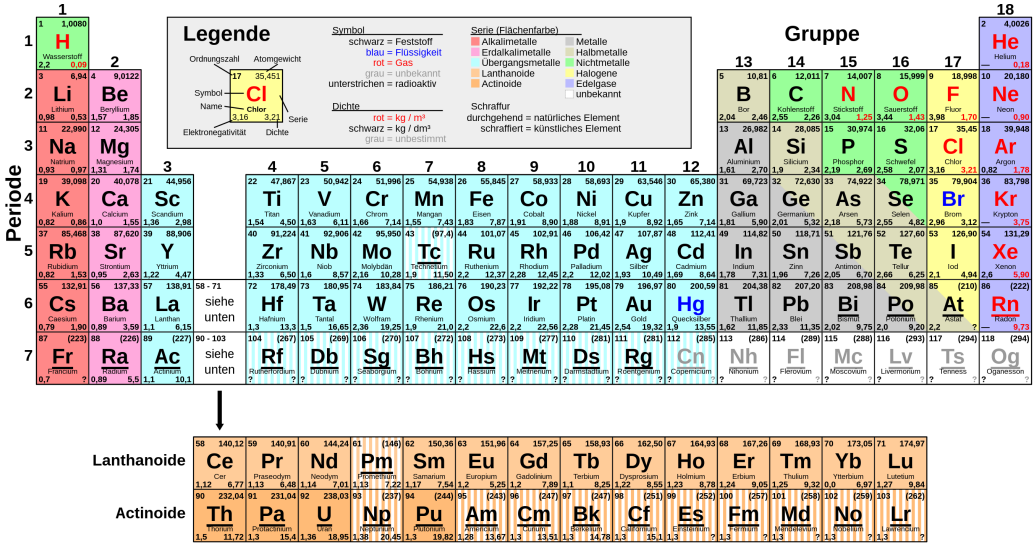
COURSE – MINT CHEMISTRY

TOPIC 2
Atoms, Atomic Structure, Periodic Table of the Elements

MONTANUNIVERSITÄT LEOBEN Chair of General and Analytical Chemistry © Thomas Prohaska 2019

The Tool....



COMPOSITION OF MATTER

- An **atom** is the smallest particle that has the chemical properties of that element
- An **element** is a substance made up of one type of atom, all of which have the same chemical properties
- Currently 118 elements are known

Chemical elements are mostly non-atomic in nature (they form molecules from ONE type of atom)

Molecules are made up of more than one atom:

H_2, N_2, Cl_2, O_2, Fe, Au (Metals form crystals from one type of atom)

Molecules of Compounds

Molecules composed of more than one element (atoms of different elements)

H_2O, NH_3, HCl, Fe_2O_3 (Example of an iron ore as it occurs in nature)

More of that in unit 3!

ATOMS

Atomic theory from John Dalton 1805:

1) All matter is made up of **atoms**
2) All atoms of an element are the same
3) Atoms of different elements have different masses
4) A compound is a special combination of atoms from different elements
5) In a chemical reaction, atoms are neither created nor destroyed, only rearranged to form new substances

John Dalton, 1776-1844

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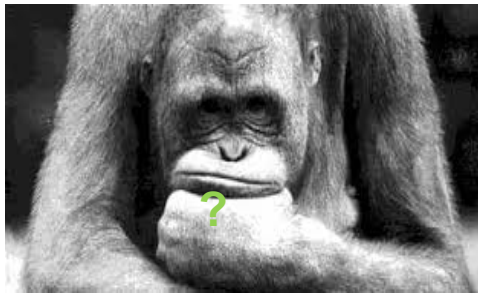
HOW IS AN ATOM CONSTRUCTED? (Chat in groups)

Sketch an atomic structure on the concept board

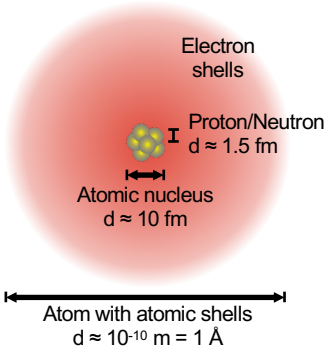


https://app.conceptboard.com/board/qxdu-pyip-gpxe-2ouu-cb6x

ATOMIC STRUCTURE

Meaning of the word atom:

- „the indivisible“ ατομος/átomos
- not further divisible by chemical means



CAUTION:
Drawing is NOT to scale!!
Sizes range from fm (10^{-15} m) to nm (10^{-9} m)

ATOMIC STRUCTURE

⇨ However, atoms are made up of even smaller particles:

Nucleons

In the nucleus are

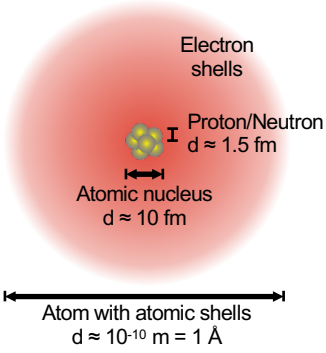
Determine the "type of element"

- Protons
- Neutrons

In the electron shells are

- Electrons

Responsible for reactivity and bonding



Atomic Structure

The **nucleus** (number of protons) determines:

- The **type of element**
- The **number of electrons**,
- The **electron probability density** (=orbitals**)**
- The **reactivity** (acceptance and donation of electrons)

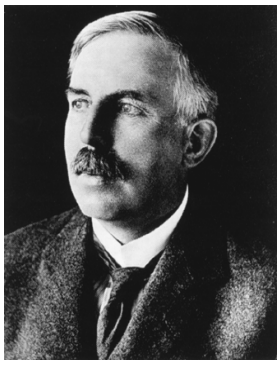
Atomic Structure

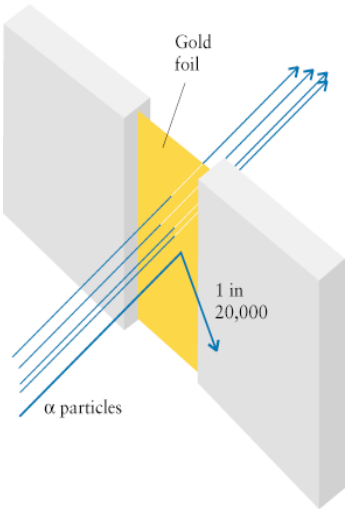
The **electronic structure** (electrons) of the atom determines:

- the **properties** of the elements (e.g.: Reactivity)
- the **reactions** that these atoms participate in
- the **form/type of molecules** that make up these elements

DISCOVERY OF THE NUCLEUS STRUCTURE

(Experiments by Ernest Rutherford with his students Hans Geiger and Ernest Marsden around 1910)





PROTON/NEUTRON/ELECTRON PROPERTIES

	Mass		
Carrier of the negative charge			
	Mass [g]	Atomic mass[a] m_a [Da]	Charge[b]
Electron	$9.109535 \cdot 10^{-28}$	0.0005485803	-1
Proton	$1.672649 \cdot 10^{-24}$	1.007276	+1
Neutron	$1.674954 \cdot 10^{-24}$	1.008665	0

