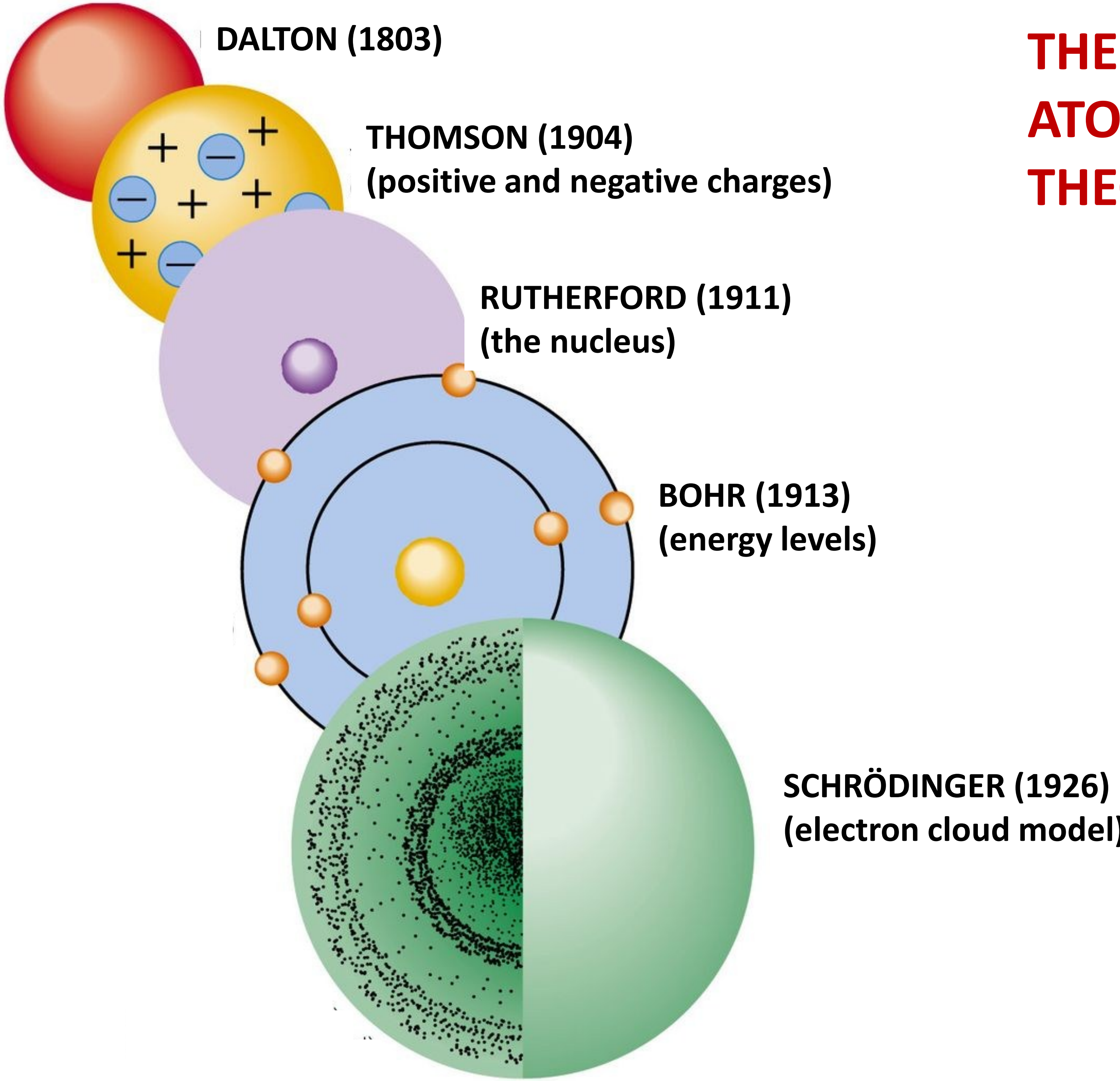
CHAPTER-2: ATOMS, MOLECULES AND IONS

- The atomic theory
- The structure of an atom
- The periodic table
- Molecules and ions
- Chemical formulas and naming of compounds

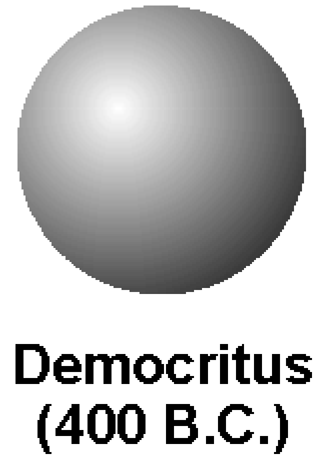
THE ATOMIC THEORIES



2.1. The Atomic Theory

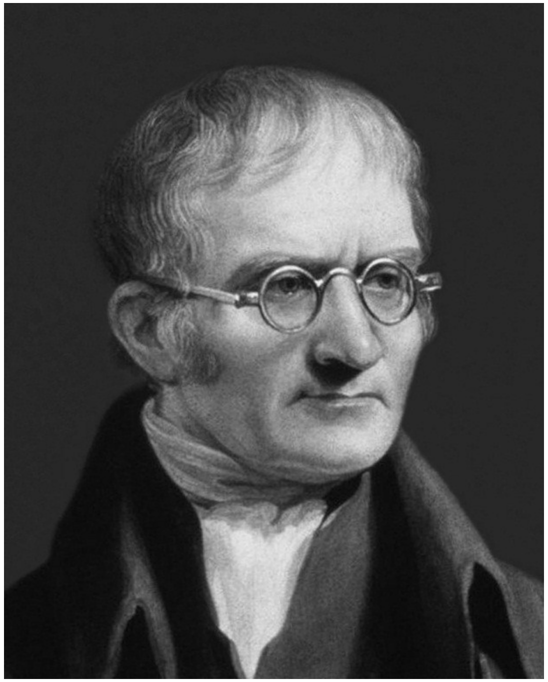
Greek philosopher Democritus
400 (B.C)

- Democritus created first atomic model



- ***All the matter consist of very small, indivisible particles, which he named «atomos» (mean: indivisible)***

2- DALTON’S ATOM THEORY



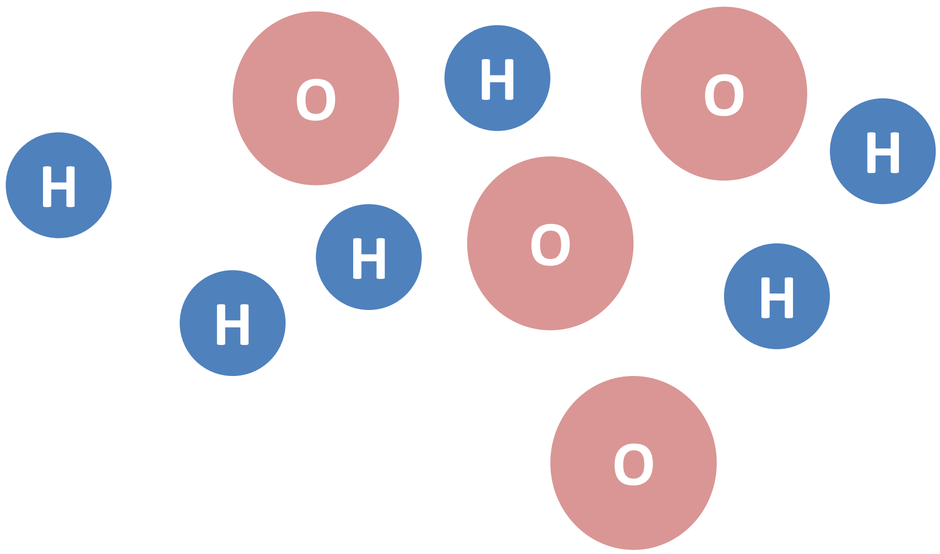
English scientist and school teacher **John Dalton** in 1808, formulated a precise definition of the indivisible building blocks of matter that called **atoms**

HYPOTHESIS OF DALTON'S ATOMIC THEORY

1- Elements are composed of extremely small particles called **atoms**.

