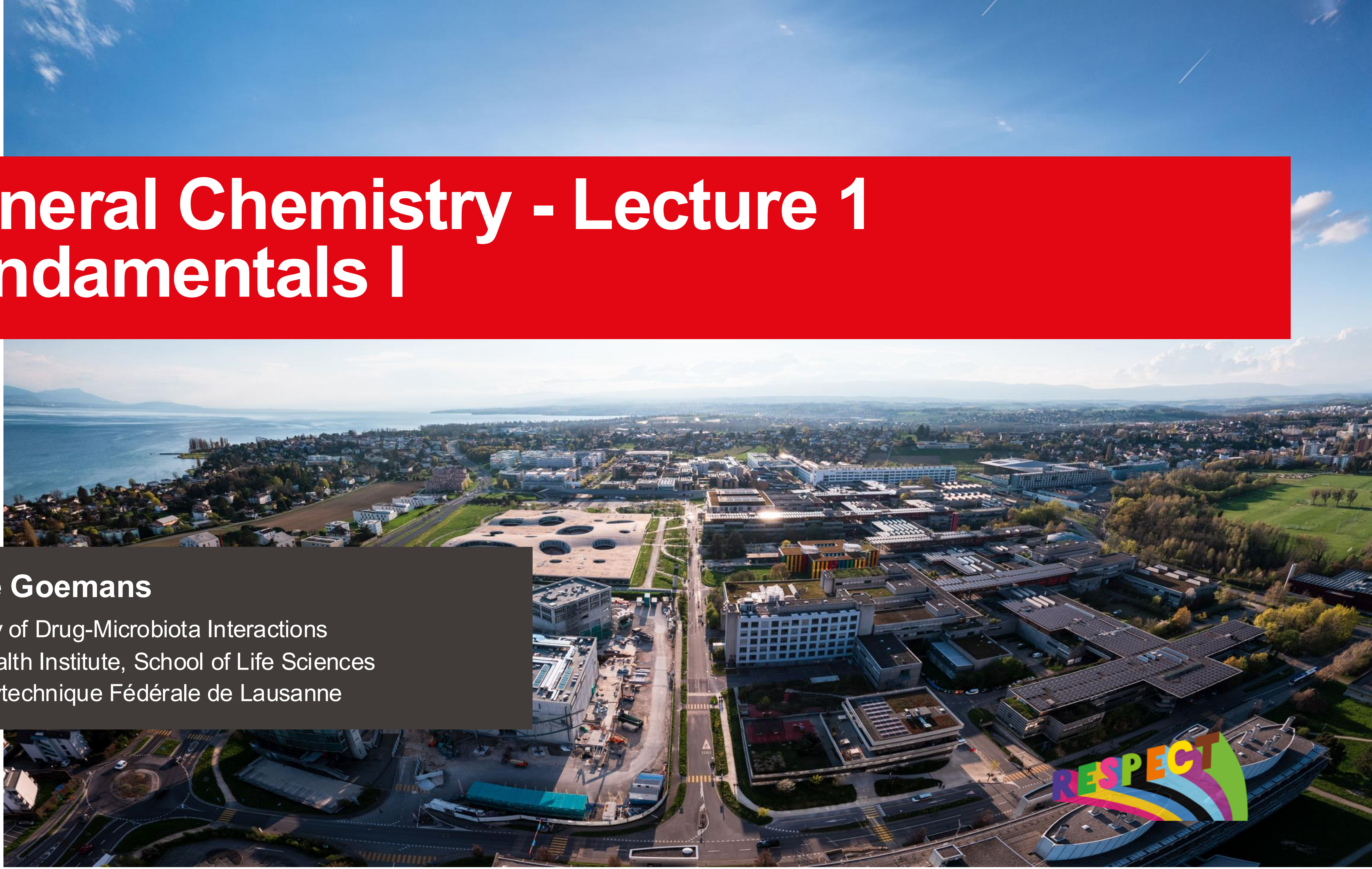


What you need to know

- **Fundamentals – lectures 01 and 02**

- You should be familiar with all these notions as they are the basics to understand what comes next

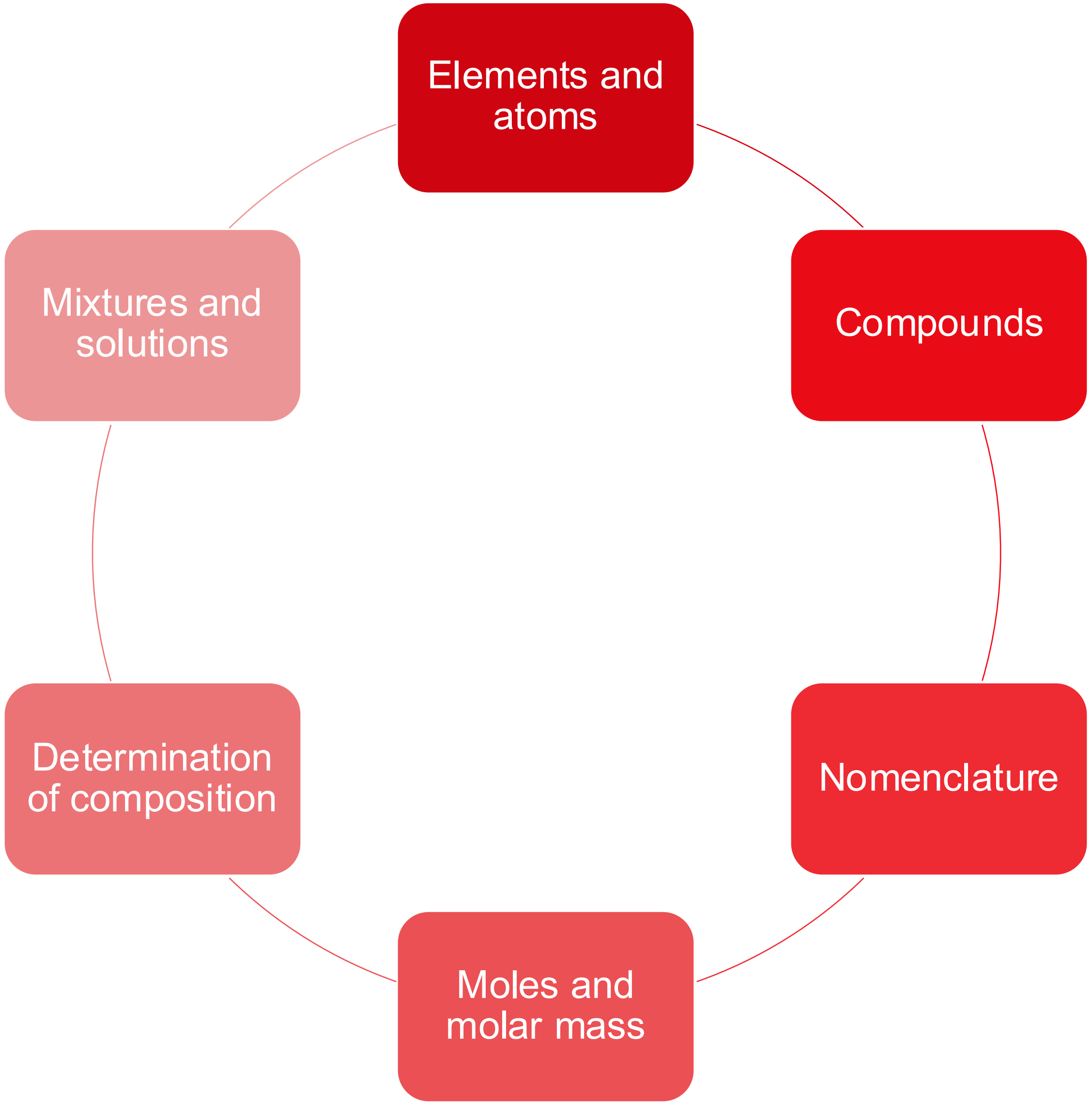
- This class is supposed to be a **reminder** of concepts that you already know

- The goal is to have everybody on the same page

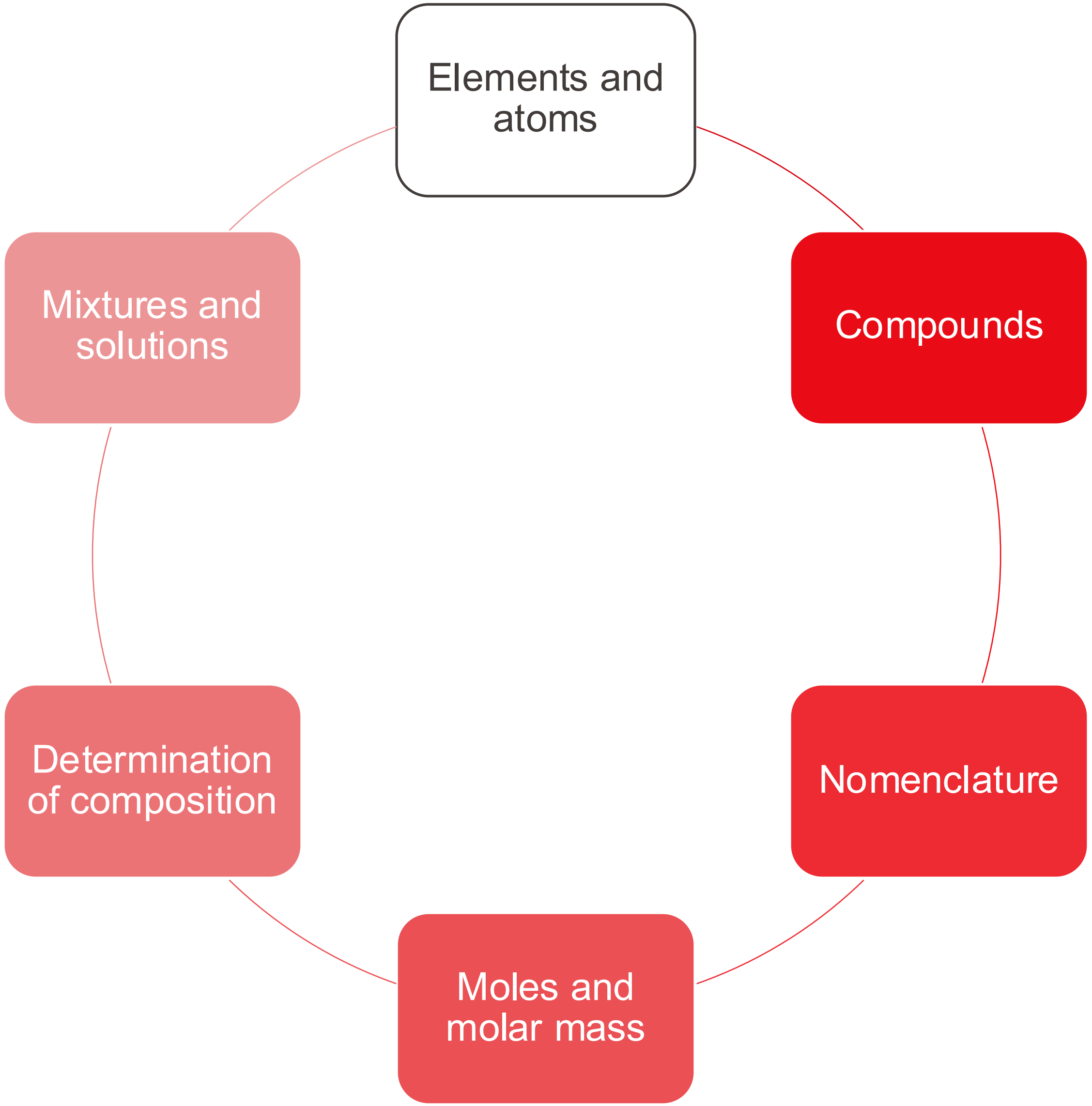
- For the next classes, we consider that **all of these concepts are known** by each of you

- If it is not the case: make sure to spend some time **now** to familiarize with those, in order to be able to follow the next lectures

Plan


Elements and atoms
Compounds
Nomenclature
Moles and molar mass
Determination of composition
Mixtures and solutions