Carrier of the positive charge

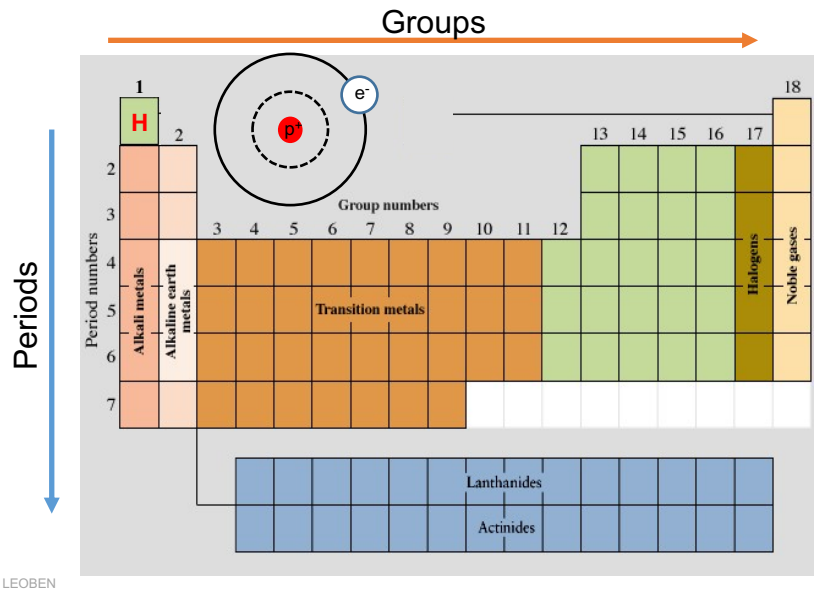
[a] Atomic mass unit $u = 1.6605 \cdot 10^{-27}$ kg
[b] Charges in multiples of $e = 1.602 \cdot 10^{-19}$ C

Note:
Protons and neutrons are around ≈ 1840 times heavier than an electron!
=> The mass of an atom is determined by the number of particles in its nucleus

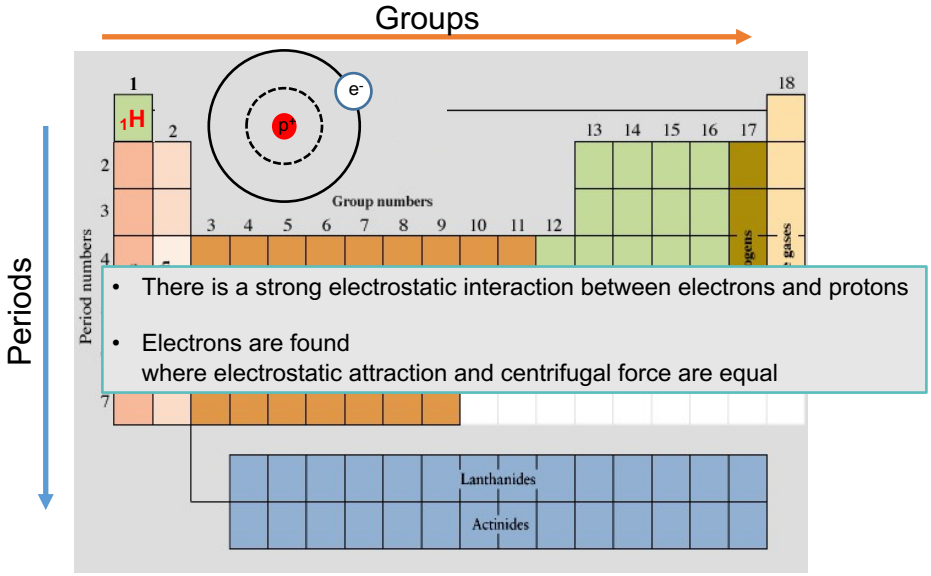
CLASSIFICATION OF THE CHEMICAL ELEMENTS

- The 'type' of the chemical element is determined by the number of protons.
- The elements are arranged in order of increasing number of protons
- This arrangement is shown in the periodic table of elements.
- A neutral atom (= atom without charge) has equally as many electrons as protons
- The mass of an atom results from the number of protons and neutrons in the nucleus

THE PERIODIC TABLE OF THE ELEMENTS



ARRANGEMENT OF THE ELEMENTS ACCORDING TO THE NUMBER OF PROTONS



- There is a strong electrostatic interaction between electrons and protons
- Electrons are found where electrostatic attraction and centrifugal force are equal

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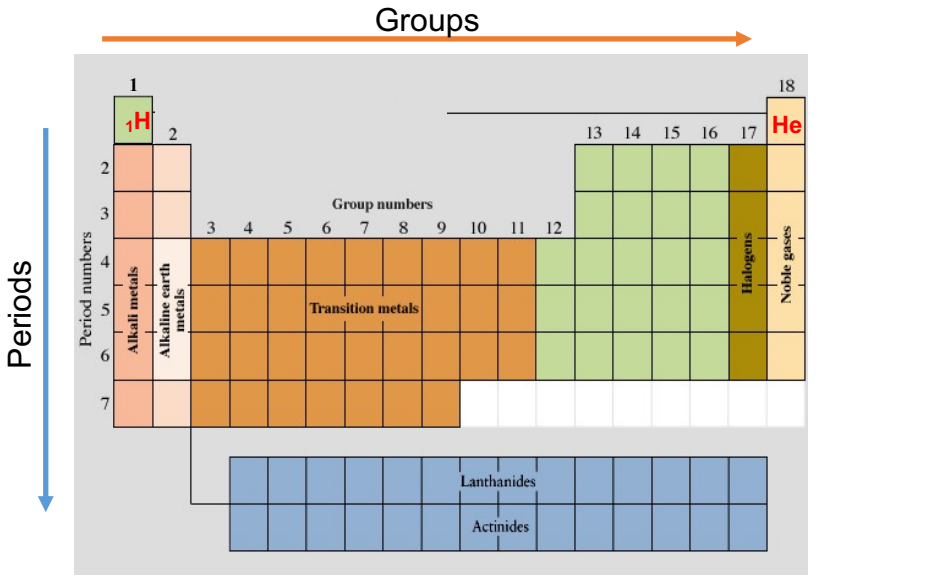

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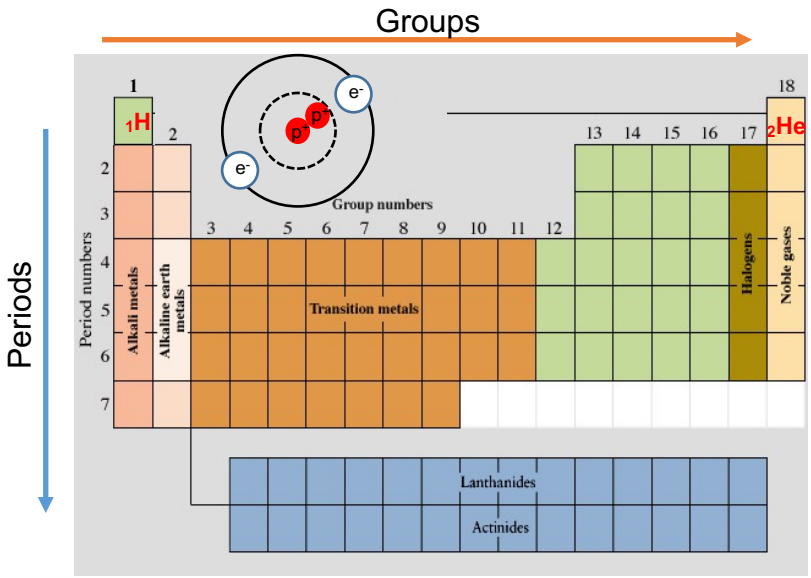