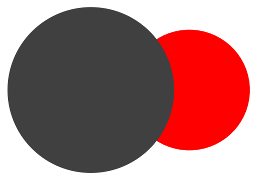
All the atoms of a given element are **identical** : having the same size mass and chemical properties

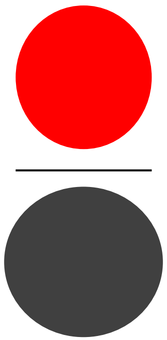
The atoms of one element are **different** from the atoms of all other elements

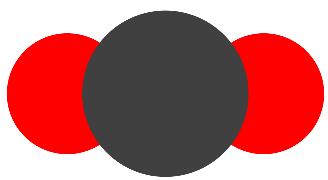


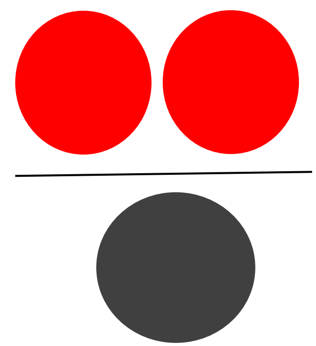
2- Compounds are composed of atoms of more than one element

In any compound, **the ratio of the numbers of atoms** of the elements present as **a simple fraction**

Carbon monoxide (CO) 

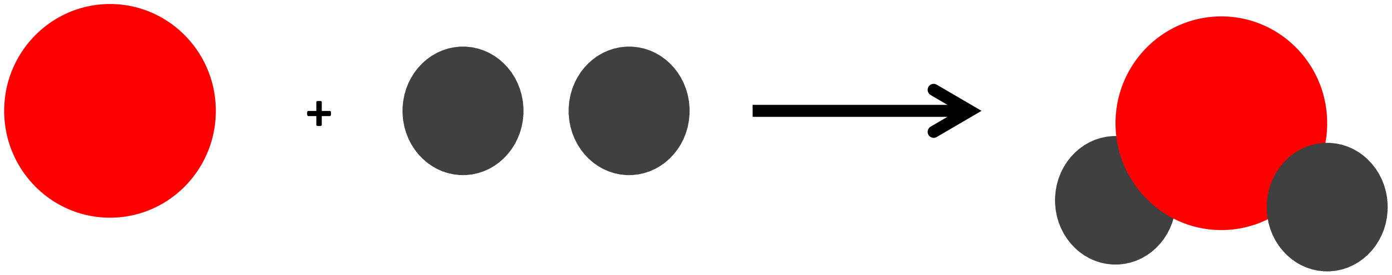
$\frac{O}{C}$ =  = $\frac{1}{1}$

Carbon dioxide (CO_2) 

$\frac{O}{C}$ =  = $\frac{2}{1}$

This hypothesis was supported with **the law of of definite proportions** by **Joseph Proust** (a French chemist) in 1799.

3- A chemical reaction involves only seperation, combination or rearrangement of atoms; it **does not** result in their creation or destruction.



1 oxygen atom at 16 mass units each: **16 mass units**	2 **hydrogen** atoms at 1 mass unit each: **2 mass units**	1 **water molecule** at 18 mass units each: **18 mass units**

This hypothesis is supperted later on with **the law of conversation of mass** which is that **matter can be neither created nor destroyed.**

NOT TRUE in DALTON'S THEORY!

- Atoms aren't indivisible-

They are composed of **sub-atomic particles**!!

Late 1890’s:

Theorical structure of the universe «**complete**»

- Atomic theory of matter
- Newtonian mechanics

DISCOVERY OF ELECTRONS (1897)

An English physicist J.J. Thomson

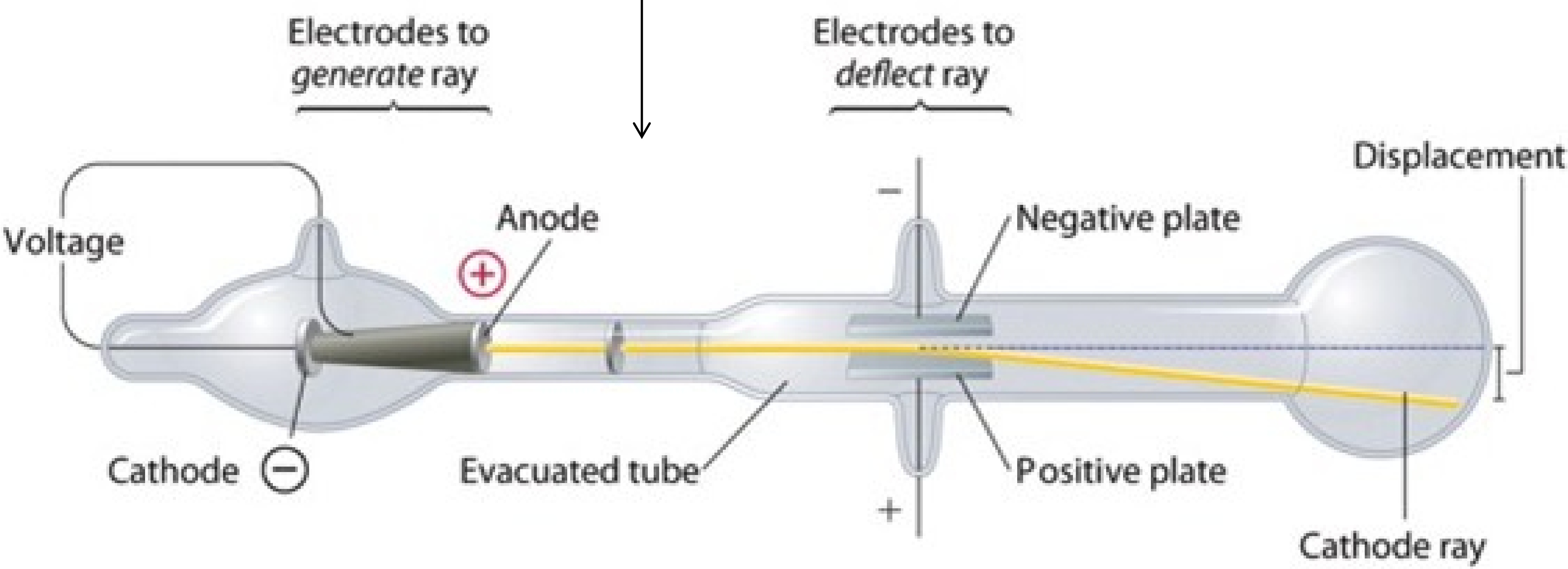
(University of Manchester)