Plan



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Elements and atoms

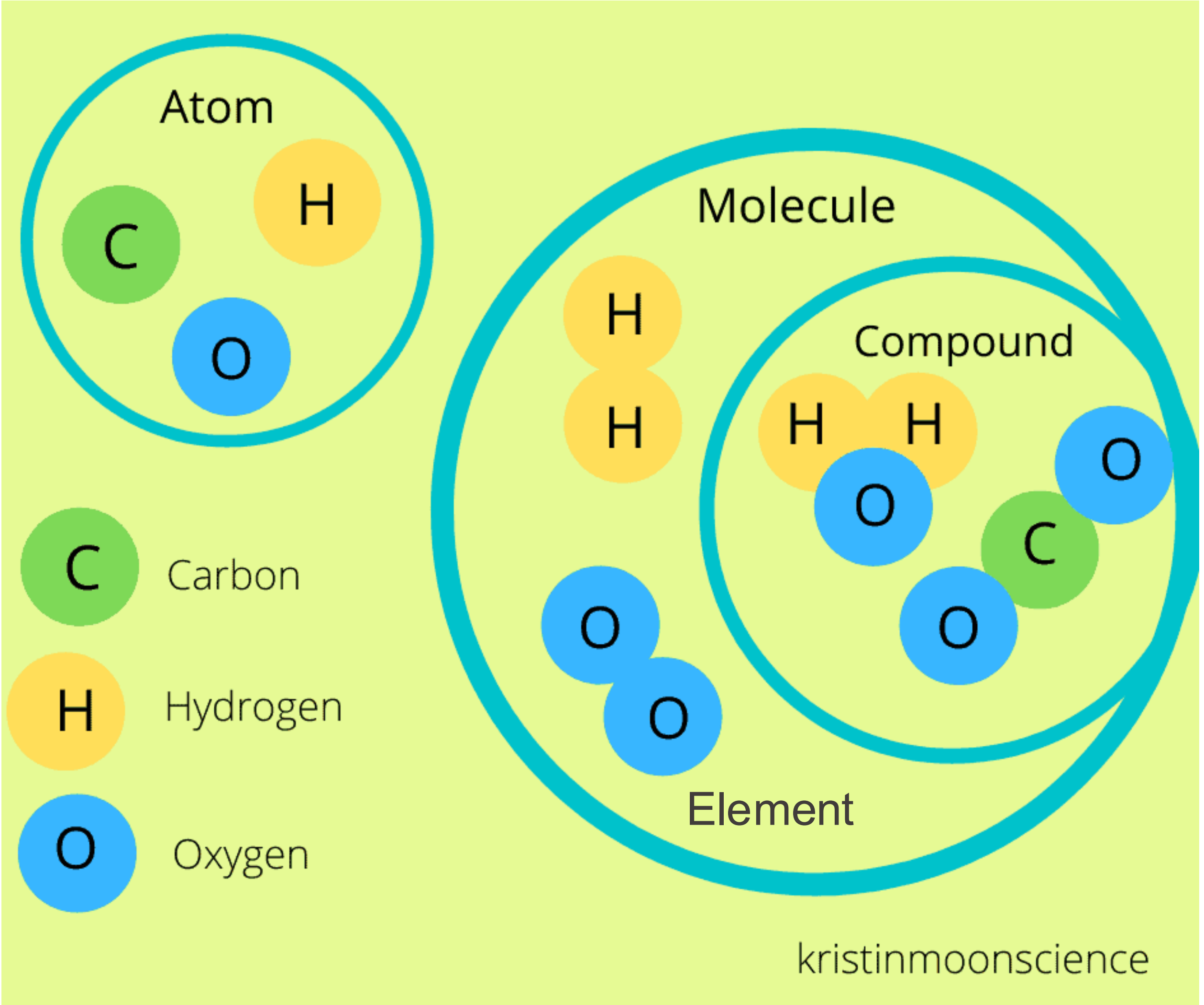
- Everything around us is made out of a few elements
- We know a little over 100 elements
- Each element has a name and a chemical symbol (1 or 2 letters)

Dalton's atomic hypothesis (~1800)

- All atoms of a given element are identical *(not always actually true, see isotopes)*
- The atoms of different elements have different masses
- A compound is a specific combination of atoms of more than one element
- In a chemical reaction, atoms are not created or destroyed, they exchange partners to produce new substances

John Dalton

Elements and atoms

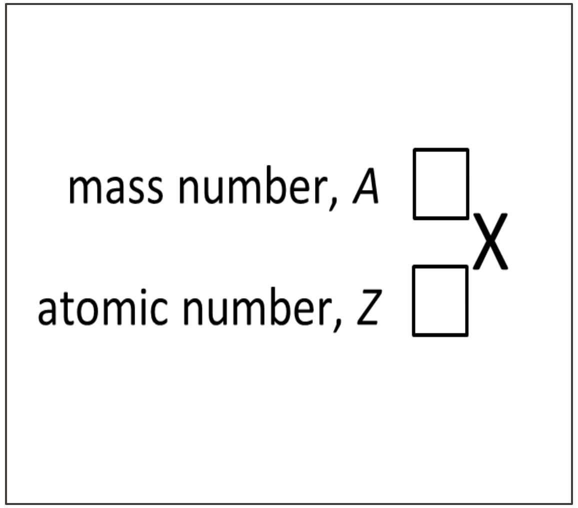


The nuclear model

- The nucleus contains positively charged **protons**, neutral **neutrons** and is surrounded by negatively charged **electrons**

Particle	Symbol	Charge	Mass (kg)
electron	e^-	−1	9.109×10^{-31}
proton	p	+1	1.673×10^{-27}
neutron	n	0	1.675×10^{-27}

- The **negative** charge of the electron cancels the **positive** charge of the proton (the atom is electrically neutral)
- The **atomic number Z** of an element represents the number of **protons** in the nucleus of one atom of this element
- The **mass number A** represents the number of **protons and neutrons** in a nucleus



Isotopes

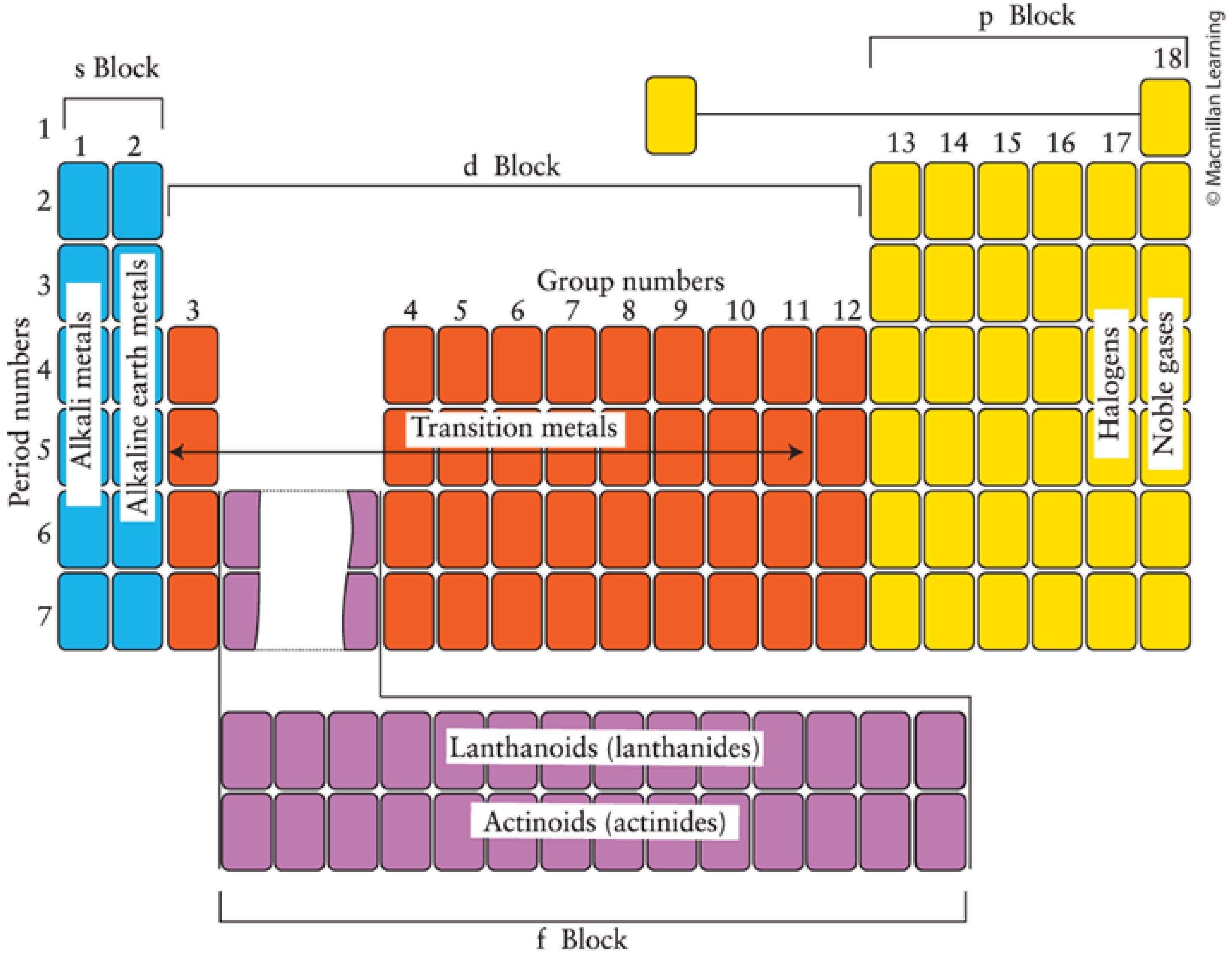
- Isotopes from a given element have the same atomic number but a different mass number
- Their nuclei have the same number of protons but a different number of neutrons

Element	Symbol	Atomic number, *Z*	Mass number, *A*	Abundance, %
hydrogen	^{1}H	1	1	99.985
deuterium	^{2}H or D	1	2	0.015
tritium	^{3}H or T	1	3	____*
carbon-12	^{12}C	6	12	98.90
carbon-13	^{13}C	6	13	1.10
oxygen-16	^{16}O	8	16	99.76

*means radioactive and short-lived.

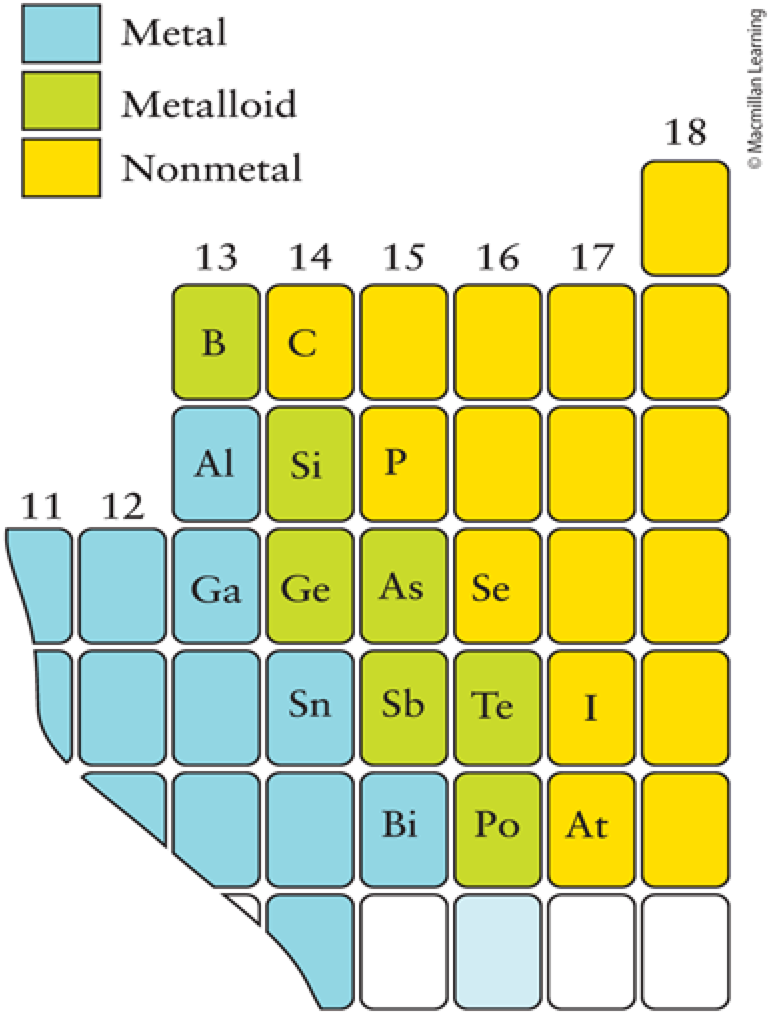
The periodic table

- Groups are vertical columns (1-18)
- Periods are horizontal rows (1-7)



The periodic table

- A **metal** conducts electricity and is malleable and ductile (=étirable)
- A **nonmetal** is an insulator and is not malleable or ductile
- A **metalloid** appears like a metal but can behave as a metal or non-metal