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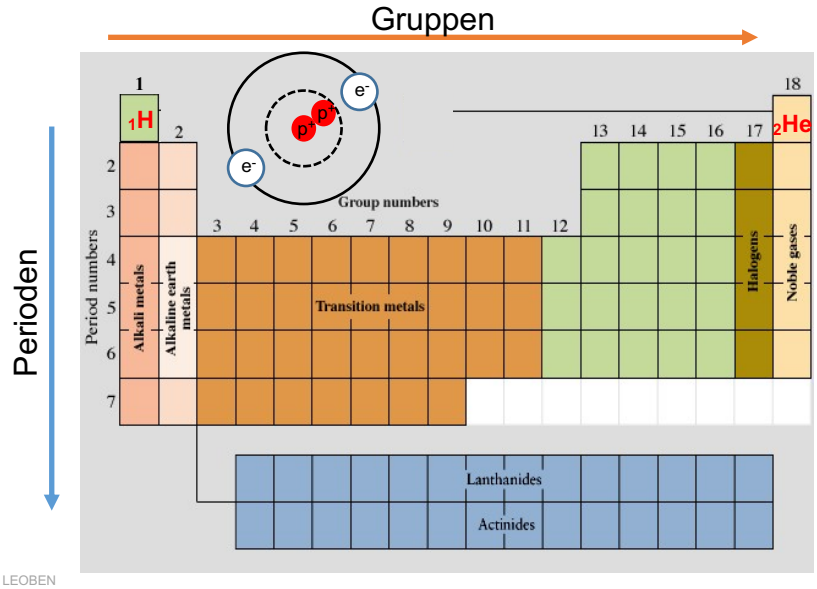

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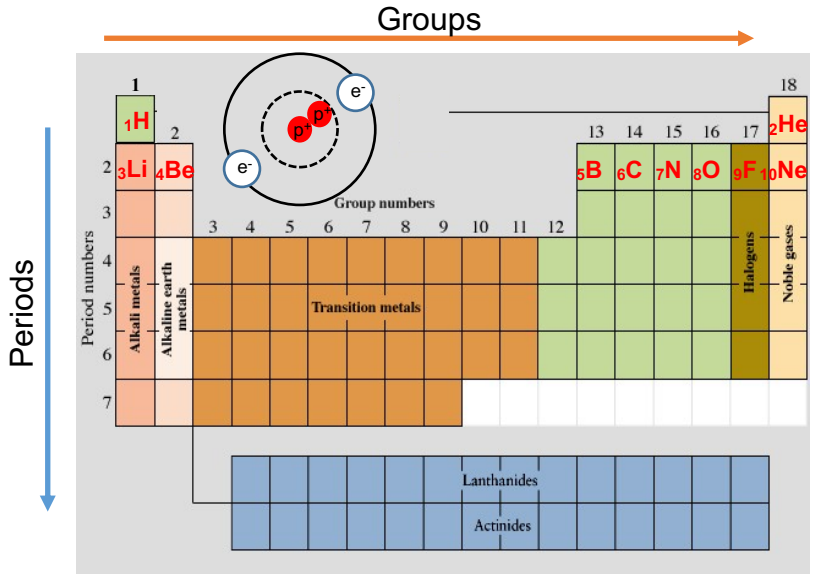

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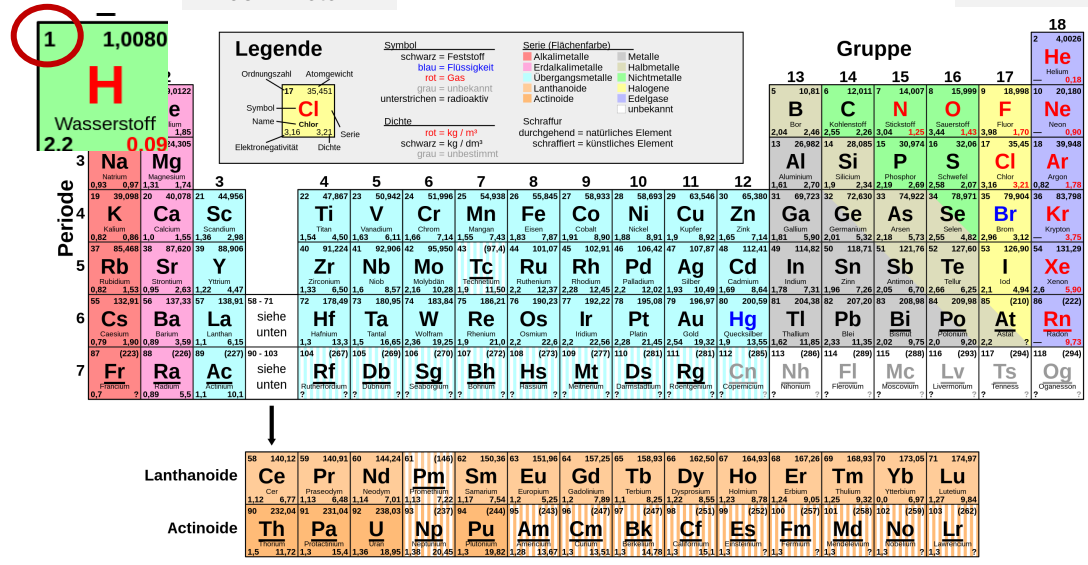
Arrangement of the periodic table of elements according to the number of protons:

Atomic number = 1

H has 1 Proton.....

He has 2 Protons.....



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ATOMS AND IONS

- A neutral atom has equally as many electrons as protons:

How many electrons does the chlorine atom have (Cl)?

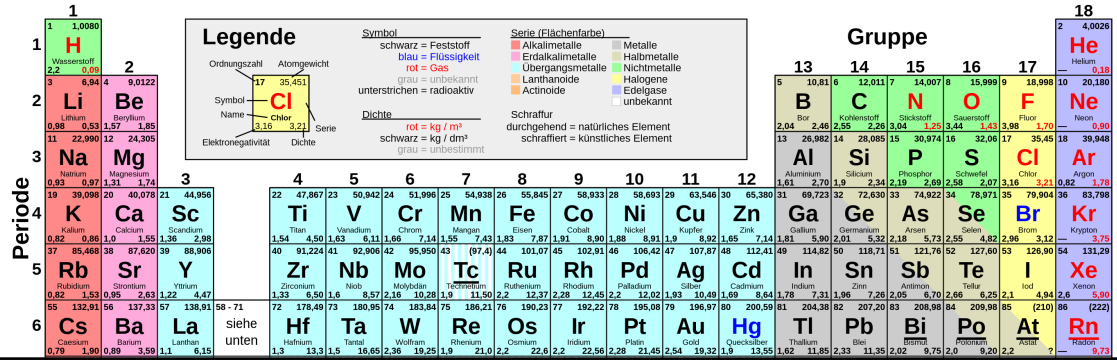
How many electrons does the sodium atom have (Na)?

ATOMS AND IONS

- A neutral atom has equally as many electrons as protons:

How many electrons does the chlorine atom have (Cl)? - 17

How many electrons does the sodium atom have (Na)? - 11



ATOMS AND IONS

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What happens if I “take” an electron from an atom?

What happens if I "add" an electron to an atom?

ATOMS AND IONS

- A neutral atom has equally as many electrons as protons:

How many electrons does the chlorine atom have (Cl)? - 17

How many electrons does the sodium atom have (Na)? – 11

What happens if I “take” an electron from an atom?

It loses a negative charge, so becomes positive;

a positively charged ion is formed (Cation); $Na \rightleftharpoons Na^+ + e^-$

What happens if I "add" an electron to an atom?