Nobel prize in Physics in 1906 for

discovering electron

The Experiment:

$H_{2\,(g)}$



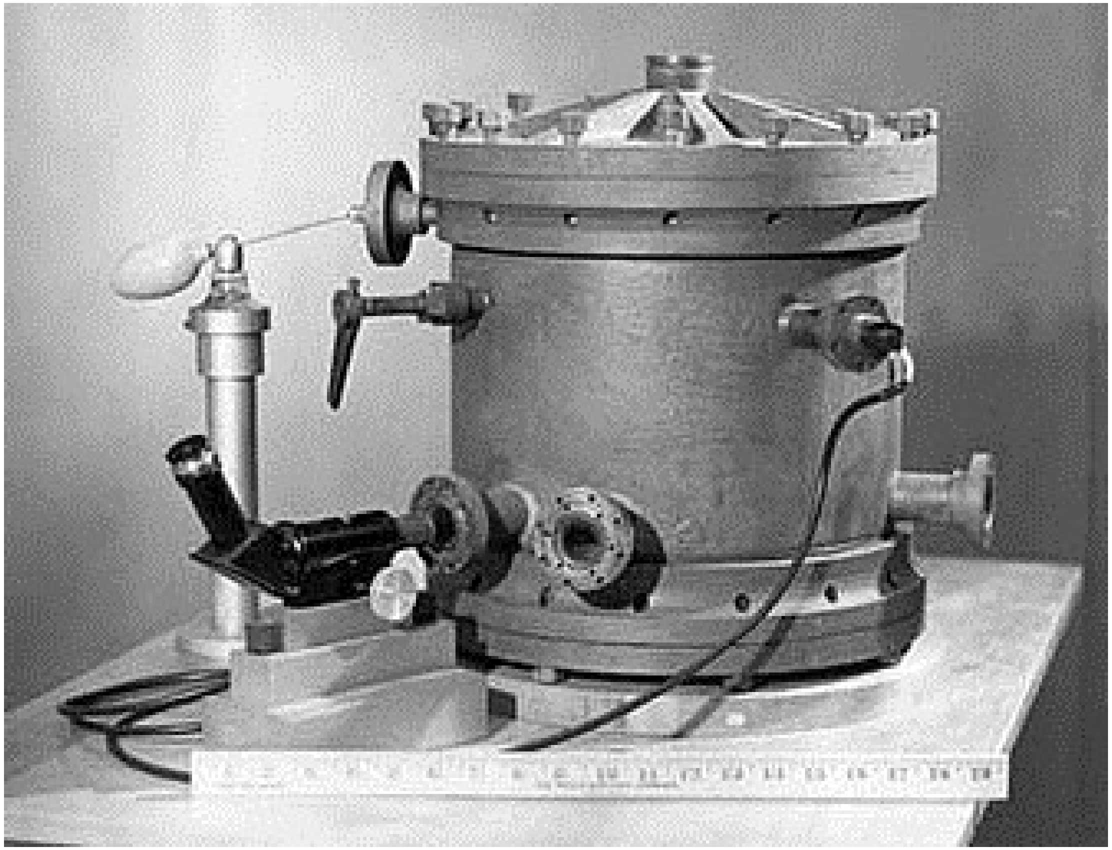
$$\frac{e(-)}{m\ (-)} = \mathbf{-1.76x10^{8}\ C/g}$$

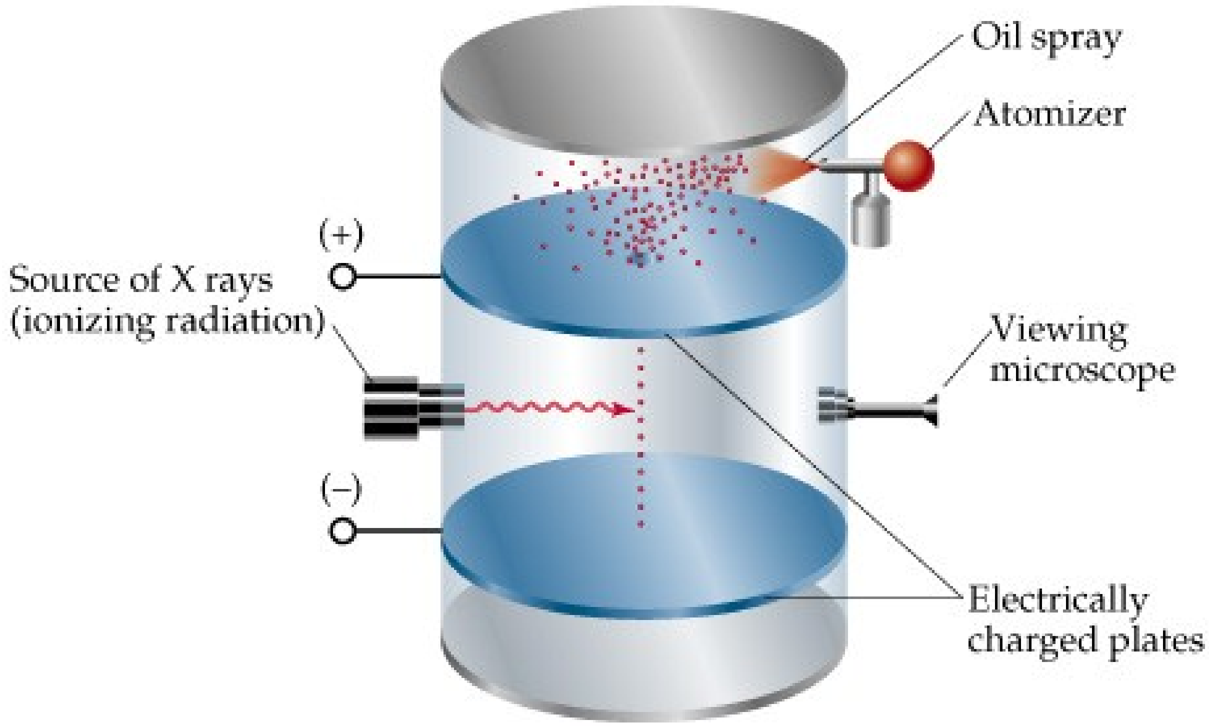
DISCOVERY OF ELECTRONS (1897)

Cathode ray tube that was used by J.J. Thomson **to discover electron** exhibiting in **Science Museum in London**

The charge of the electron

R.A Millikan (American physicist) who was awarded the Nobel prize in Physics in 1923 for **determining the charge of the electron**





1- Electrons are produced by the action of X-rays on the molecules of which air is composed.