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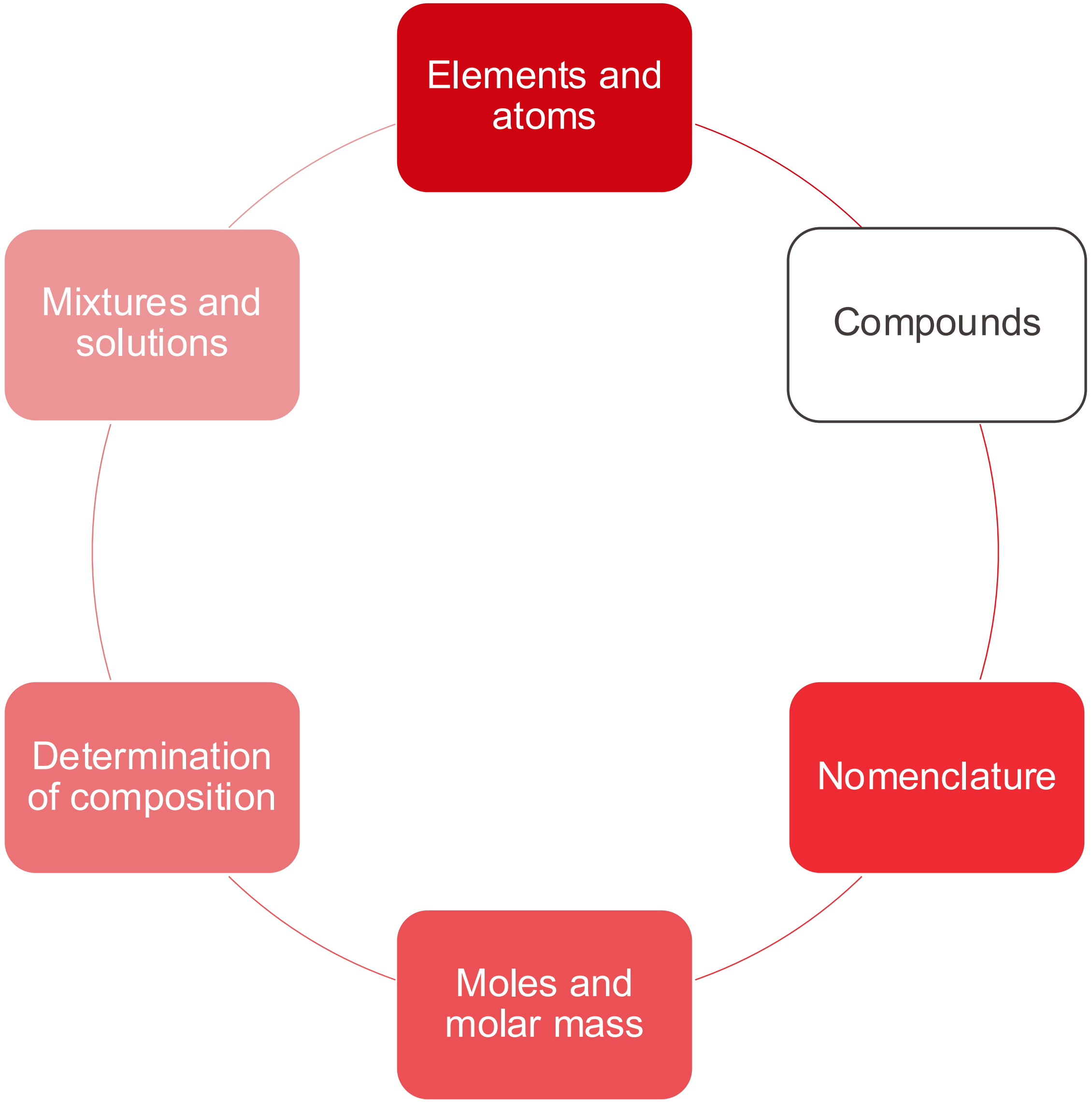
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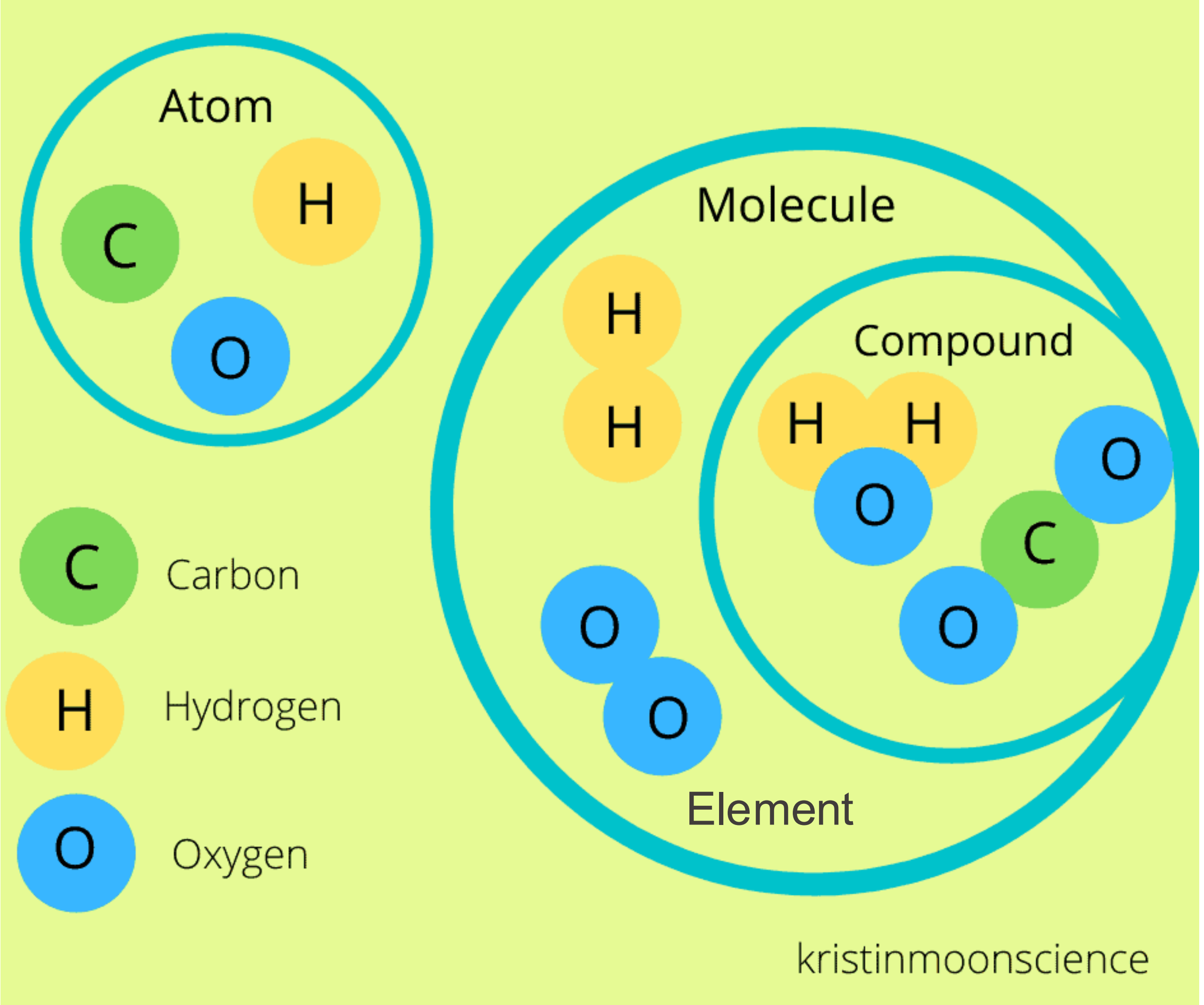
Elements and atoms



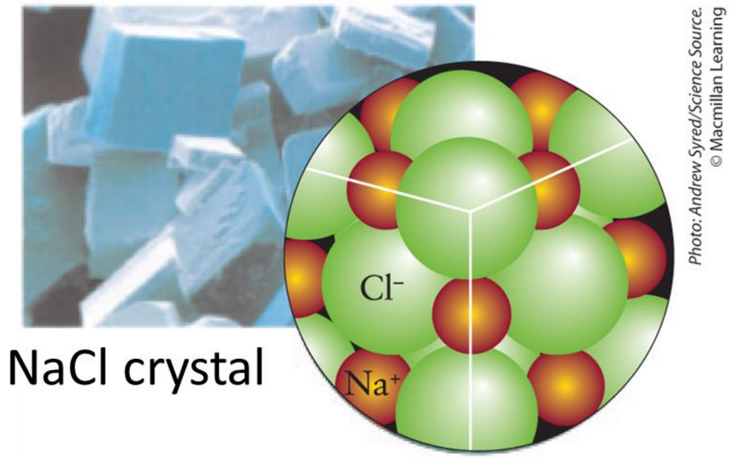
Compounds

- **Combinations** of a small number of elements form **any type of matter**
- Chemistry **analysis** is the discovery of what is actually combined in a substance
- Chemistry **synthesis** is combining elements to produce compounds

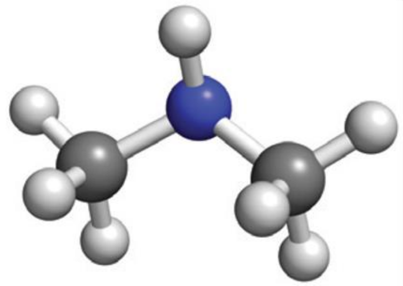
Compounds – which atoms are they made of ?

- Compounds are electrically **neutral** and consist of **two or more elements** (binary compounds consist of two elements, e.g. H_2O)
- They are classified as **organic** or **inorganic**
- **Organic** compounds contain **carbon** and usually hydrogen (derived from life)
- **Inorganic** compounds are all the **other compounds**

Compounds – what type of interaction ?



- **Ions** are positively (cations) or negatively (anions) **charged** atoms. They are not isolated; they are held together in a **crystal – ionic compounds**



- **Molecular compounds** are **discrete** groups of atoms bonded together in a specific arrangement

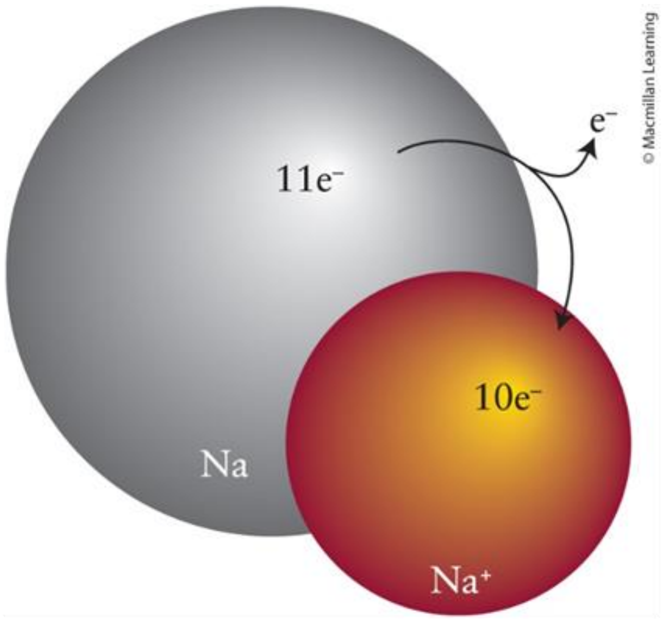
Cations and anions

- **Cations** are **positively** charged
  - Na^+ is the sodium cation
  - Ca^{2+} is the calcium cation
  - Some cations are “poly-atomic” like ammonium, NH_4^+

- **Anions** are **negatively** charged
  - Cl^- is the chloride anion
  - Some anions are “poly-atomic” like carbonate, CO_3^{2-}

Cation formation

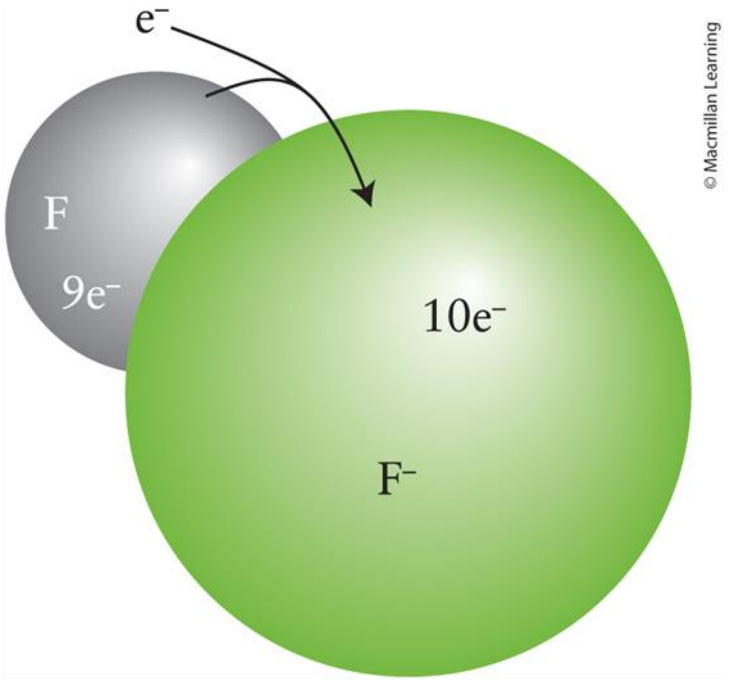
- An **electron** has **one unit** of negative charge (e-)
- **Removing** an electron from a neutral atom leaves a **cation**
  - Ex: a sodium cation is a sodium that lost one electron
  - Ex: a calcium atom that loses two electrons is a doubly positively charged cation, Ca^{2+}



Sodium has 11 protons.

Anion formation

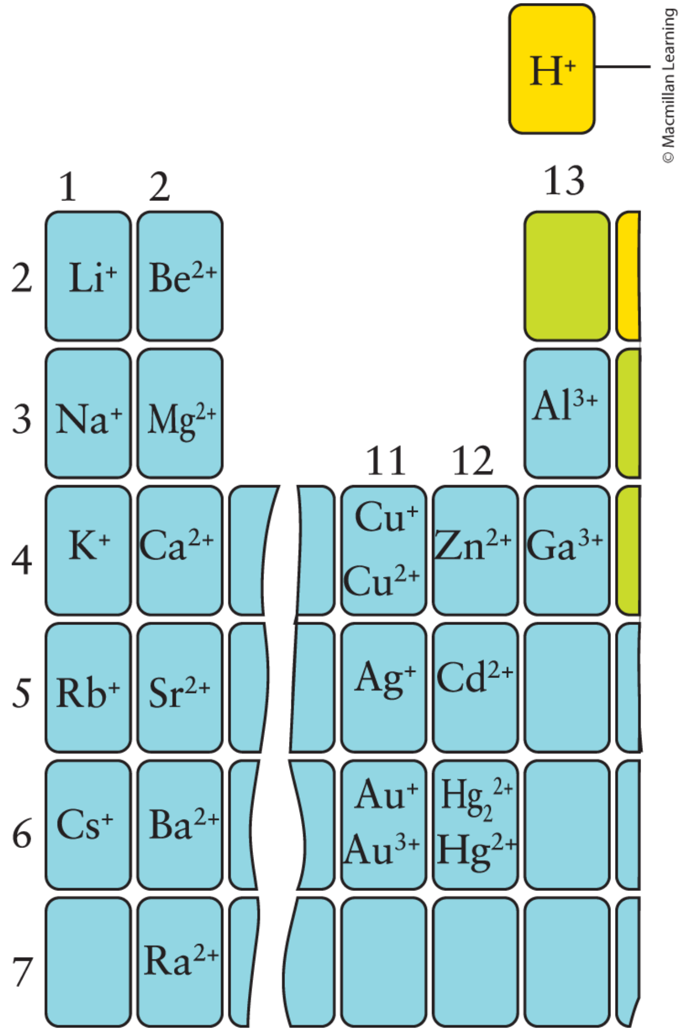
- **Adding** an electron to a neutral atom forms an **anion**
  - Ex: a fluorine atom gains one electron and becomes negatively charged, F^-
  - Ex: an oxygen atom gains two electrons and becomes doubly negatively charged, O^{2-} (oxide ion)



Fluorine has 9 protons.