It gains a negative charge, so becomes negative;

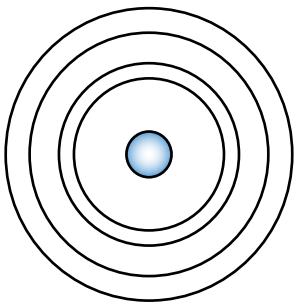
a negatively charged ion is formed (Anion); $Cl + e^- \rightleftharpoons Cl^-$

ATTENTION: the number of protons does NOT change - it remains the same chemical element

The Bohr Model of the Atom

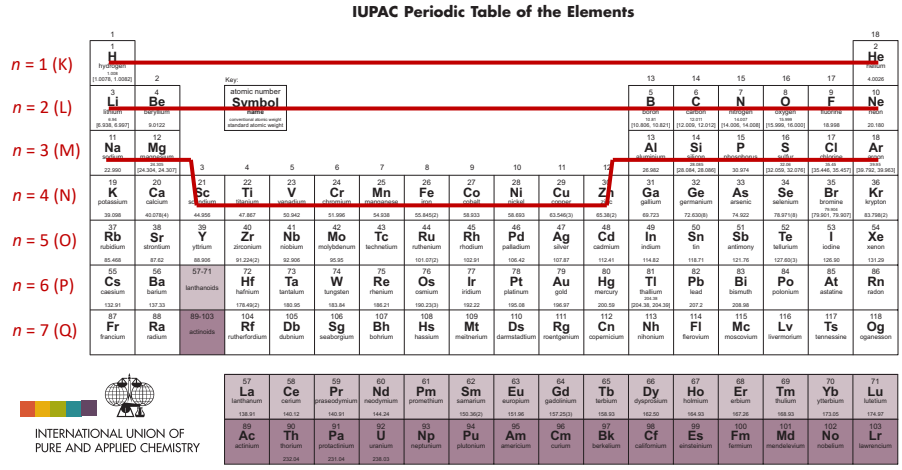
first "mechanistic" atomic model by Niels Bohr

- The electrons are located in specific orbits around the nucleus
- Simplified, these are the "shells" denoted by K, L, M, N...
- The electrons in the outermost shell are the outer electrons or valence electrons



Niels Bohr
1885 - 1962

Principal Quantum Number and the Periodic Table of the Elements



United Nations Educational, Scientific and Cultural Organization · 2019 IYPT International Year of the Periodic Table of Chemical Elements · IUPAC

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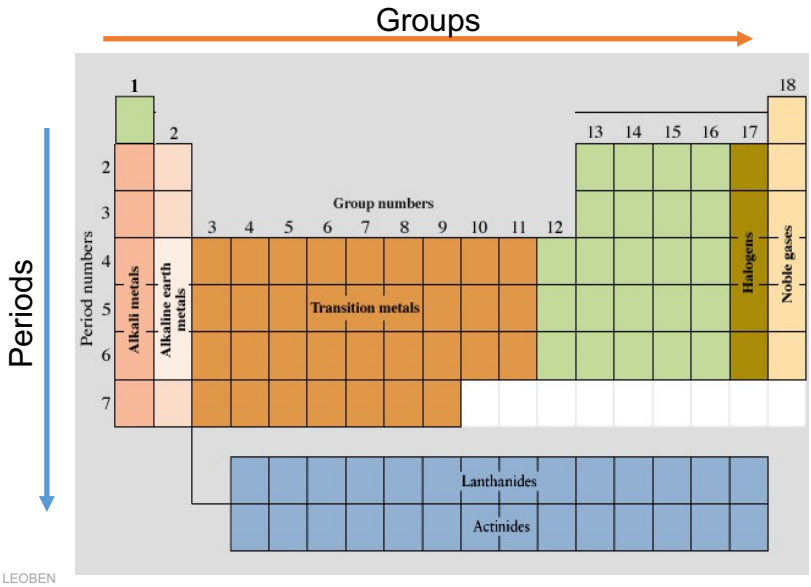
THE PERIODIC TABLE OF THE ELEMENTS



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STRUCTURE OF THE PERIODICAL TABLE

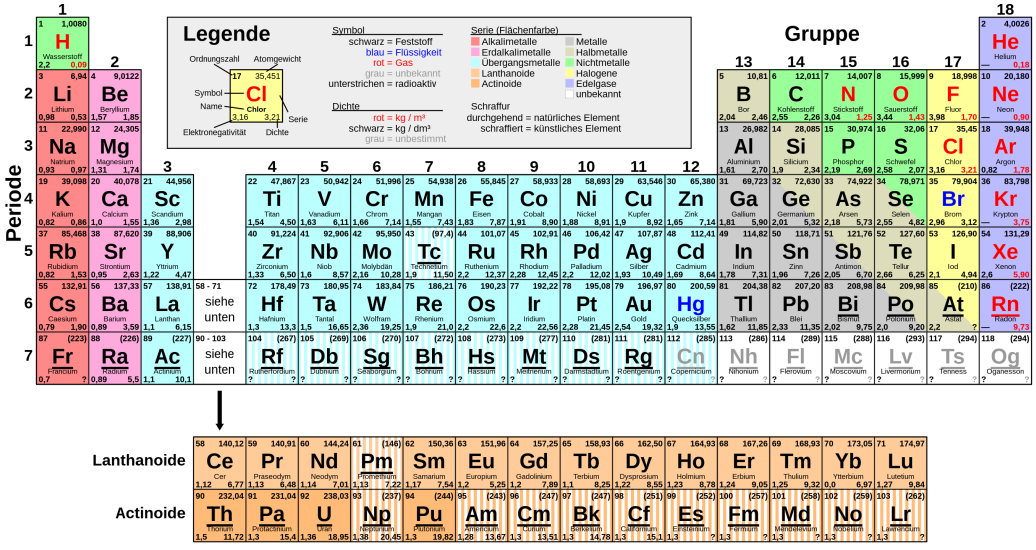
Columns of the periodic table: Groups

⇨ Elements in a group (homologs) have similar properties with gradual increments

Rows of the periodic table: Periods

⇨ Elements in a period show strongly different properties from left to right

THE IDEA OF THE GROUP PROPERTIES

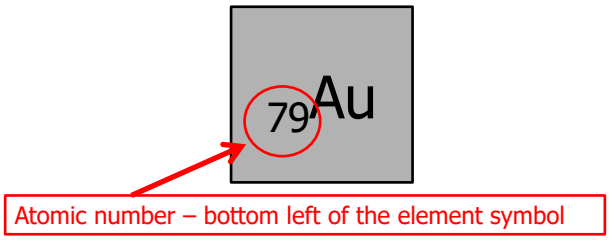


THE ATOMIC NUMBER

Atomic number (Z)

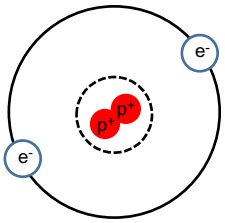
= Number of protons in the nucleus

(corresponds to the number of electrons in the electron shells of the neutral atom)



NUCLEONS

Atomic number (Z)
= Number of protons in the nucleus



$_2$He

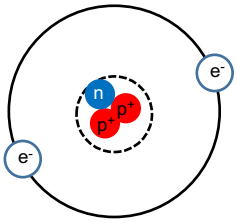
Why is an atomic nucleus stable?
- Positive particles repel each other
- However, the nuclear binding energy is greater than the repulsive forces between the protons

NUCLEONS

Atomic number (Z)
= Number of protons in the nucleus

Mass number (A)
= Sum of the protons and neutrons
$A = Z + N$

The nucleus makes up the mass of the atom!