2- Oil pick up electrons and acquire electric charges

3- The oil drops are allowed to settle between two horizontal plates, and the mass of a particular drop is determined by measuring its rate of fall

4-When the plates are charged, the rate of fall of the drop is altered because the negatively charged drop is attracted to the upper, positive plate

5-The charge on the drop can be calculated from the mass of the drop

q= - e = e (-) = -1.6022×10^{-19} coulomb

e is called a unit **electrical charge**

The electron has a unit a negative charge

The mass of the electron ($m_{electron}$):

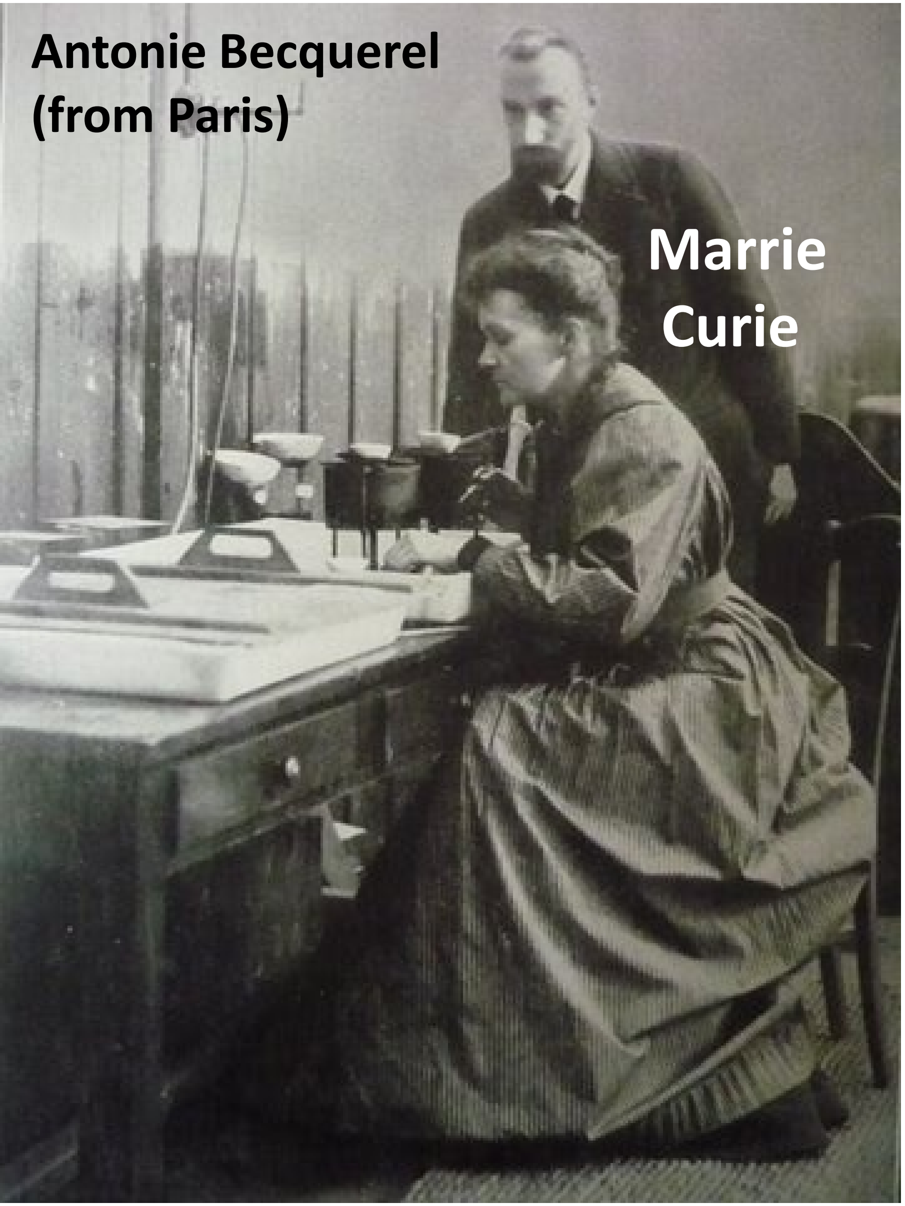
$$m = \frac{q}{q/m} = \frac{-1.6022\text{x}10^{-19}\ \text{C}}{-1.7588\text{x}10^{8}\ \text{C/g}} = \mathbf{9.1096\text{x}\ 10^{-28}\ g}$$

The mass of the proton (m_{proton}):

$$m = \frac{q}{q/m} = \frac{+1.6022\text{x}10^{-19}\ \text{C}}{+9.5791\text{x}10^{4}\ \text{C/g}} = \mathbf{1.6726\text{x}\ 10^{-24}\ g}$$

$$\frac{m_{proton}}{m_{electron}} = \frac{1.6726\text{x}\ 10^{-24}\ \text{g}}{9.1096\text{x}\ 10^{-28}\ \text{g}} = \boxed{1836}$$

RADIOACTIVITY



- They have both Nobel prize in Physics

about radioactivity (1903, 1911)

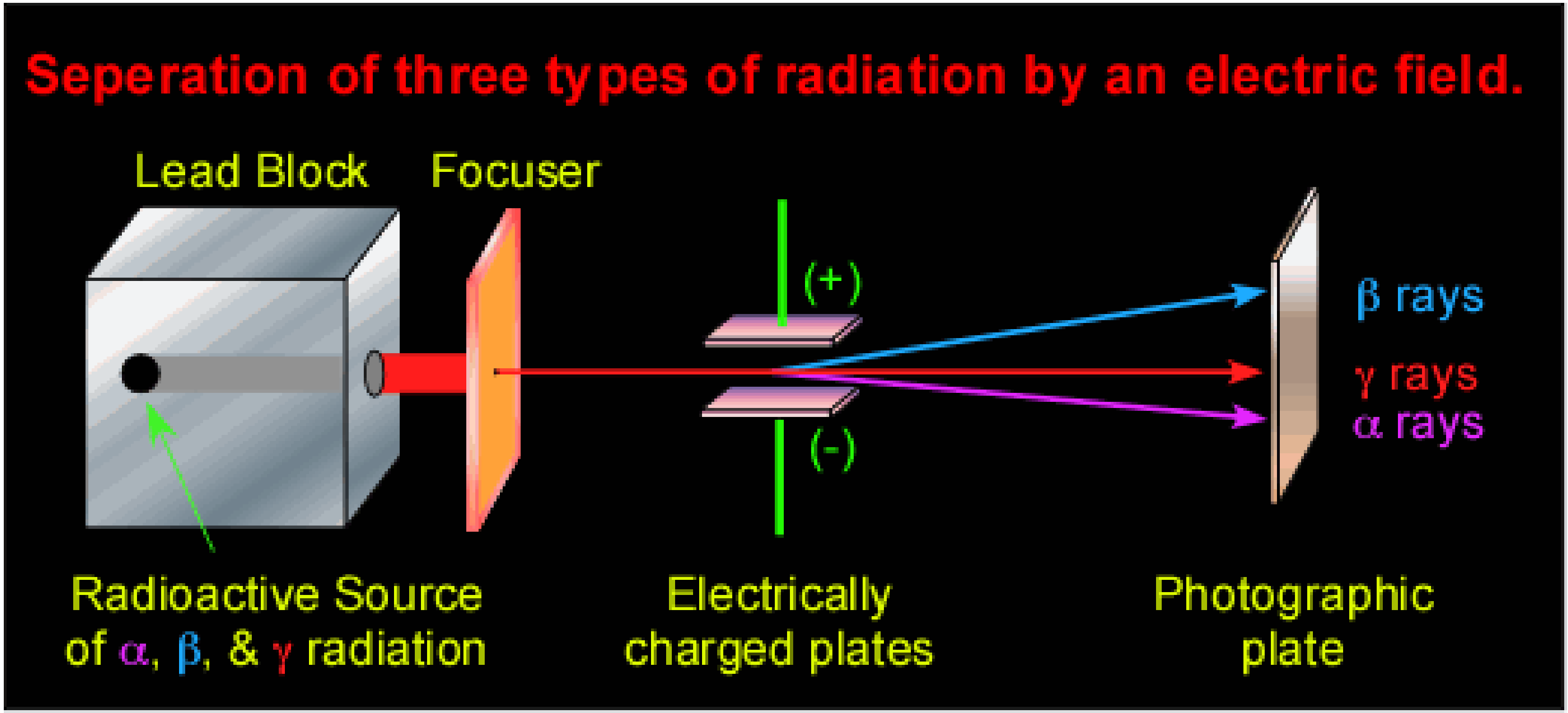
-studying on **fluorescent properties** of substances