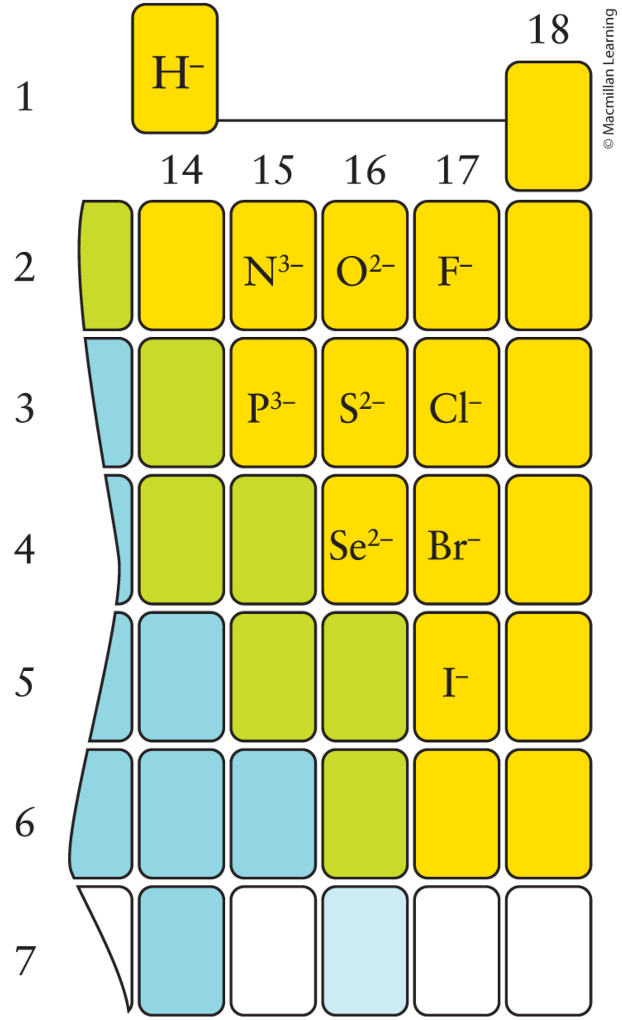
Metals typically form cations

- **Metallic** elements typically form **cations** by electrons loss
- Elements from **group 1, 2, 3** form **+1, +2, +3** cations respectively
- Some elements from the d-block can form cations with **different charges** (ex: Cu^+ and Cu^{2+})



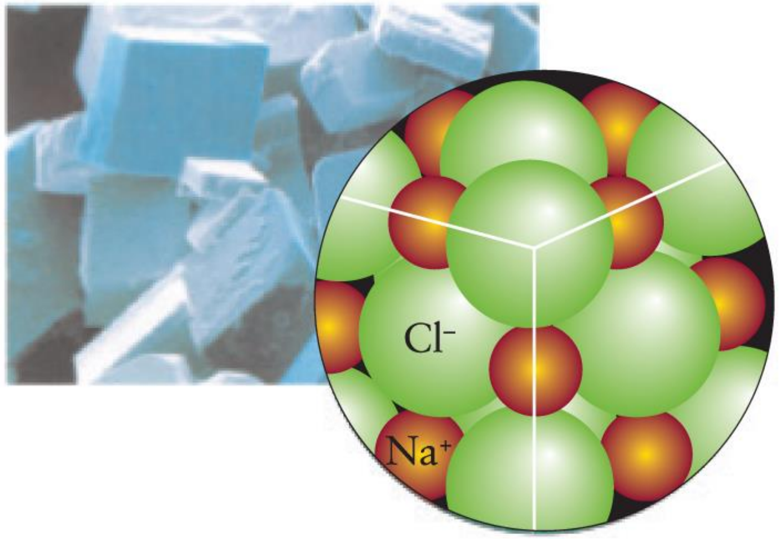
Nonmetals typically form anions

- **Nonmetals** typically form **anions** by electrons gain
- Elements from **group 15, 16 and 17** form **-3, -2 and -1 anions** respectively



Ionic compounds

- **Ionic solids** contain **anions and cations**
- Each **crystal** may have different amounts of anions and cations from another crystal, but the ratio stays the same
  - Ex: In sodium chloride (NaCl), the ratio between Na^+ and Cl^- is always 1:1



Ionic compounds

- All compounds are overall **neutral**
  - Sodium carbonate has two Na^{+} (sodium) ions per CO_3^{2-} (carbonate) ion; so, its formula is Na_2CO_3
- When subscripts are added to a polyatomic ion, the ion is written within parentheses
  - NH_4^{+} SO_4^{2-} $\Rightarrow$ $(NH_4)_2SO_4$
  - The "2 subscript" on the outside of ammonium means that there are two NH_4^{+} (ammonium) ions for each SO_4^{2-}

Molecular or ionic compounds

- **Two nonmetals** combine to form a **molecular compound**
  - Nonmetal + nonmetal
  - Electrically neutral
  - Ex: water, H_2O (binary molecular compound)

- **A nonmetals and a metal** combine to form an **ionic compound**
  - Nonmetal + metal
  - Combination of ions that are in total electrically neutral
  - Ex: sodium chloride or salt, NaCl (binary ionic compound)

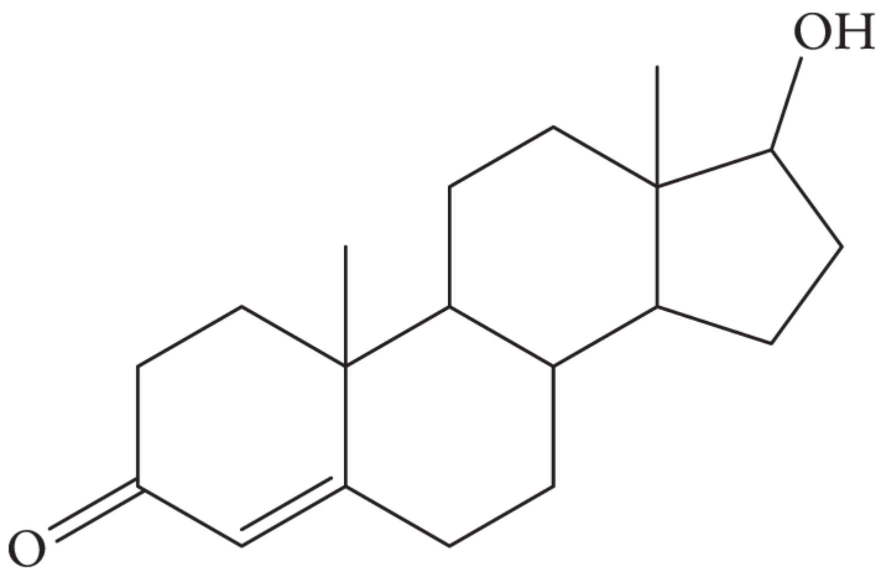
Compounds – how many atoms ?

- **How many atoms in the compound?**
  - **Diatomic** molecules are made of **two atoms** (NO, CO, H_2, O_2)
    - ✓ ! Different from binary compounds
  - **Polyatomic** molecules consist of more than **two atoms** (NH_3, H_2O_2)
  - **Ions** can also be diatomic or polyatomic
    - CN^- (cyanide) - diatomic
    - NH_4^+(ammonium) - polyatomic
    - carbonate, CO_3^{2-}
    - nitrate NO_3^-
    - phosphate, PO_4^{3-}
    - sulfate, SO_4^{2-}

Polyatomic - common ions containing oxygen are called oxanions

Chemical formulas – how to write compounds?

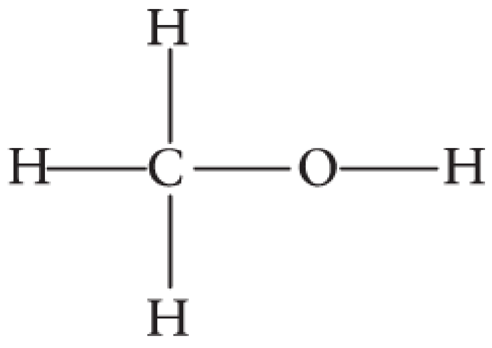
- **Chemical formulas** represent the **composition of elements** in a compound



4 Testosterone, $C_{19}H_{28}O_2$

Molecular, condensed or structural formulas

- The **molecular** formula of methanol is $\mathbf{CH_4O}$
- The **condensed** structural formula is $\mathbf{CH_3OH}$**,** which gives information about the structure
- The **structural** formula indicates how atoms are linked together. Each line represents a chemical bond.



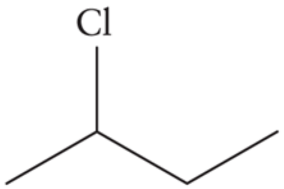
1 Methanol, CH_3OH

Line structures

- **Carbons** form 4 bonds; there is no need to show **C-H** explicitly
- The other atoms are shown by their **symbol**

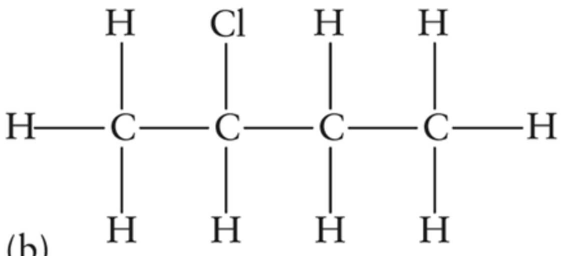
line structure

(a)



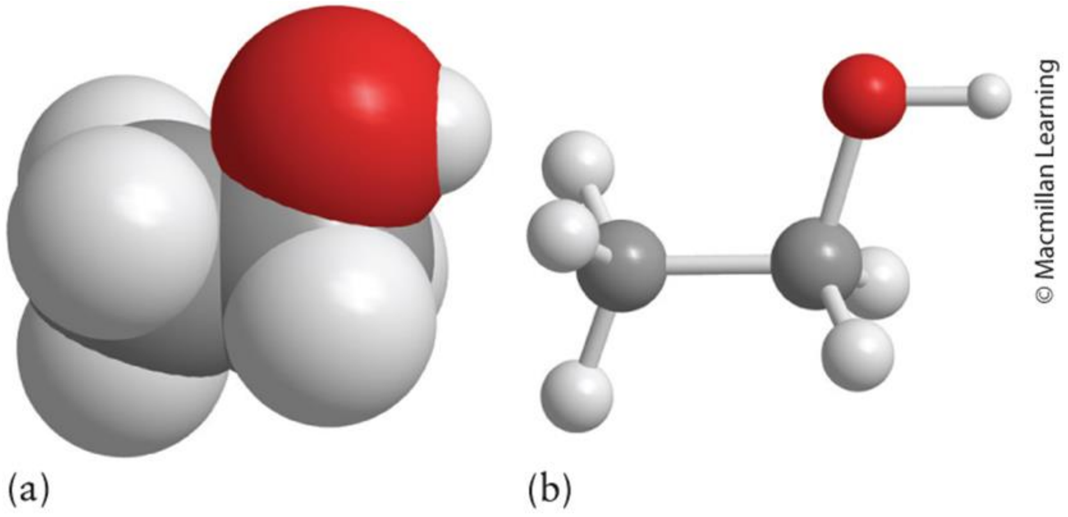
structural formula

(b)