$^{3}_{2}\mathbf{He}$ $Z = 2$; $N = 1$; $A = 3$

	Mass	
	Mass [g]	Atomic mass[a] m_a [Da]
Electron	$9.109535 \cdot 10^{-28}$	0.0005485803
Proton	$1.672649 \cdot 10^{-24}$	1.007276
Neutron	$1.674954 \cdot 10^{-24}$	1.008665

NUCLEONS

Atomic number (Z)
= Number of protons in the nucleus

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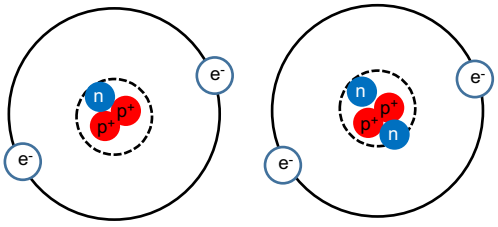
= Sum of the protons and neutrons
$A = Z + N$

The same type of atom **(= same number of protons)** can have a **different number of neutrons** = **different mass / different mass number**



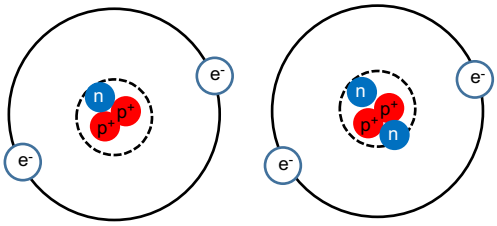
$^{3}_{2}\mathbf{He}$ $N = 1$ $^{4}_{2}\mathbf{He}$ $N = 2$; $A = 4$

Both atoms are He – atoms, meaning the same element.
They only differ in mass:
ISOTOPE

NUCLEONS

Atomic number (Z)
= Number of protons in the nucleus

Mass number (A)
= Sum of the protons and neutrons
$A = Z + N$



$^{3}_{2}He$ $N = 1$
0,000137 %

$^{4}_{2}He$ $N = 2$
99,999863 %

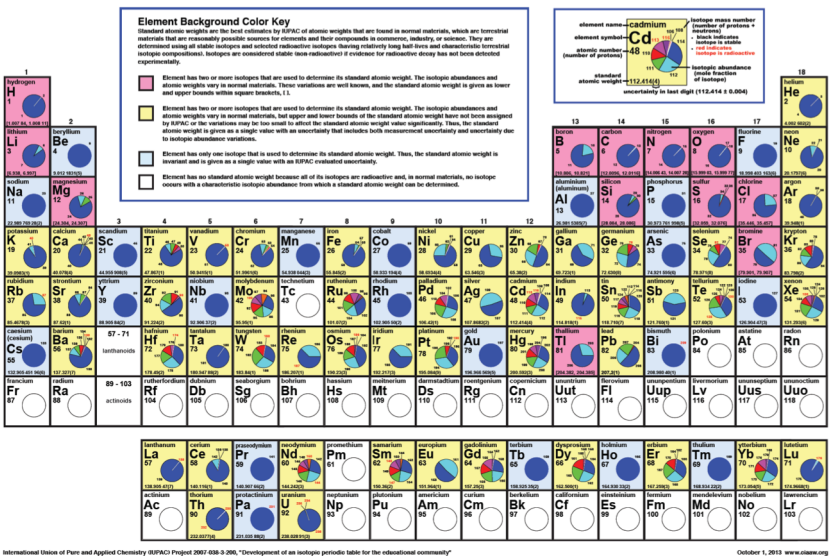
Both atoms are He – atoms, meaning the same element.
They only differ in mass:
ISOTOPE

Natural isotopes do not occur in nature with the same abundance. The ratio of the abundances is called the **ISOTOPE RATIO**

$^{4}He/^{3}He = 729926$

ISOTOPIC ABUNDANCES (ciaaw.org)

IUPAC Periodic Table of the Isotopes



TO THE MASS OF ATOMS....

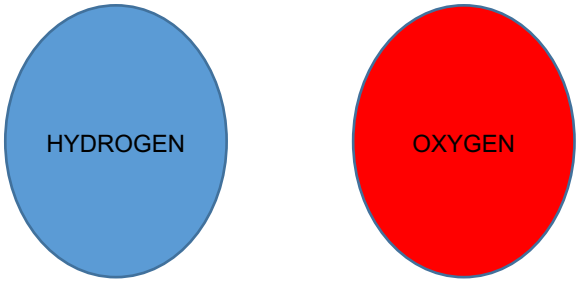
Since an atom is relatively small, it only has a veeeery small absolute mass (m_a):

An atom of the hydrogen isotope ^{1}H is $1.673532812 \times 10^{-27}$ kg

....AVOGADRO

Lorenzo Romano Amedeo Carlo **Avogadro**, Conte di Quaregna e Cerreto
1776 - 1856

p = const.; T = const.;



$V_1 = V_2$

$N_1 = N_2$

$m_1 \neq m_2$ $m_2 = 16 \times m_1$

TO THE MASS OF ATOMS....

Atomic masses were determined relative to hydrogen

(1858, Stanislao Cannizzaro)):

Hydrogen (H): has the relative atomic mass of 1

Oxygen (O): has the relative atomic mass of 16 x 1 = 16

etc....

TO THE MASS OF ATOMS....

(relative) Atomic masses (A_r) were determined **relative to hydrogen**

(1858, Stanislao Cannizzaro)):

Hydrogen (H): has the relative atomic mass of 1

Oxygen (O): has the relative atomic mass of 16 x 1 = 16

etc....

Later, (1865, Jean Servais Stas) A_r was determined **relative to oxygen**.

TO THE MASS OF ATOMS....

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Hydrogen (H): has the relative atomic mass of 1

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etc....

Later (1865, Jean Servais Stas), A_r was determined **relative to oxygen**.

Since 1957 (Nier und Ölander), the carbon isotope **^{12}C** was chosen as a reference point.

RELATIVE ATOMIC MASSES A_r *(atomic weight)*

Relative atomic mass A_r

The relative atomic mass A_r is the absolute atomic mass m_a of an atom relative to 1/12 of the atomic mass of the carbon-12 atom (m_a (^{12}C))

$$A_r = \frac{m_a}{m_a(^{12}C) \times \frac{1}{12}}$$

RELATIVE ATOMIC MASSES A_r *(atomic weight)*

absolute atomic mass m_a

The relative atomic mass A_r is the absolute atomic mass m_a of an atom relative to 1/12 of the atomic mass of the carbon-12 atom (m_a (^{12}C))

The unit of the relative atomic mass is
u (unified atomic mass) or the **Da (Dalton)**

1/12 of the relative atomic mass of ^{12}C is exactly 1 Dalton

1 Dalton therefore corresponds to $1.660539040 \times 10^{-27}$ kg

The absolute mass m_a of a ^{12}C-atom is therefore
$12 \times 1.660539040 \times 10^{-27}$ kg = $1.99264685 \times 10^{-26}$ kg

ATOMIC MASSES

One atom of the hydrogen isotope ^1H is $1.673532812 \times 10^{-27}$ kg

One atom of the hydrogen isotope ^1H is 1.007825032 Da

Atomic masses of the isotopes are determined experimentally.
(Atomic Mass Evaluation, 2016 – IUPAP)

AVERAGE RELATIVE ATOMIC MASS (A_r) (standard atomic weight)

Determination of the **average relative atomic mass** of Cu:

Naturally occurring copper contains on average:

Copper-63 69.15 % ^{63}Cu A_r = 62.929 597

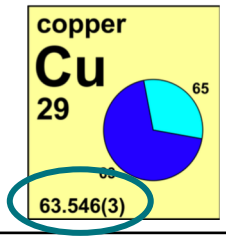
Copper-65 30.85 % ^{65}Cu A_r = 64.927 790

$$A_r = 0.6915 \times 62.929597 + 0.3085 \times 64.927790 = 63.546$$

m_a = 63.546 Da

AVERAGE RELATIVE ATOMIC MASS
(Standard Atomic Weight)

The mean relative atomic masses with less significant numbers of digits are those that are given in the periodic table and are called "Abridged Standard Atomic Weights"



„Abridged Standard Atomic Weight"

NOTE: In the periodic table, the simplified average relative atomic masses are given, even if they exist in a larger interval in nature (see ciaaw.org)

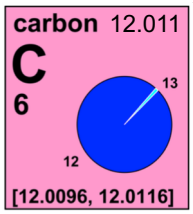
AVERAGE RELATIVE ATOMIC MASS

In nature, some elements have such a wide distribution of abundances that no single value can be given.