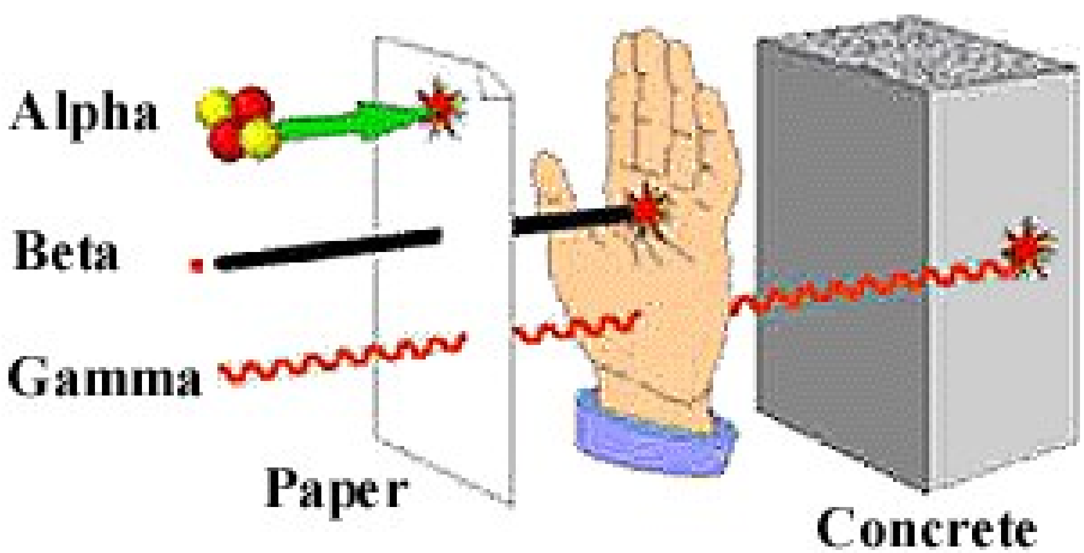
Accidently, he found that exposing thickly wrapped photographic plates to a certain of uranium compound caused them to darken

-Marie Curie suggested **«radioactivity»** spontaneously emission of particles and/or radiation

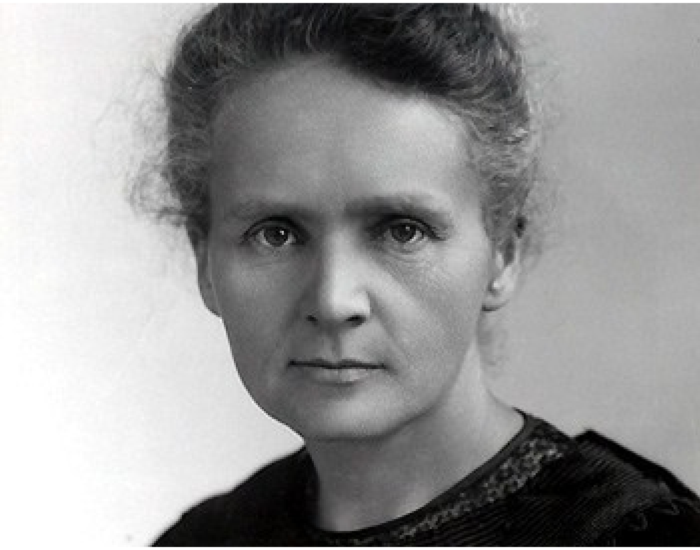
-These elements called **«radioactive»**

RADIOACTIVITY



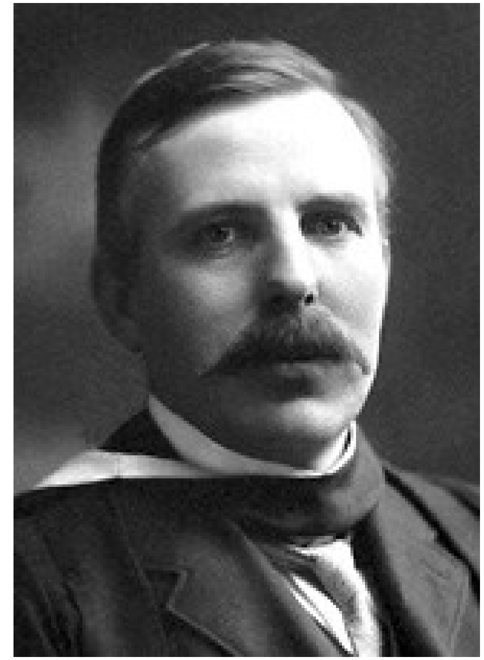


DISCOVERY OF NUCLEUS (1911)



shipping →

$RaBr_2$



Marie Curie

(France, Paris)

$RaBr_2$

α particles →

Ernest Rutherford

(England)