3 2-Chlorobutane, $CH_3CHClCH_2CH_3$

Space-filling and ball-and-stick models

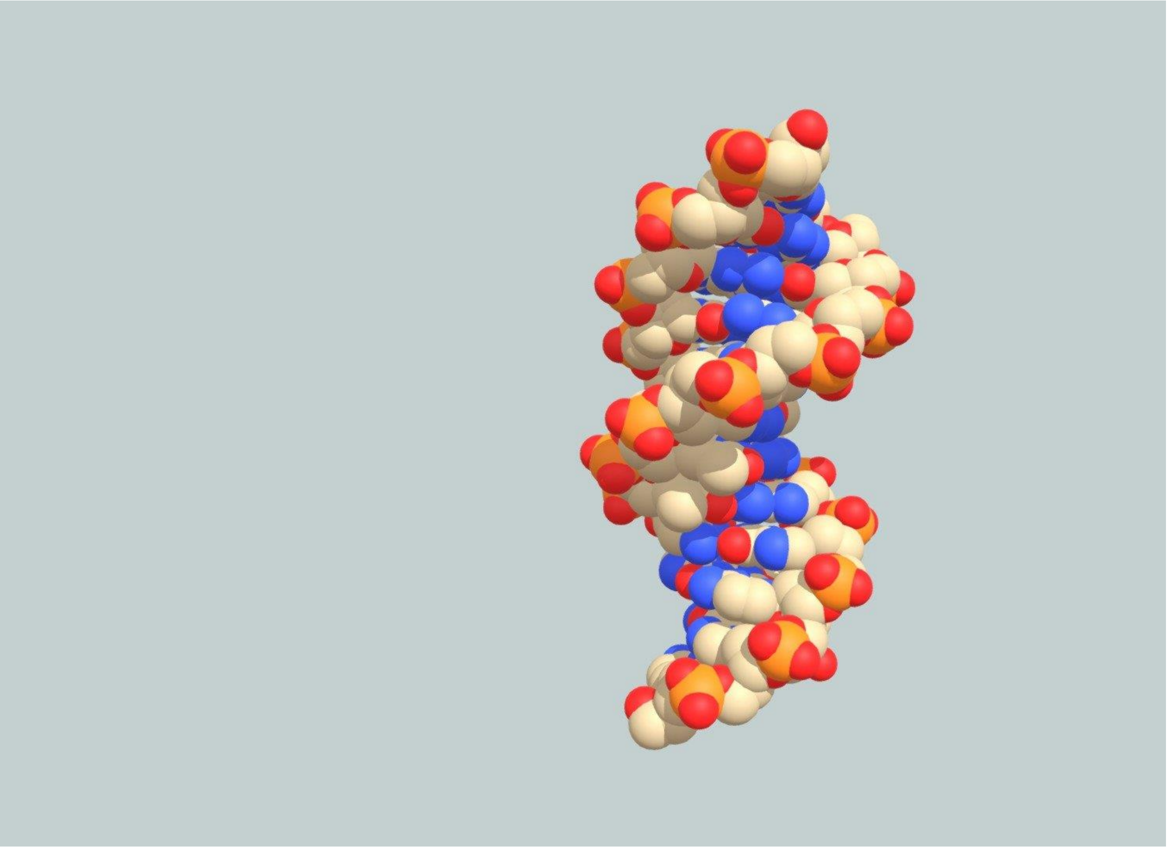


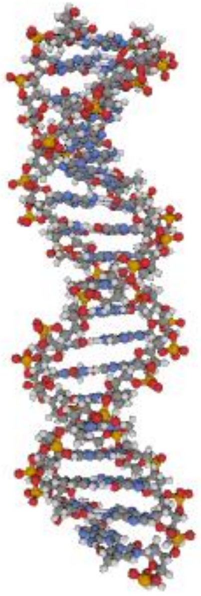
CH_3CH_2OH

Ethanol

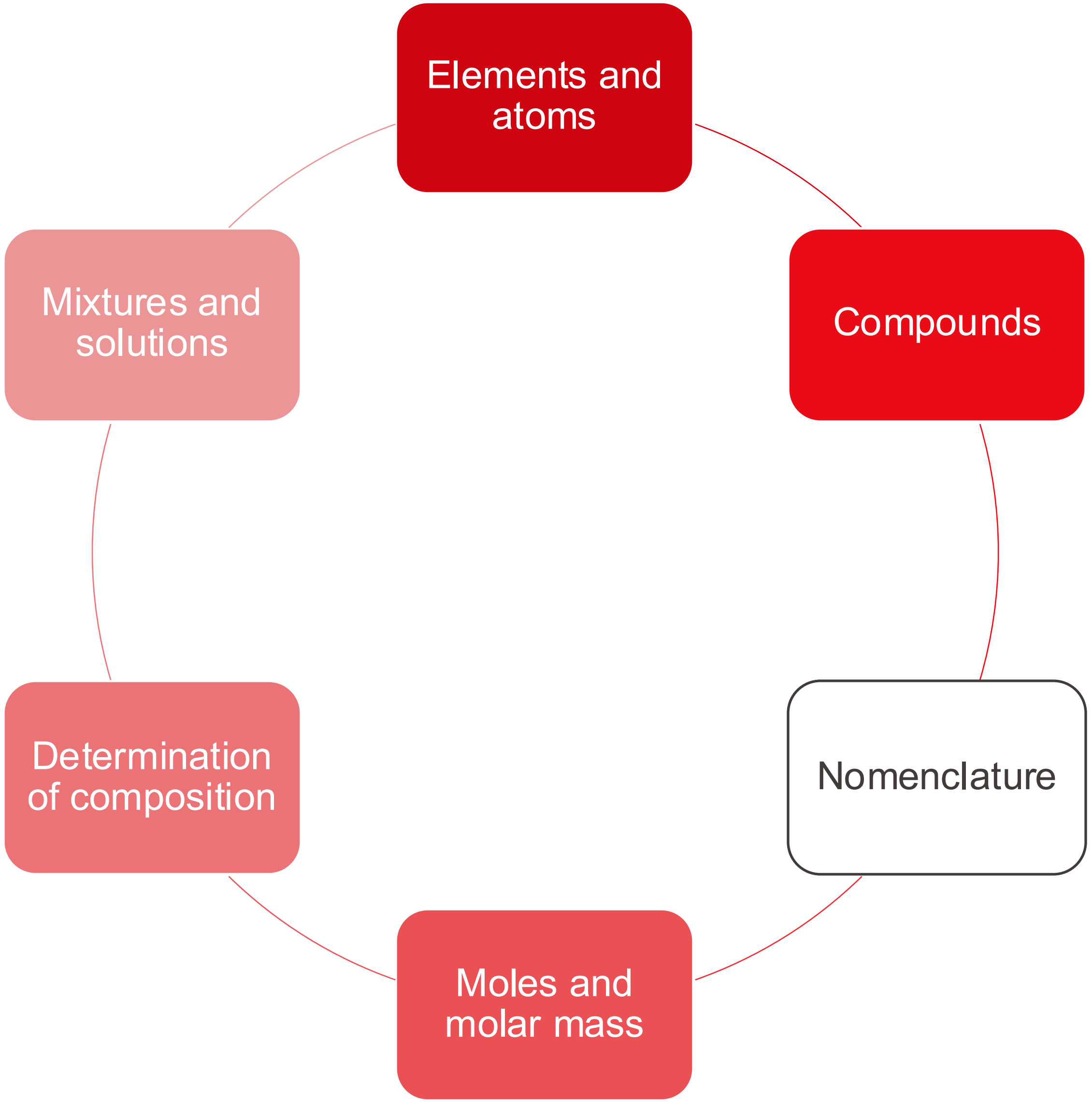
- **Space-filling model:** atoms are represented by spheres that fit into one another
- **Ball-and-stick model:** Atoms are represented by small spheres and bonds by sticks

Space-filling and ball-and-stick models





Plan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Nomenclature

- In addition to their common name (water, salt,…), compounds have a **chemical name**

- **Names of cations**
  - Na^+ is a monatomic cation so its name is "sodium ion."
  - Copper exists as Cu^+ and Cu^{2+} because it has more than one oxidation number
    - Cu^+ is a copper(I) ion
    - Cu^{2+} is a copper(II) ion
  - An *older system* of cation nomenclature uses **-*ous* and -*ic* suffixes** for ions with lower and higher charges, respectively.
    - Cu^+ is the copper(I) ion or cuprous ion.
    - Cu^{2+} is the copper(II) ion or cupric ion.

EPFL

Nomenclature

- **Names of anions**
  - Monatomic anions, such as the Cl^- ions in sodium chloride and the O^{2-} ions in calcium oxide, are named by adding the **suffix *-ide*.**
    - Cl^- is the chloride ion.
    - O^{2-} is the oxide ion.
    - C^{4-} is the carbide ion.
    - Br^- is the bromide ion
  - If only a *single* **oxoanion** exists for an element, the suffix *-ate* is added to the stem. For example: carbonate ion, CO_3^{2-}.
  - If there are multiple forms, ions with a larger number of oxygen atoms are given the suffix -*ate*, and the smaller are given the suffix -*ite*.
    - NO_2^- = nitrite ion
    - NO_3^- = nitrate ion

Nomenclature

- **Names of anions**
  - Some elements, particularly the **halogens**, can form more than two kinds of oxoanion
    - That with the greatest number of oxygen atoms has a *per*- prefix and -*ate* ending.
    - That with the least number of oxygen atoms has a *hypo*- prefix and -*ite* ending.
      - **per**fluor**ate** ion FO_4^-
      - chlor**ate** ion ClO_3^-
      - brom**ite** ion BrO_2^-
      - **hypo**iod**ite** ion IO^-

Nomenclature

- **Names of anions**

  - Anions with **hydrogen**
    - HS^- and HCO_3^- are anions beginning with "hydrogen."
      - HS^- is the hydrogen sulfide ion.
      - HCO_3^- is the hydrogen carbonate ion.

    - If two hydrogen atoms are present in an anion, use the *di*- prefix.
      - $H_2PO_4^-$ is dihydrogen phosphate, and
      - $H_2PO_3^-$ is dihydrogen phosphite.

    - An older system of nomenclature used the prefix *bi*-, as in bicarbonate ion for HCO_3^-.

Nomenclature Rules

- **Ionic** are compounds that contain at least one metal. When writing ionic compound names, the metal name goes first (the more positive element first).
- **Molecular** compounds have no metals.

- **Ionic compounds**
  - Most main group metals have a **single oxidation state**.
    - **Rule:** name of cation + name of anion
    - Ex: LiCl – Li^+ Cl^- - Lithium chloride
  - Most d-block metals and some metals in Groups 12-15 have **multiple oxidation states**
    - **Rule:** name of cation(oxidation number in Roman numerals) + name of anion

Formula	**Ions**	**Name**
$TiCl_2$	Ti^{2+} Cl^-	titanium(II) chloride
$TiCl_3$	Ti^{3+} Cl^-	titanium(III) chloride
$TiCl_4$	Ti^{4+} Cl^-	titanium(IV) chloride

Nomenclature Rules

- **Naming hydrates**
  - Add the appropriate Greek prefix (which indicates the number of water molecules) followed by “hydrate” after the ionic compound name.
    - calcium sulfate **tri**hydrate = $CaSO_4 \cdot 3H_2O$
    - barium phosphite **hexa**hydrate = $Ba_3(PO_3)_2 \cdot 6H_2O$

Nomenclature Rules

- **Molecular compounds**
  - **Rule:** (# of atoms as a Greek prefix)name of first element + (# of atoms as a Greek prefix)name of second element with its ending changed to *–ide*

Formula	**Name**
BF_3	boron trifluoride
SO_3	sulfur trioxide
CO	carbon monoxide
P_2O_5	diphosphorous pentaoxide

Nomenclature Rules

- **Compounds starting with hydrogen, acid or gas**

Aqueous (aq):
-*ide* goes to *hydro…-ic acid*
-*ate* goes to -*ic acid*
-*ite* goes to -*ous acid*
Gases (g): -*ide* goes to hydrogen _-*ide* gas

Formula	**Information**	**Name**
HCl (aq)	(aq) species are acids, and Cl^- is chloride	hydrochloric acid
HCl (g)	(g) means gas, and Cl^- is chloride	hydrogen chloride gas
$HClO_4$ (aq)	ClO_4^- perchlorate, -*ate* → -*ic*	perchloric acid
$HBrO_3$ (aq)	BrO_3^- is bromate, -*ate* → -*ic*	bromic acid
HIO_2 (aq)	IO_2^- is iodite, -*ite* → -*ous*	iodous acid
HClO (aq)	ClO^- is hypochlorite, -*ite* → -*ous*	hypochlorous acid
H_2SO_3 (aq)	SO_3^{2-}, sulfite	sulfurous acid
H_3PO_3 (aq)	PO_3^{2-}, phosphite	phosphorous acid

Nomenclature Rules

- **Some organic compounds (see next semester)**
  - Compounds of hydrogen and carbon are called **hydrocarbons**. They include methane, CH_4; ethane, C_2H_6; and benzene, C_6H_6.
  - Hydrocarbons that have no carbon-carbon multiple bonds are called **alkanes**. Thus, methane and ethane are both alkanes.
  - Hydrocarbons with double bonds are called **alkenes**. Ethene, $CH_2{=}CH_2$ is the simplest example of an alkene.

Nomenclature Rules

- **Some organic compounds (see next semester)**

Number of carbon atoms	Formula	Name of alkane
1	CH_4	methane
2	CH_3CH_3	ethane
3	$CH_3CH_2CH_3$	propane
4	$CH_3(CH_2)_2CH_3$	butane
5	$CH_3(CH_2)_3CH_3$	pentane
6	$CH_3(CH_2)_4CH_3$	hexane
7	$CH_3(CH_2)_5CH_3$	heptane
8	$CH_3(CH_2)_6CH_3$	octane
9	$CH_3(CH_2)_7CH_3$	nonane
10	$CH_3(CH_2)_8CH_3$	decane
11	$CH_3(CH_2)_9CH_3$	undecane
12	$CH_3(CH_2)_{10}CH_3$	dodecane

Nomenclature Rules

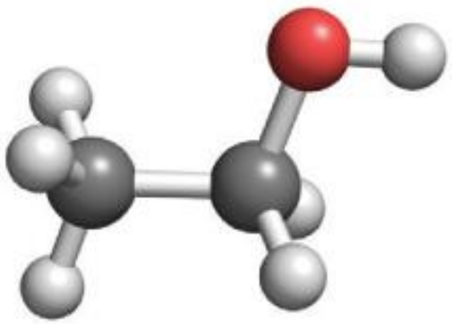
- **Some organic compounds (see next semester)**

  - Specific groups of atoms derived from hydrocarbons, such as:
    - $-CH_3$, methyl
    - $-CH_2CH_3$, ethyl
  - They are named by replacing the ending of the parent hydrocarbon's name with the suffix -*yl*.