These elements have an interval in which the atomic weight value is found for a single sample.

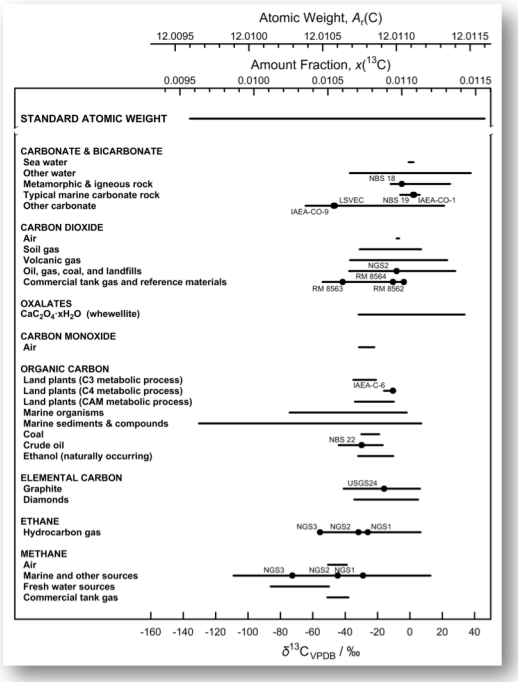
Example: Carbon

Atomic weight distribution of carbon on Earth (Source: ciaaw.org)



Simplified standard atomic weight

Interval



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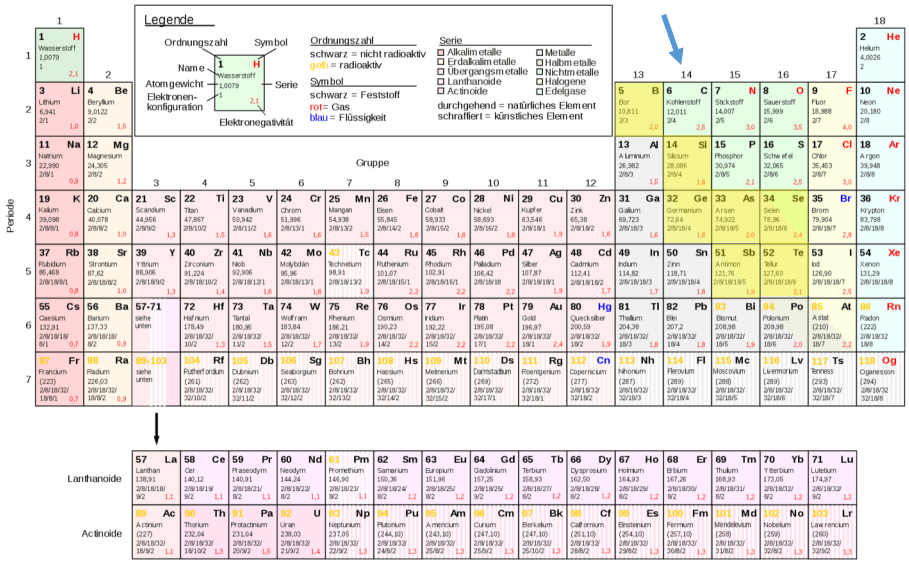
12.011 (Da)



SI Units

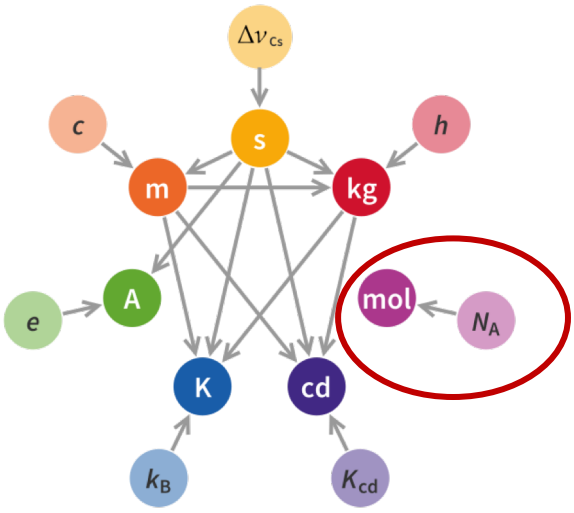
The internationally valid SI system of units - SI , is an abbreviation for the French expression *Systéme international d'unités*.

It is the modern form of the metric system and the most widely used system of measurement in the world.

It consists of a total of

- a **coherent system of 7 basic units**,
- a set of **20 decimal prefixes** - prefixes representing multiples or fractions of the units (giving the non-coherent units (e.g. mg or km)) -
- and **22 SI units derived** from the basis set.

Système international d'unités (see MINT Physics)



Amount of substance

mol

Quantity symbol: *n*

Dimension symbol: N

Unit: mol

DEFINITION OF THE MOLE:

The mole, unit symbol mol, is the SI unit of amount of substance.

One mole contains exactly 6.022 140 76 × 10^{23} individual particles.

This number corresponds to the fixed numerical value applicable to the Avogadro constant N_A, expressed in units of mol^{-1}, and is known as the Avogadro number.

The amount of substance, sign *n*, of a system is a measure of a number of specified constituents.

A single particle can be an atom, a molecule, an ion, an electron, another particle or a group of such particles with specified composition.

THE MOLE ...

The number of particles corresponds to **6,022** 140 76 **x 10^{23}** particles.

The quantity is called the **Avogadro number** (N_A)

Thus the amount of substance of 1 mol has exactly 6.02214076 x 10^{23} particles (=natural constant)

THE MOLE ...

The number of particles corresponds to **6,022** 140 76 **x 10^{23}** particles.