- New Zeland chemist
- Colleauge with J.J. Thomson

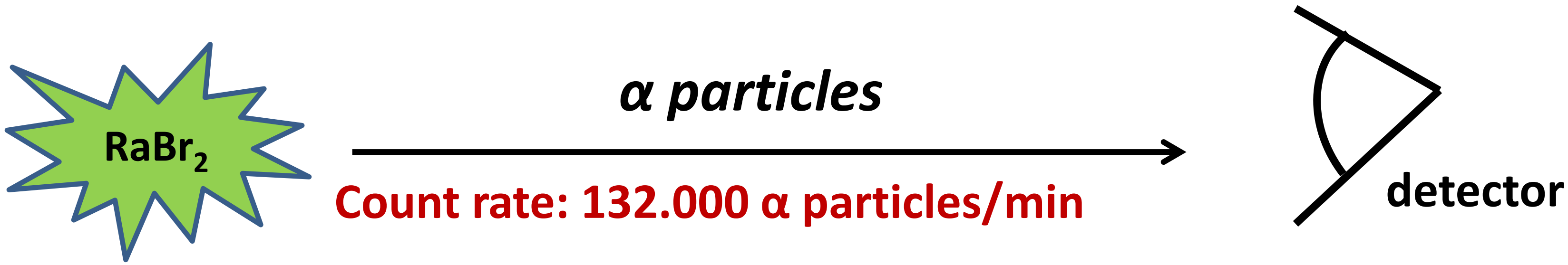
at Cambridge university

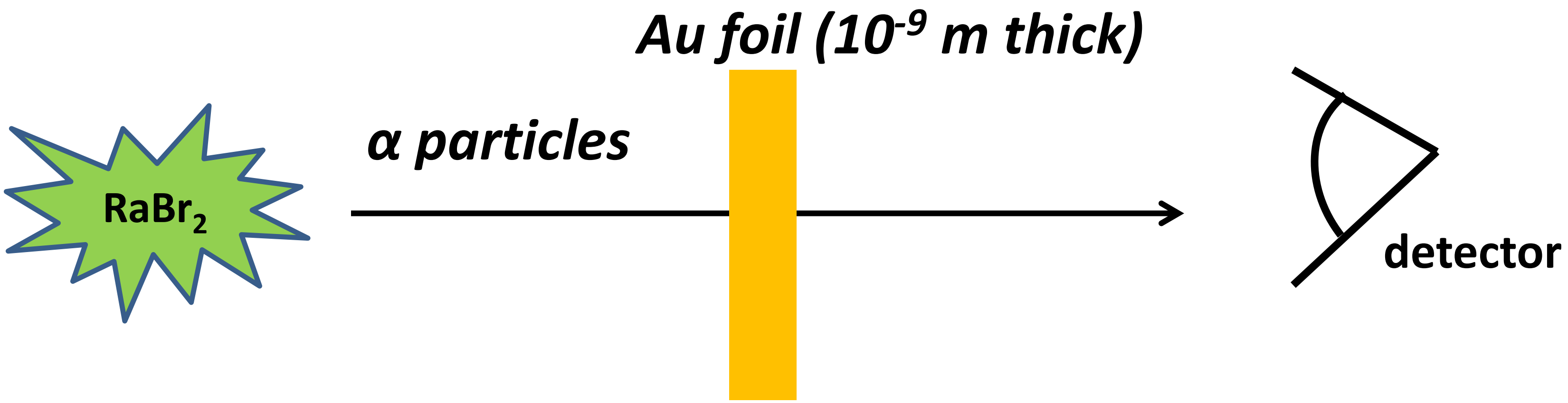
α particles was unknown in 1911

post-doc ***Hans Geiger*** and undergraduate student ***E. Marsden***

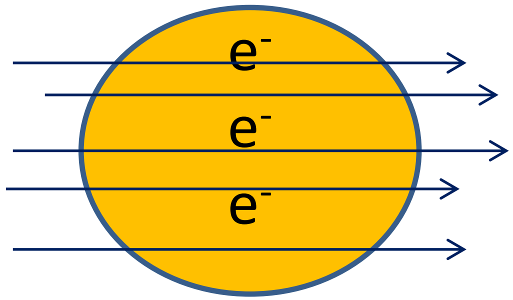
How many α particles coming from $RaBr_2$?

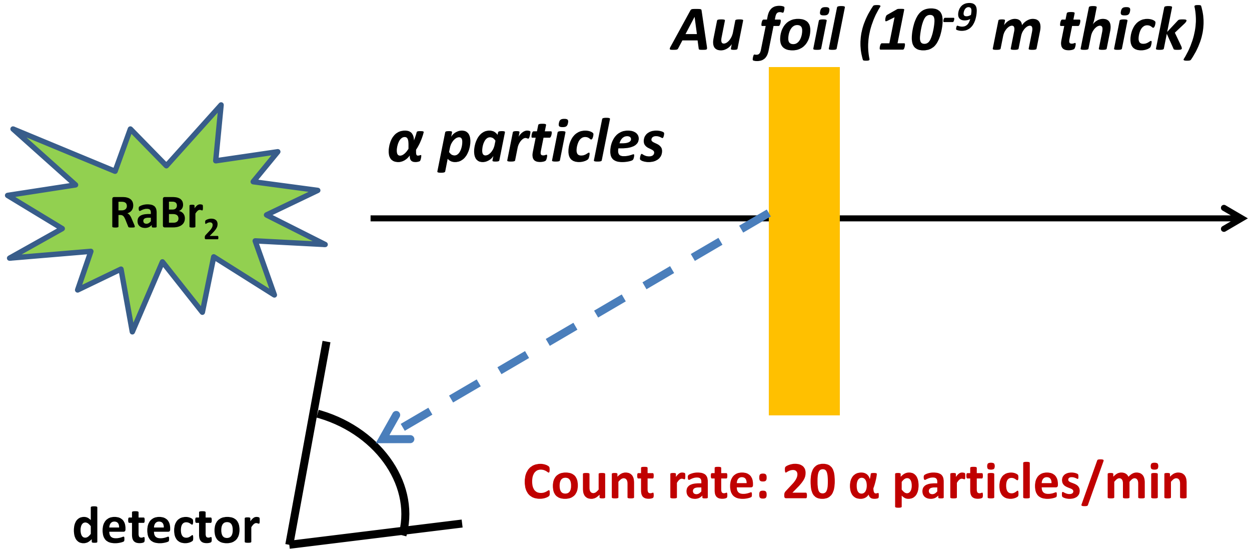
-





Count rate: 132.000 α particles/min





- That was not expected, they were expected «0»
- <u>Backscattering was detected</u>

Probability of backscattering:

$$\mathbf{P} = \frac{\text{Count rate backscattered}}{\text{Countrate of incident particles}} = \frac{20}{132{,}000} = 20 \times 10^{-5} \quad \mathbf{(0.02\%)}$$

«.. about as credible as if you had fired a 15 inch shell at a piece of tissue paper , it came back and hit you»

-***Rutherford***

Interpretation

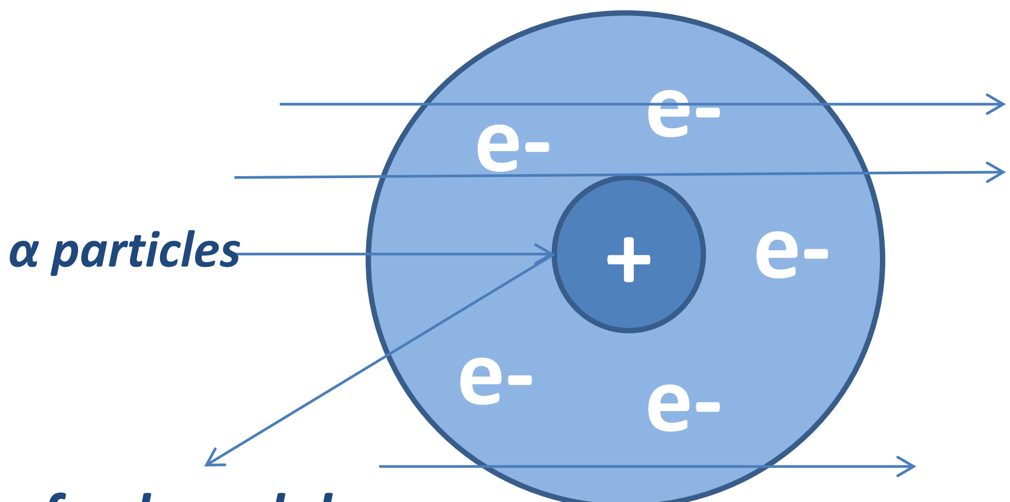
1- The Au atoms are ***mostly empty*** (just passing through and did not hit anything)

2- The majority of each ***atom's mass is concentrated*** in a very small volume compared to the volume of atom.