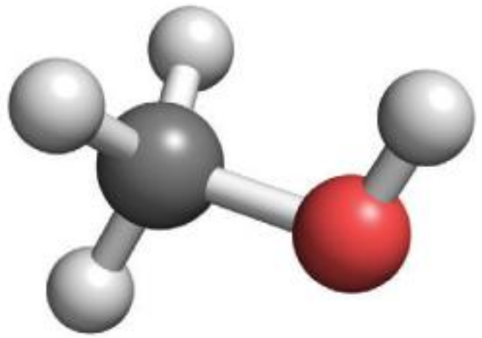
Nomenclature Rules

- **Some organic compounds (see next semester)**

  - An **alcohol** is a type of organic compound that contains an -OH group.
    - Ethanol, CH_3CH_2OH, the "alcohol" of beer and wine, is an ethane molecule in which one H atom has been replaced by an -OH group.
    - CH_3OH is the toxic alcohol called methanol, or wood alcohol.



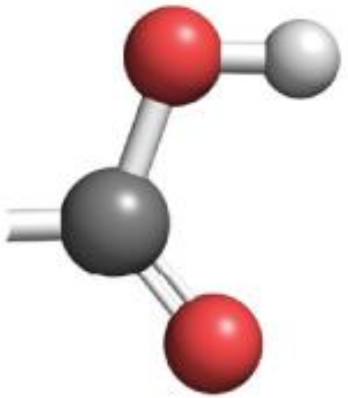
4 Ethanol, CH_3CH_2OH



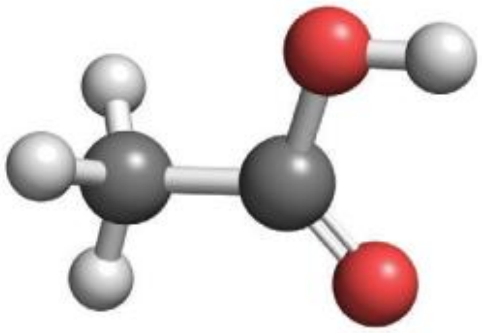
5 Methanol, CH_3OH

Nomenclature Rules

- **Some organic compounds (see next semester)**
  - A **carboxylic acid** contains the carboxyl group, -COOH. The most common example is acetic acid, CH_3COOH.

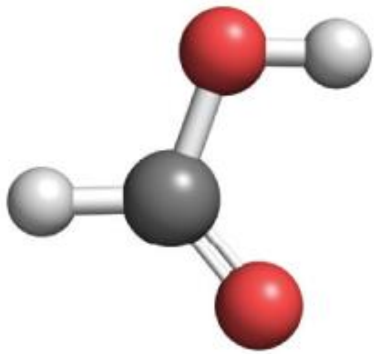


6 Carboxyl group, —COOH



7 Acetic acid, CH_3COOH

Ethanoic acid

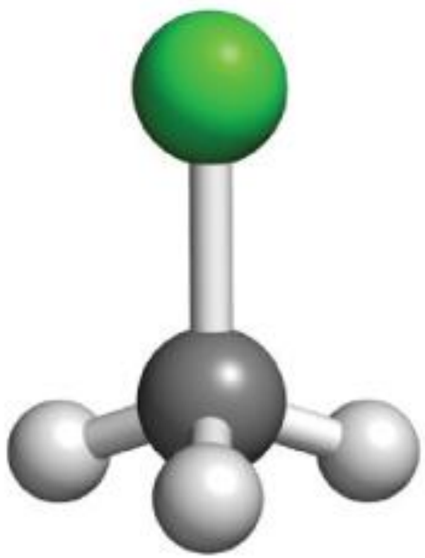


8 Formic acid, HCOOH

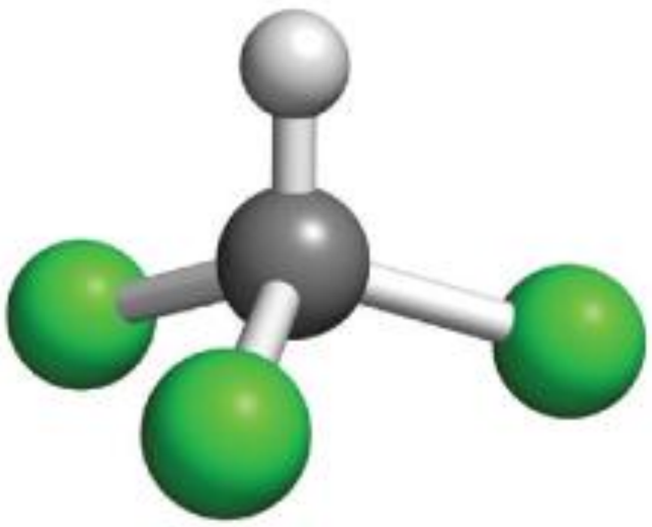
Formic acid is the acid of ant venom.

Nomenclature Rules

- **Some organic compounds (see next semester)**
  - A **haloalkane** is an alkane in which one or more H atoms have been replaced by halogen atoms.

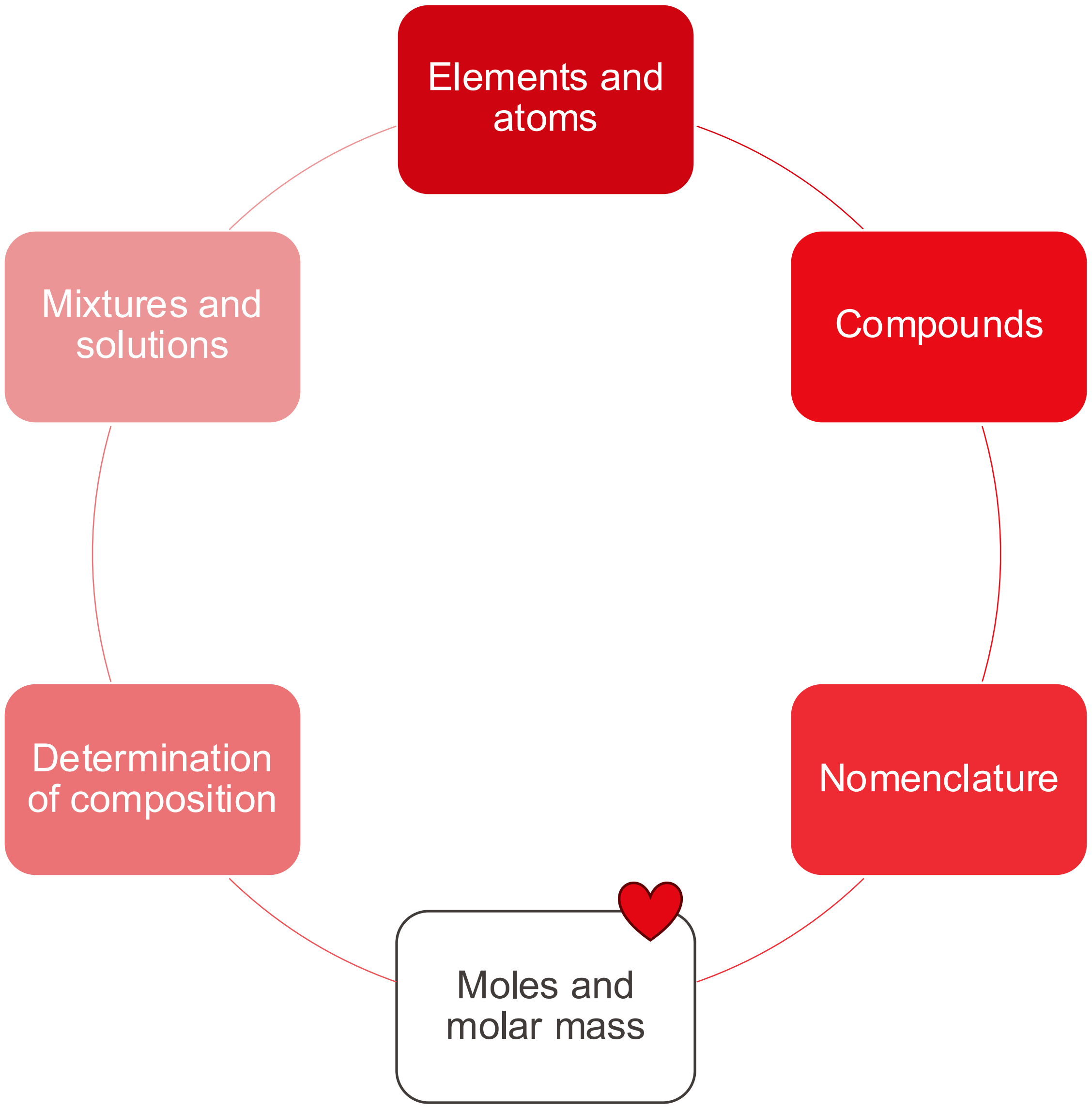


9 Chloromethane, CH_3Cl



10 Trichloromethane, $CHCl_3$

Plan



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The mole: a unit for very large numbers

- Single atoms or molecules are too small for any chemical application.
- 1 **mole** is the number of atoms in carbon-12 that weighs exactly 12 g.
- We know a single carbon-12 atom's mass: 1.99265×10^{-23} g. It follows that the number of atoms in exactly 12 g of carbon-12 is $\mathbf{6.0221 \times 10^{23}}$.

$$\text{Number of C atoms} = \frac{\overbrace{12\text{ g (exactly)}}^{\text{Mass of sample}}}{\underbrace{1.99265 \times 10^{-23}}_{\text{Mass of one carbon atom}}} = 6.0221 \times 10^{23} = 1\text{ mol C atoms}$$

The mole: a unit for very large numbers

1 mol of objects = 6.0221 × 10^{23} of those objects

mol is a unit, like *g* is for gram or *m* for meter

- Ultimately, the average mass of a proton and neutron = 1.67 × 10^{-24} g. Therefore, the mass of 1 mol of protons or neutrons is equal to 6.0221 × 10^{23} × 1.67 × 10^{-24} g = 1 g.

- The number of objects per mole, 6.0221 × 10^{23} mol^{-1}, is called **Avogadro's constant**, N_A, in honor of Amedeo Avogadro (19th century).

Science Source.

Molar mass

Molar mass, *M*, has units of grams per mole ($g{\cdot}mol^{-1}$).

- The molar mass of an element is the mass per mole of its *atoms*.
  1 mole Chromium = 51.9961 g Cr **or** 51.9961 $g{\cdot}mol^{-1}$ Cr

- The molar mass of a molecular compound is the mass per mole of its *molecules*.
  1 mole H_2O = 18.00 g H_2O **or** 18.00 $g{\cdot}mol^{-1}$ H_2O

- The molar mass of an ionic compound is the mass per mole of its *formula units*.
  1 mole of NaCl = 58.5 g **or** 58.5 $g{\cdot}mol^{-1}$ NaCl

*also called **atomic weight / molecular weight / formula weight**

Let's be precise - Isotopic mass

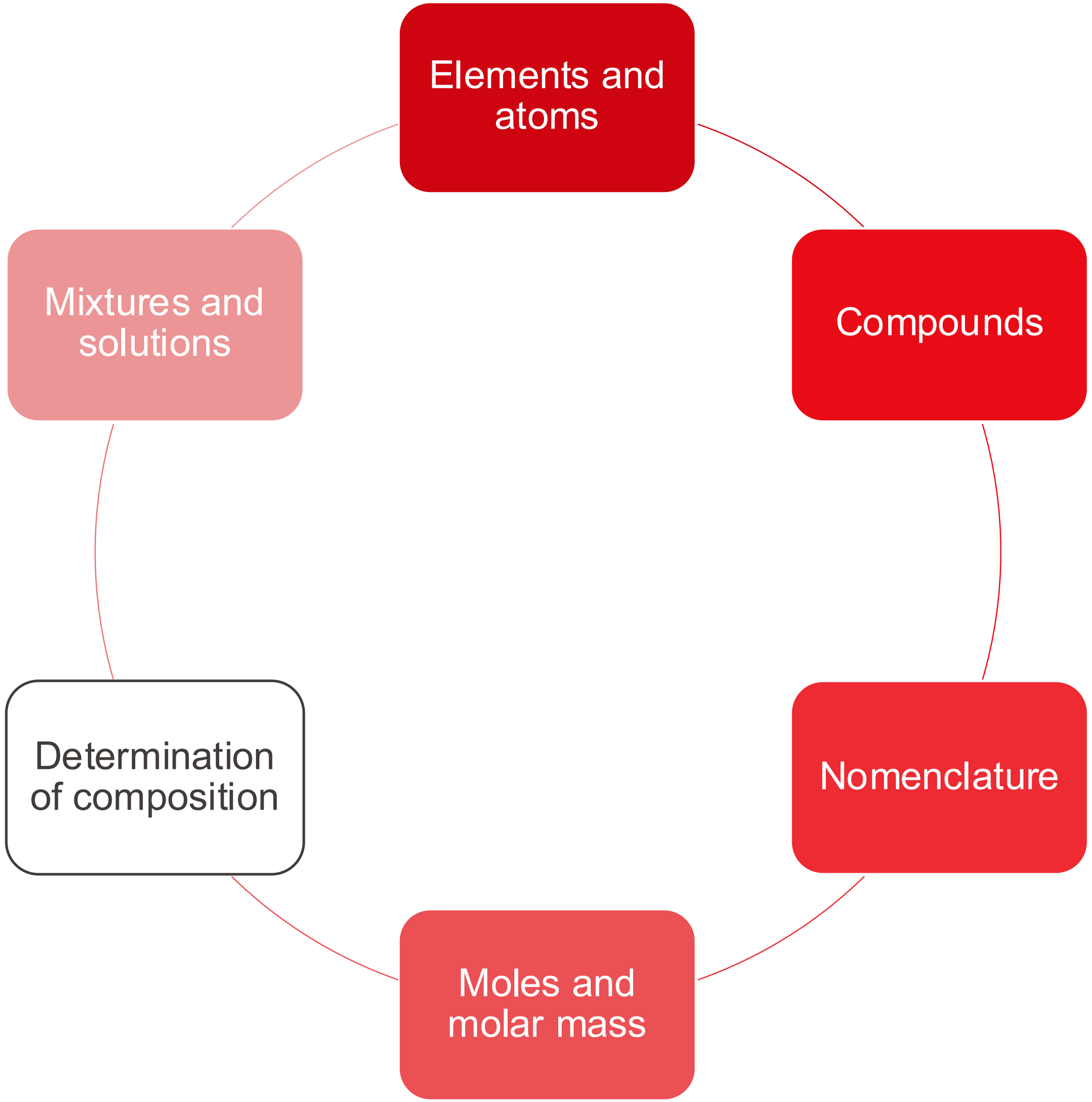
$$\text{Atomic Mass} = \sum(\text{fractional abundance of isotope})_n \times (\text{mass of isotope})_n$$