The quantity is called the **Avogadro number** (N_A)

Thus the amount of substance of 1 mol has exactly 6.02214076 x 10^{23} particles (=natural constant)

(This is like 1 dozen = 12 particles)

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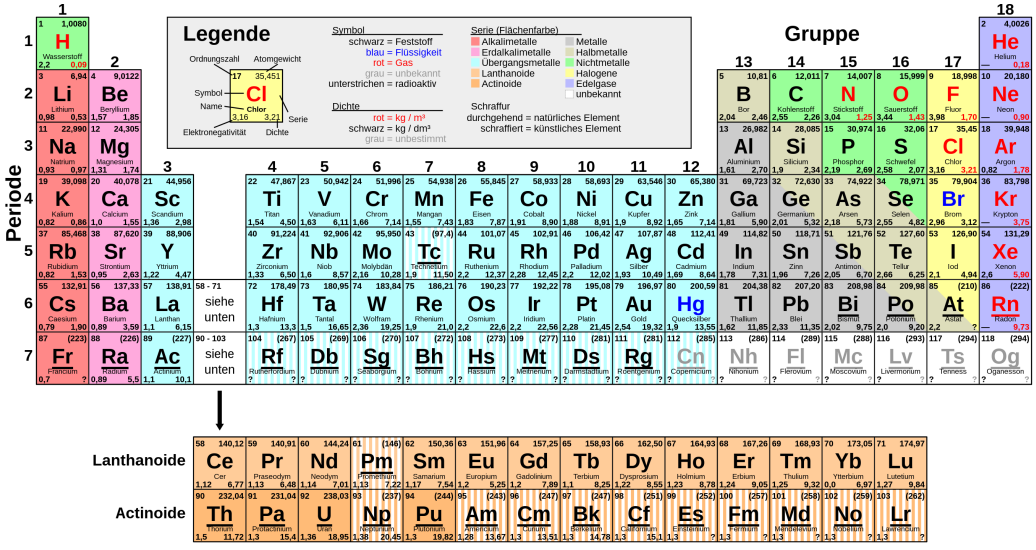
MOL und MOLAR MASSES (*M*)

The relative average atomic masses (Ar) in the periodic table correspond **in numerical value** (approximately) to the average **molar mass *M* in g/mol**

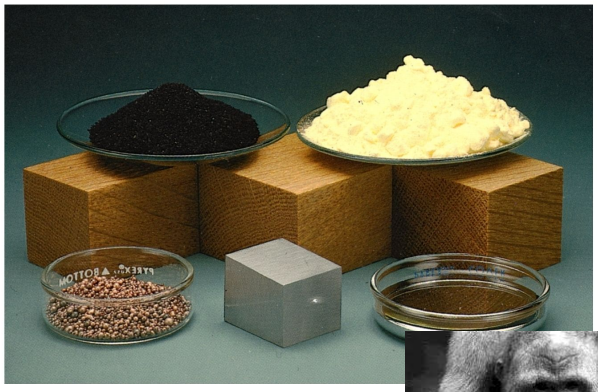
Molar Masses....



Each of these samples consists of 1 mole of the element

Clockwise from top right:

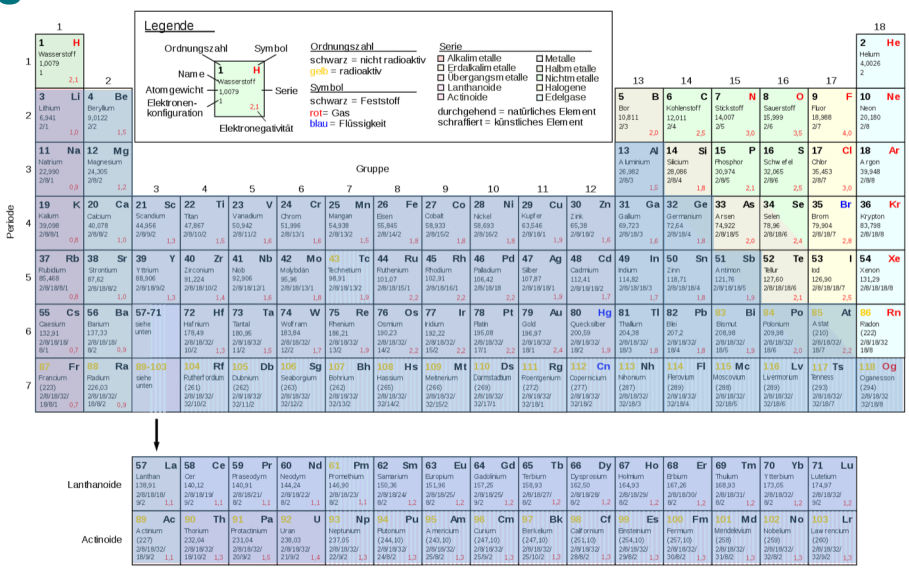
32.065 g	Sulphur
200.59 g	Mercury
207.2 g	Lead
63.546 g	Copper
12.011 g	Carbon



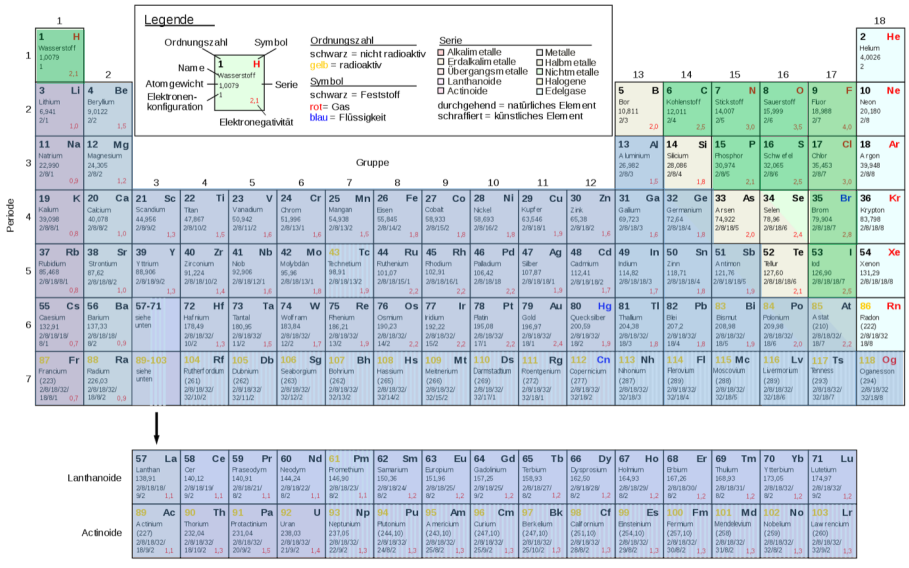
...how many atoms are there in each?
...and it's 6.02214076 x 10^{23} atoms of that element each time

EVALUATION OF ELEMENTS BASED ON POSITION ON THE PERIODICAL TABLE

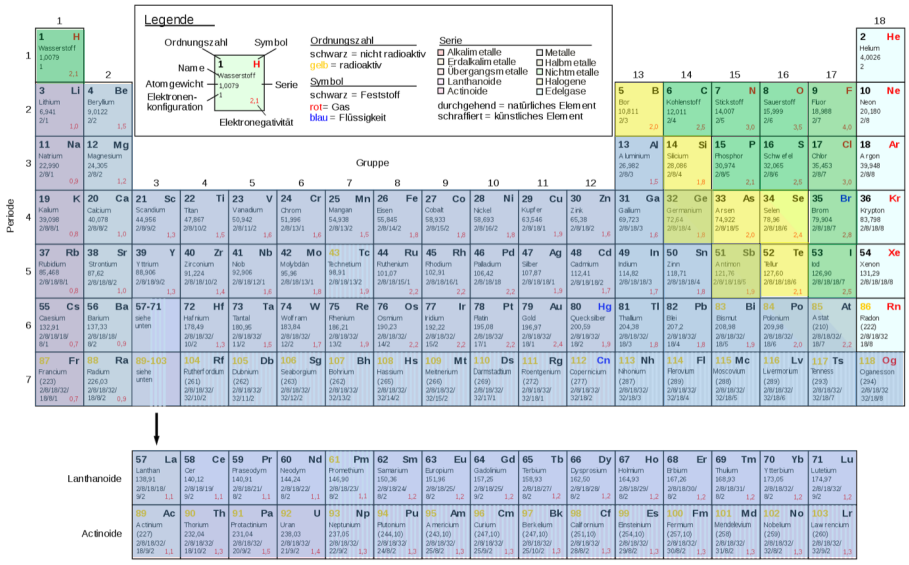
METALS



NONMETALS

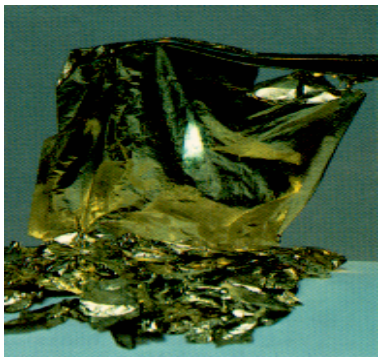


SEMIMETALS



Metals, Nonmetals, Semimetals

- A **metal** is a substance that conducts electricity, has a metallic sheen, and is ductile*.
- A **nonmetal** does not conduct electricity and is neither malleable nor ductile*.