We now call this region «**Nucleus**»

3-Together, these observations it was generated a new atom model:

Rutherford model



Rutherford model

- In a seperate experiment, the positively charged particles in the nucleus are called «***protons***»

- Each proton carries the same quantity of charge as an electron and has a mass $\mathbf{1.67262x10^{-24}}$ -about **1840** times the mass of the electron

- Nucleus occupies **1/13** of the volume of the atom

NEUTRON

Rutherford’s model of atomic structure left one major problem unsolved.

H proton:1

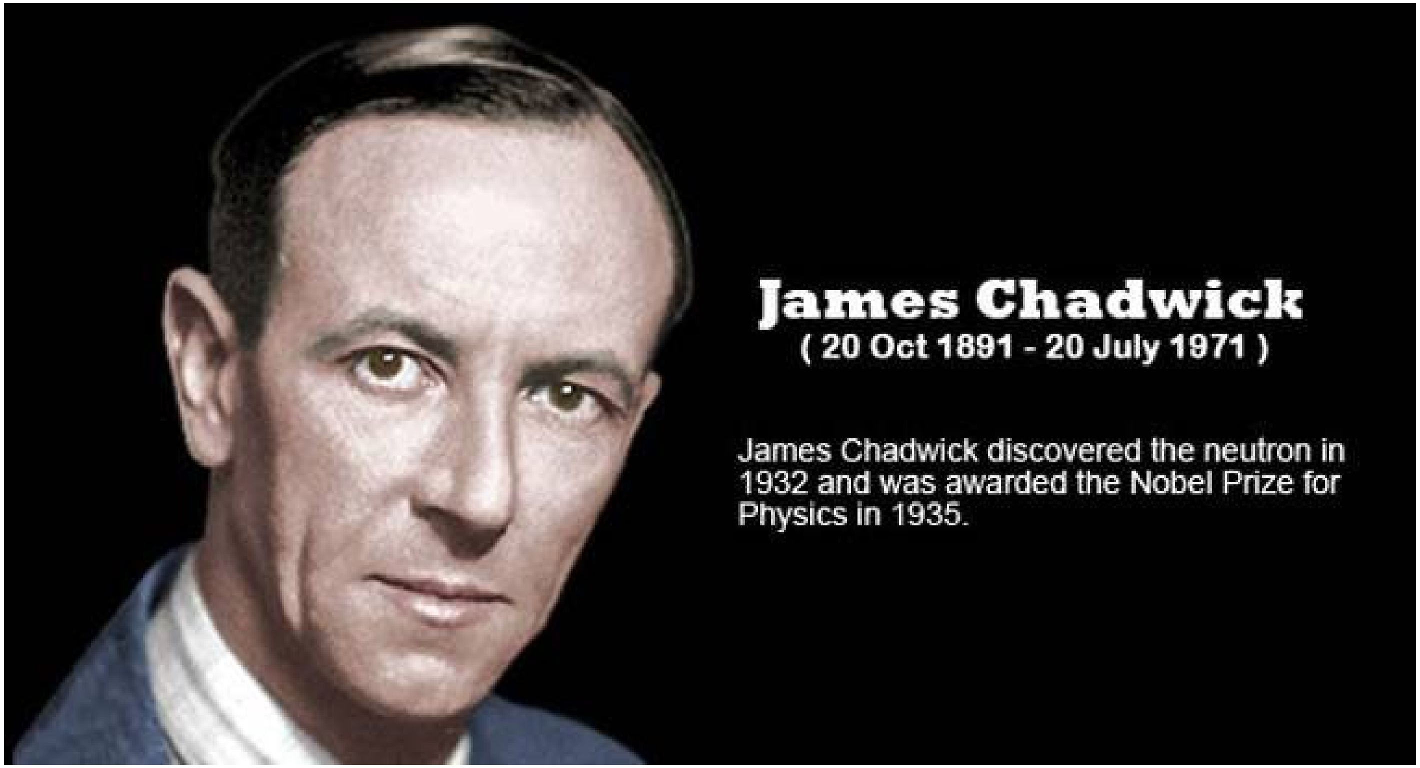
He proton:2

So, the ratio of the mass of a helium to hydrogen atom should be 2:1

BUT the ratio is 4:1

There must be another type of subatomic particles!!!!

NEUTRON



He named «**neutrons**», because they proved to ***be electrically neutral particles having a mass slightly greater than that of protons***

TABLE 2.1 Mass and Charge of Subatomic Particles

		Charge	
Particle	**Mass (g)**	**Coulomb**	**Charge Unit**
Electron*	9.10938×10^{-28}	-1.6022×10^{-19}	-1
Proton	1.67262×10^{-24}	$+1.6022 \times 10^{-19}$	$+1$
Neutron	1.67493×10^{-24}	0	0

*More refined measurements have given us a more accurate value of an electron's mass than Millikan's.

2.3. ATOMIC NUMBER, MASS NUMBER AND ISOTOPES

Atomic number (*Z*): is **the number of protons** in the nucleus of each atom of an element

Mass number (***A***): is the **total number of neutrons and protons** present in the nucleus of an atom of an element.

mass number

$^{A}_{Z}\mathrm{X}$

atomic number

X: *an element*

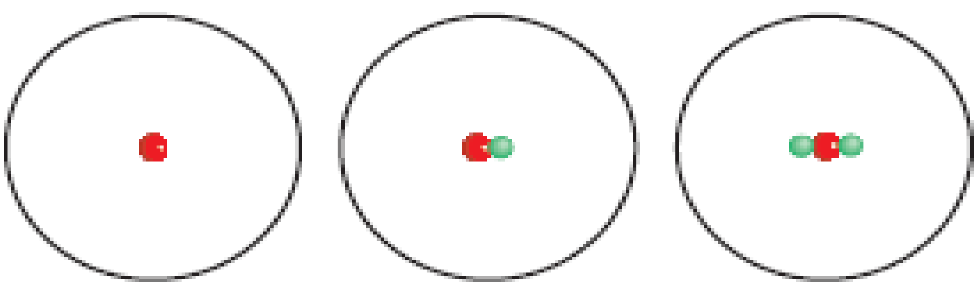
$$\begin{aligned}\text{mass number} &= \text{number of protons} + \text{number of neutrons}\\ &= \text{atomic number} + \text{number of neutrons}\end{aligned}$$

Number of electrons=Number of protons= atomic number İn a neutral element

Most elements in nature found as ***isotopes***, atoms that have the same atomic number but diffrent mass number

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

hydrogen deuterium tritium



$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

$^{235}_{92}U$ $^{238}_{92}U$

Nuclear reactor;
Atomic bomb

NOT!!!

Practice Exercise: Give the number of protons, neutrons and electrons

$$^{17}_{8}O$$

$$^{199}_{80}Hg$$

$$^{200}_{80}Hg$$

2.4 PERIODIC TABLE

More than half of the elements known today were discovered between **1800 and 1900.**

↓

Chemists noted that many elements show strong similarities to one another.