Data for different **isotopes** of oxygen:

^{16}O	99.759%,	15.99491 g·mol^{-1}
^{17}O	0.0370%,	16.99913 g·mol^{-1}
^{18}O	0.204%,	17.99916 g·mol^{-1}

(0.99759)(15.99491) = 15.956 g·mol^{-1}
(0.000370)(16.99913) = 0.00629 g·mol^{-1}
(0.00204)(17.99916) = 0.0367 g·mol^{-1}
15.956 g·mol^{-1} + 0.00629 g·mol^{-1} + 0.0367 g·mol^{-1} = 15.99899 g·mol^{-1}

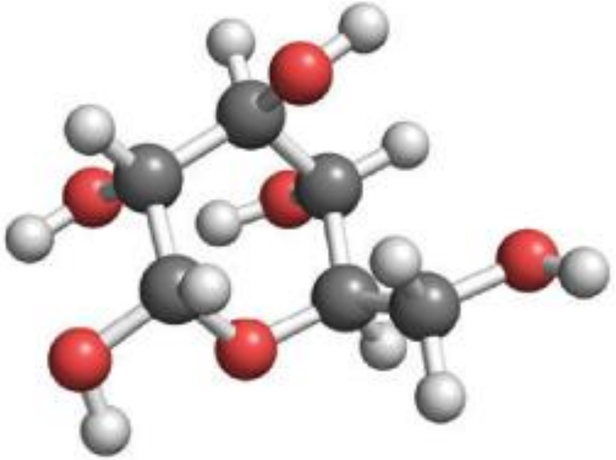
Plan


Elements and atoms
Compounds
Nomenclature
Moles and molar mass
Determination of composition
Mixtures and solutions

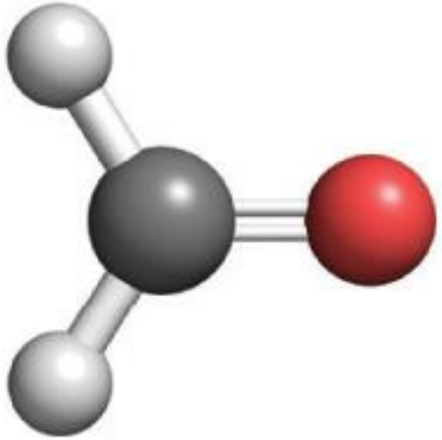
Empirical and molecular formulas

- The **empirical formula** shows the *relative* numbers of atoms of each element present in the compound using the smallest possible whole numbers.
  - For glucose, the carbon, hydrogen, and oxygen ratio is 1:2:1.
  - Other molecules with a 1:2:1 ratio are: formaldehyde, CH_2O (a preservative); acetic acid, $C_2H_4O_2$ (vinegar); and lactic acid, $C_3H_6O_3$ (sour milk).

  - See **combustion** example next week



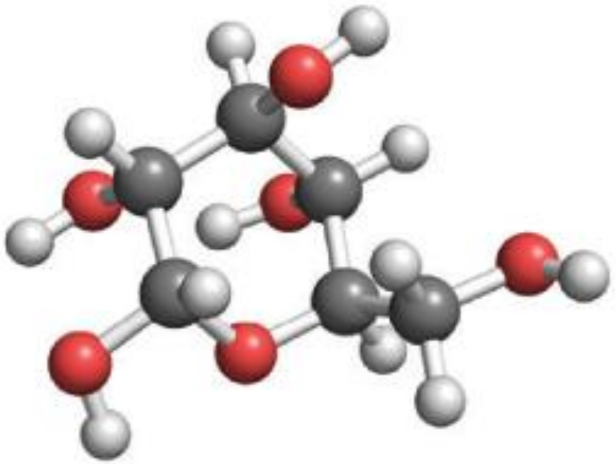
1 α-D-Glucose, $C_6H_{12}O_6$



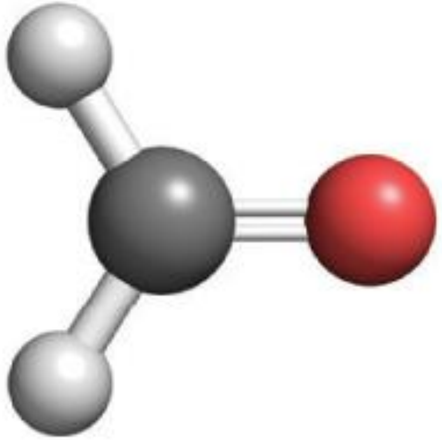
2 Formaldehyde, CH_2O

Empirical and molecular formulas

- **Molecular formulas** are the actual number of atoms; for a glucose molecule, it is $C_6H_{12}O_6$.

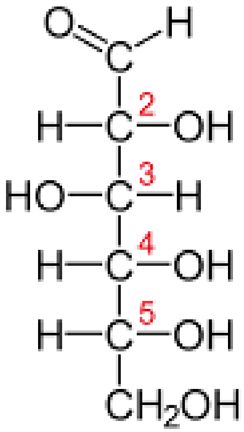


1 α-D-Glucose, $C_6H_{12}O_6$

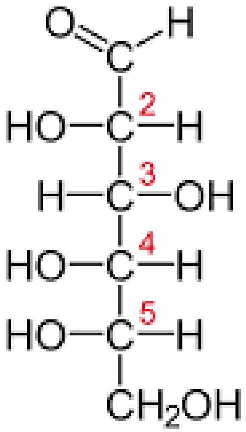


2 Formaldehyde, CH_2O

Just because we are curious (i.e. not for the exam)



D-Glucose

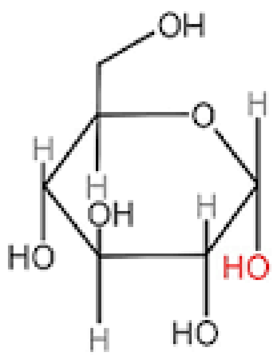


L-Glucose

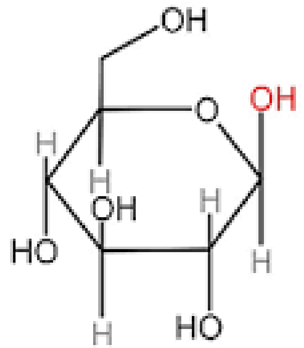
1. **D in glucose**

- The **D** in **D-glucose** refers to the **stereochemistry** of the molecule, specifically the configuration of the **chiral carbon farthest from the carbonyl group** (in glucose, this is carbon-5).
- If the hydroxyl group (**–OH**) on C-5 points to the **right,** it is a **D-sugar**. If it points left, it is an **L-sugar**.
- Most naturally occurring sugars (like glucose in our bodies) are **D-sugars**.

Just because we are curious (i.e. not for the exam)



Alpha-glucose



Beta-glucose

2. α (alpha) in glucose

When glucose cyclizes in solution, it usually forms a **6-membered ring (pyranose)**.

In the ring form, the **anomeric carbon** (C-1, the carbon that was the aldehyde in the open chain) can have its –OH pointing in different orientations:

- **α (alpha):** The OH on the anomeric carbon is **trans (opposite side)** to the CH_2OH group on C-5.
- **β (beta):** The OH on the anomeric carbon is **cis (same side)** to the CH_2OH group on C-5.

Mass percentage composition

Mass percentage composition is the mass of each element expressed as a percentage of the total mass.

$$\text{mass percentage of an element} = \frac{\text{mass of an element in the sample}}{\text{total mass of the sample}} \times 100\%$$

Mass percentage composition

Mass percentage composition is the mass of each element expressed as a percentage of the total mass.

What is the mass percentage of hydrogen in water, H_2O?

$$\frac{?\ \text{g H}}{?\ \text{g total}} \times 100 = ?\ \%\text{H}$$

Total mass of H:

$$\frac{1.0079\ \text{g H}}{1\ \text{mol H}} \times \frac{2\ \text{mol H}}{1\ \text{mol H}_2\text{O}} = 2.0158\ \text{g H}$$

Total mass of H_2O:

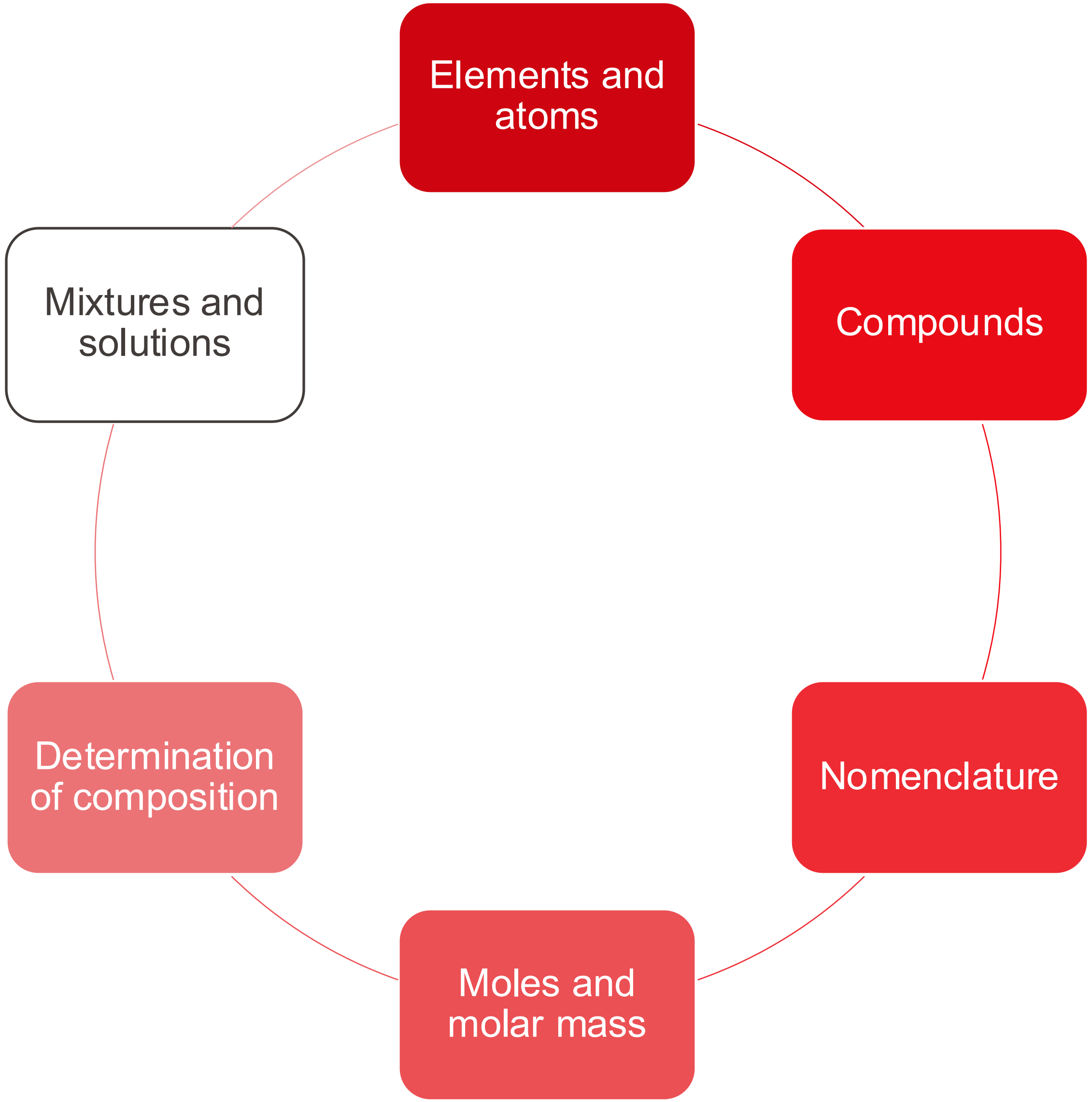
$1.0079\ \text{g}\cdot\text{mol}^{-1}\ \text{H} \times 2\ \text{mol H} = 2.0158\ \text{g H}$

$16.00\ \text{g}\cdot\text{mol}^{-1}\ \text{O} \times 1\ \text{mol O} = 16.00\ \text{g O}$ Total = 18.02 g

Mass percentage of H:

$$\frac{2.0158\ \text{g H}}{18.02\ \text{g total}} \times 100 = \mathbf{11.19\%\ H}$$

Plan



Elements and atoms
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Mixtures and classification

- Most materials are not made of **pure elements or compounds**, they are **mixtures** of substances (e.g. blood, seawater, …)

- **Compounds** have a fixed composition while mixtures can vary

- There are **heterogenous** and **homogenous** mixtures (i.e. **solutions**)

Mixture	Compound
Components can be separated by **physical** techniques (see next slides)	Components **cannot** be separated by **physical** techniques (see next slides)
Composition is variable	Composition is fixed
Properties of components are retained	Properties of individual components are lost

Solutions

- **Solutions** are homogeneous mixtures made of **solute** and **solvent**
- **Aqueous solutions** are solutions in which the solvent is water (e.g. beverages)
- **Nonaqueous solutions** are solutions in which the solvent is *not* water

(a) (b) (c)

Preparing a solution in the lab

(a) (b) (c)

1. transfer a known mass of the solid into a volumetric flask
2. dissolve it in a little volume of water
3. fill the flask up to the mark with water, and
4. then mix the solution thoroughly by tipping the flask end over end.