Rolled out gold foil that lets light shine through

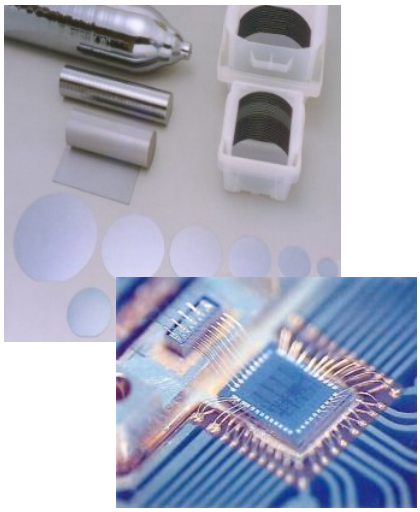
*malleable, plastic deformation

Characteristics of metals and non-metals

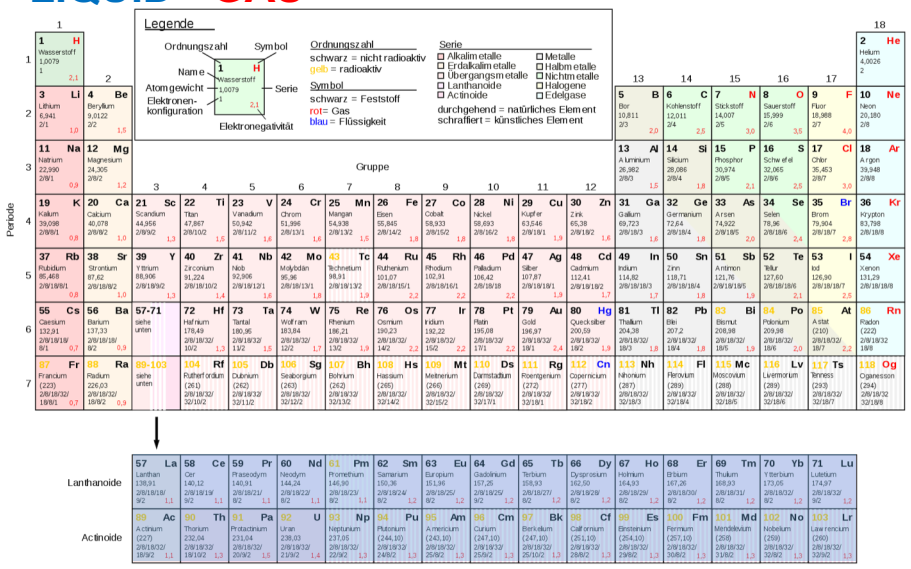
Metal	Nonmetal
physical properties	
good electrical conductor	bad electrical conductor
deformable under pressure	not deformable
malleable, ductile	not ductile
shiny	not shiny
typically:	
solid	solid, liquid or gas
high melting point	low melting point
good heat conductor	bad heat conductor
chemical properties	
react with acids	do not react with acid
form basic oxides	form acidic oxides
(that react with acids)	(that react with bases)
form cations	form anions

Metals, Nonmetals, Semimetals

Semimetals have
• the appearance and (certain) properties of metals, but
• chemically behave like nonmetals



SOLID – LIQUID - GAS



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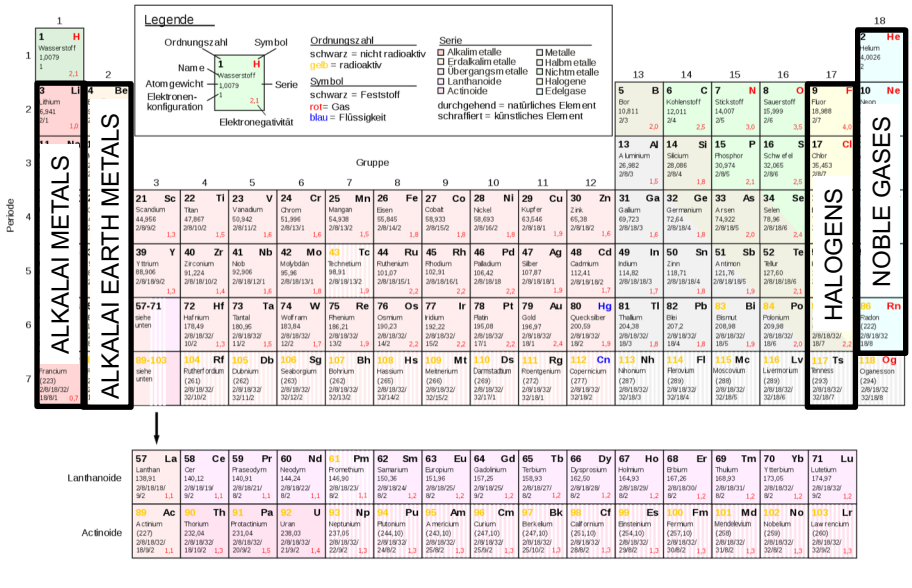
IMPORTANT GROUPS



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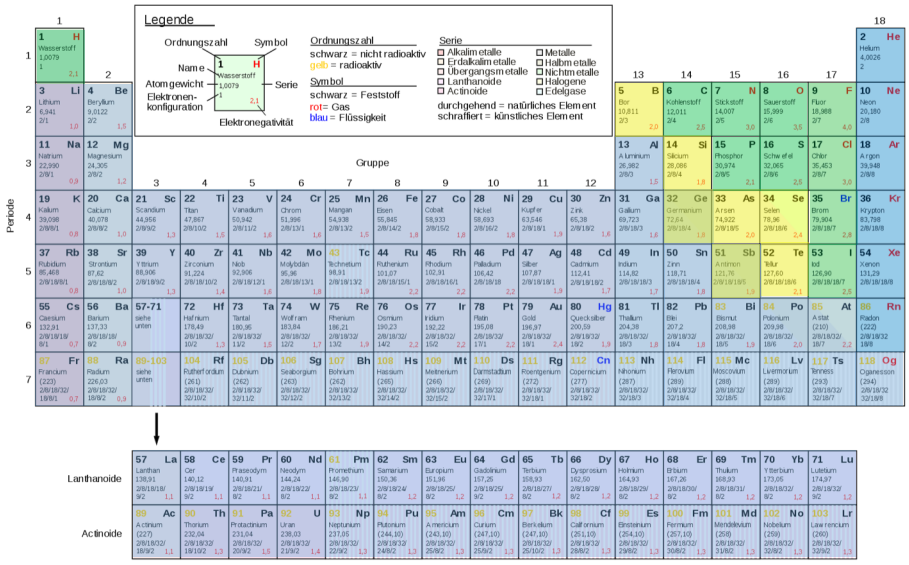
NOBLE GASES



IMPORTANT GROUPS