- Because molarity is defined in terms of the volume of the solution, not the volume of solvent, the volume must be **measured after the solute** has been added.

Crystallization and precipitation

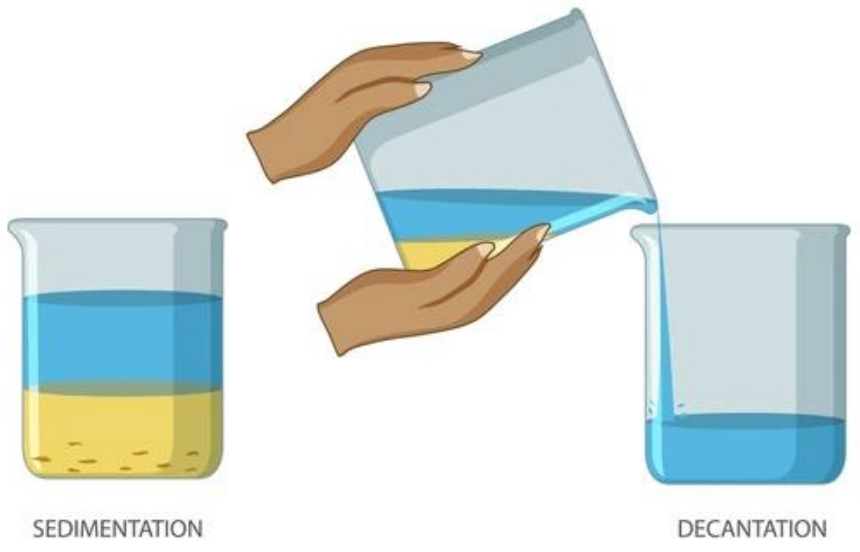
- **Crystallization** is the process in which a solid comes out of solution in the form of crystals. Crystallization is sometimes the result of evaporation (the vaporization of the solvent from a liquid to a gas).

- **Precipitation** is the process in which a solute comes out of solution very quickly as a finely divided powder, called a **precipitate**.

Using crystallization to solve protein 3D structure

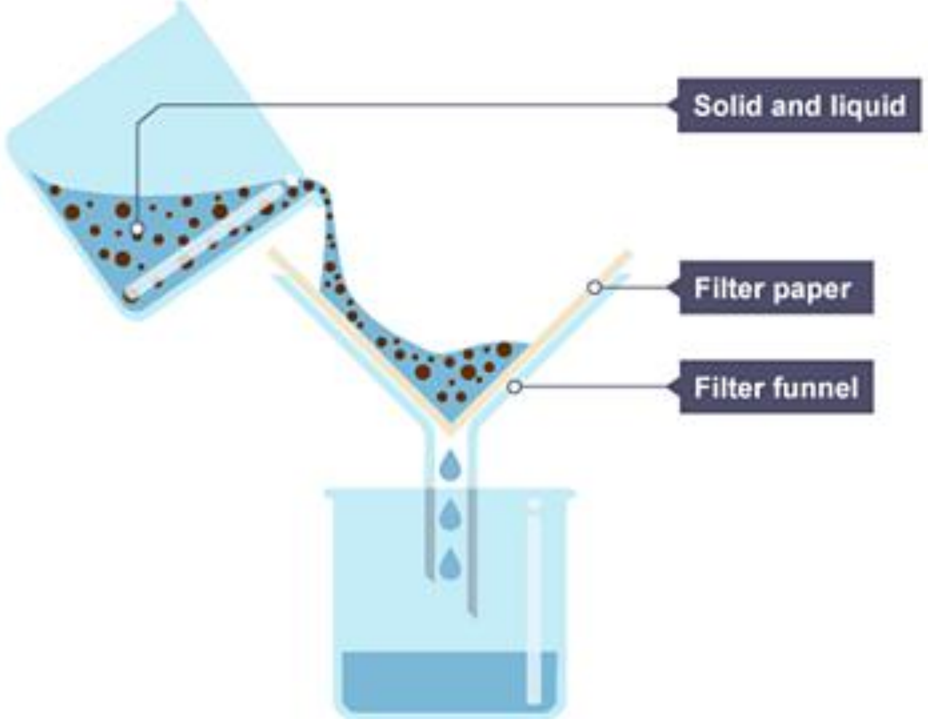
Mixtures - separation techniques (physical)

- **Mixtures** can be separated using physical separation techniques. This allows to identify its composition.
    - **Decanting** utilizes differences in density



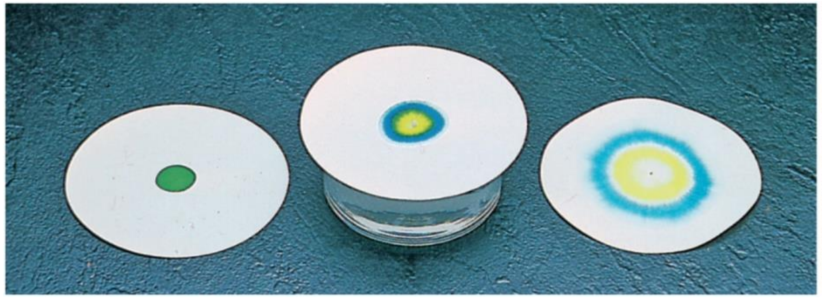
Mixtures - separation techniques (physical)

- **Mixtures** can be separated using physical separation techniques. This allows to identify its composition.
  - **Filtration** utilizes differences in solubility



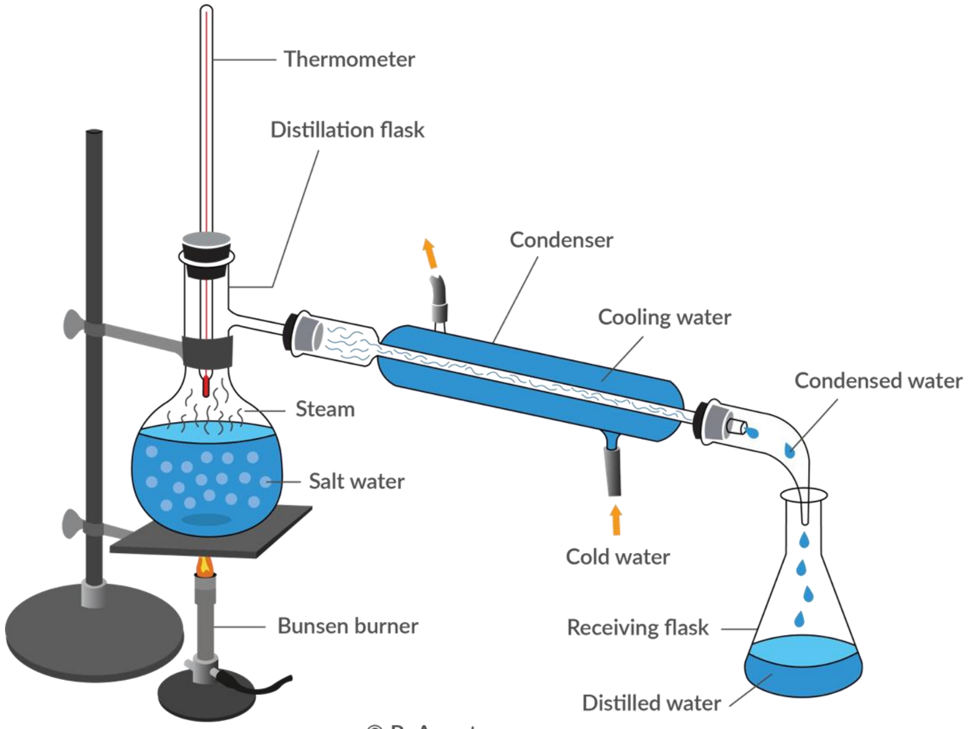
Mixtures - separation techniques (physical)

- **Mixtures** can be separated using physical separation techniques. This allows to identify its composition.
  - **Chromatography** utilizes differences in absorption



Mixtures - separation techniques (physical)

- **Mixtures** can be separated using physical separation techniques. This allows to identify its composition.
  - **Distillation** utilizes differences in boiling point



Concentration of a mixture/solution - mass percentage

- The **mass percentage** of a solution or mixture is the mass of each component per 100g of sample

For example, if 15 g of NaCl is dissolved into 60 g of water, the mass percentage of NaCl is:

$$\text{mass percentage of NaCl} = \frac{(\text{mass NaCl})}{(\text{total mass})} \times 100\%$$

$$= \frac{(15\ \text{g})}{(15\ \text{g} + 60\ \text{g})} \times 100\% = \frac{15\ \text{g}}{75\ \text{g}} \times 100\% = 20\%$$

Concentration of a mixture/solution – ppm or ppb

- Other mass-based concentration units are **parts per million** (ppm) and parts per billion (ppb). These are especially useful in environmental work.

$$1\,\text{ppm} = \frac{1\,\text{units solute}}{10^{6}\,\text{units sample}} \qquad 1\,\text{ppb} = \frac{1\,\text{units solute}}{10^{9}\,\text{units sample}}$$

- Parts per million and parts per billion can use units of volume, mass, or other units.
- For example, suppose that 25 g of a pollutant exist in a sample of 10^6 g of air. The concentration of pollutant is 25 ppm.

Concentration of a mixture/solution - molarity

- The **molar concentration or molarity**, *c*, is the amount of solute in moles divided by the volume of the solution (in liters)

$$c = \text{molarity} = \frac{\text{mol of solute}}{\text{liters of solution}}$$

Often denoted as M: 1 M = 1 $\text{mol}\cdot\text{L}^{-1}$

- The symbol M is read as "molar" and is not an SI unit. Chemists work in millimolar ($\text{mmol}\cdot\text{L}^{-1}$ or mM) or in micromolar ($\mu\text{mol}\cdot\text{L}^{-1}$ or µM).

Your new favorite formulas

- You will use these formulas everyday in the lab

- Concentration = number of mol per unit of volume
  - **c** (M or $mol.L^{-1}$) **= n** (mol) **/ V** (L)

- Number of moles = mass divided by the molar mass
  - **n** (mol) = **m** (g) **/ M** ($g.mol^{-1}$)

! Units

c is the concentration or molarity in M or $mol.L^{-1}$
n is the number of moles in mol
V is the volume in L
m is the mass in g
M is the molar mas in $g.mol^{-1}$

The concept of dilution

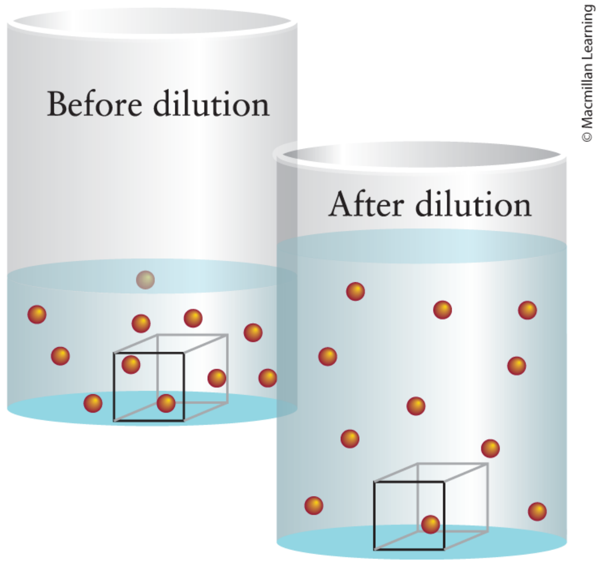
Why do we work with **concentrated solutions** in the lab (that we further **dilute**)?

- A **space-saving** practice is to store a concentrated solution called a **stock solution**, remove an aliquot of it, and then **dilute** the aliquot by adding solvent.
  - E.g. antibiotics are stored and frozen in concentrated stocks, like mg/ml, and used in the bacterial cultures at μg/ml concentrations.
- Dilution is also helpful when chemists need **very precise control** over very small amounts of substances that they are handling. Chemists can more accurately measure mL of a stock solution than measure μL of solution or weigh μg of solid.
  - E.g. same as above. This avoids to weigh μg (not possible) but mg. After that, we reach the wanted concentration by diluting the sample.

The concept of dilution

- When diluting, the same number of solute molecules occupy a larger volume, hence the solution is less concentrated.

11 particles starting



11 particles ending

$$n_{\text{before}} = n_{\text{after}}$$
$$n_{\text{initial}} = n_{\text{final}}$$

dilution formula: $c_{\text{initial}}V_{\text{initial}} = c_{\text{final}}V_{\text{final}}$

EPFL

Have a beautiful day !

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polytechnique
fédérale
de Lausanne