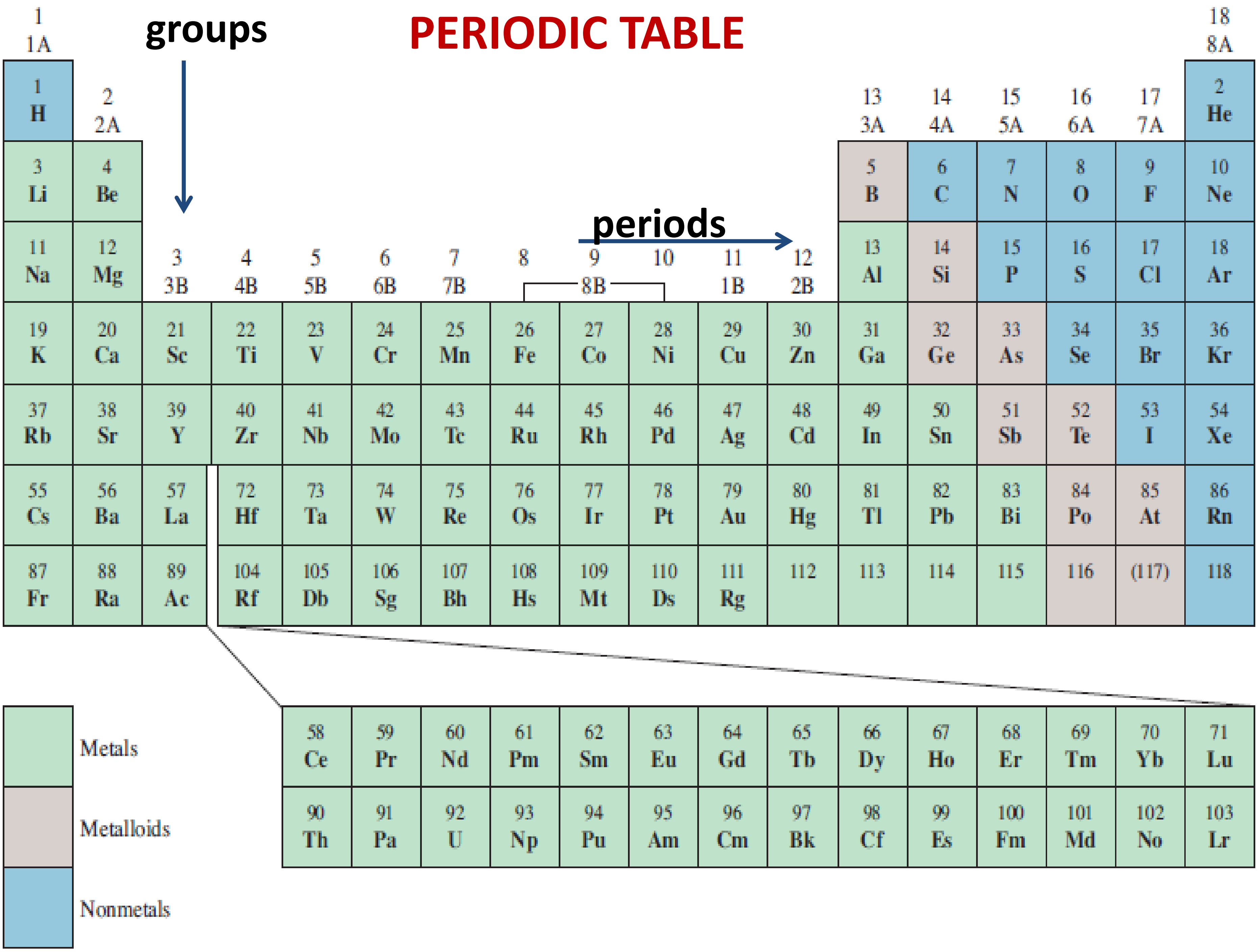
↓

They need to **organize** the large volume of info
about the structure and properties of elements

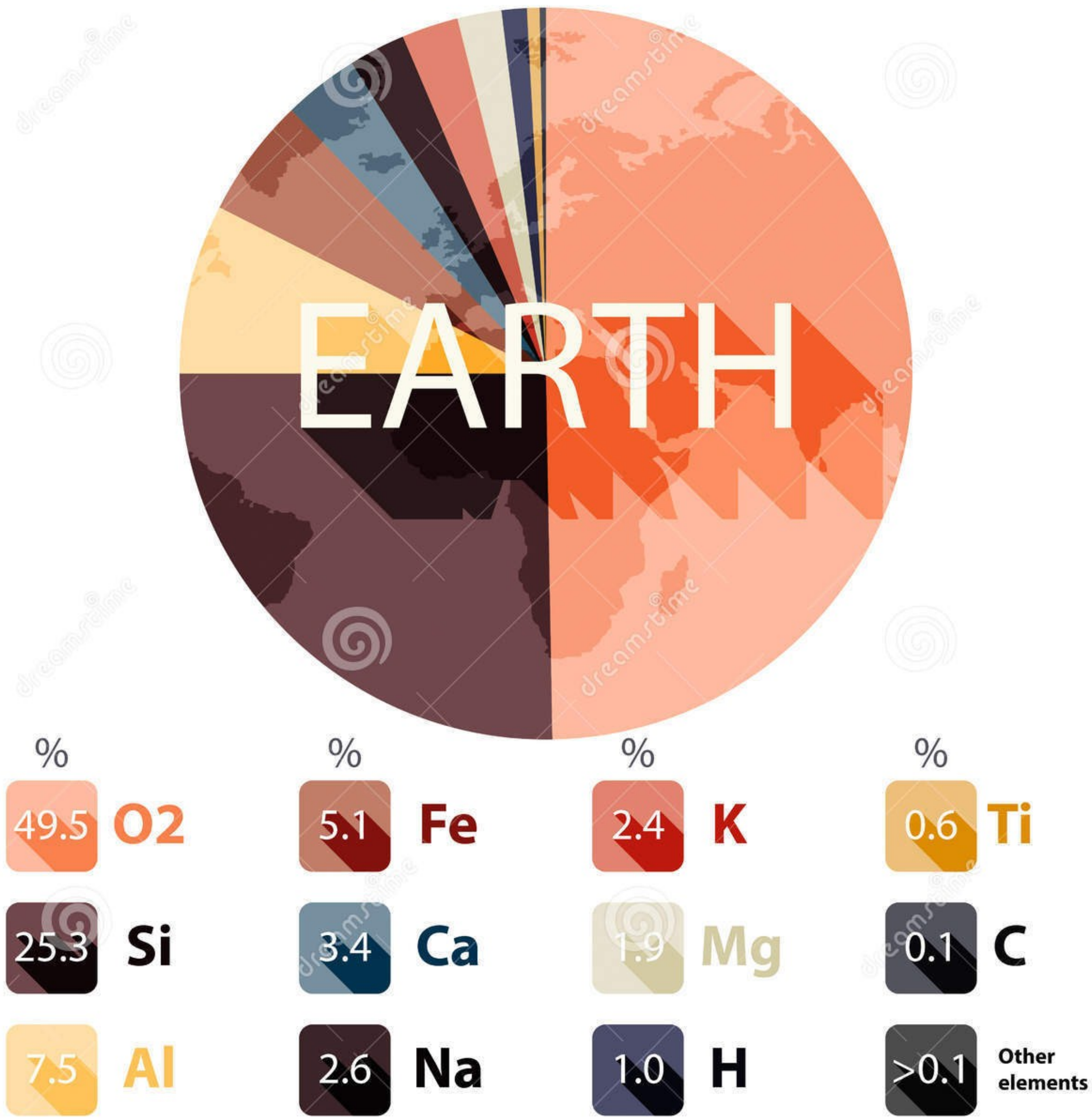
↓

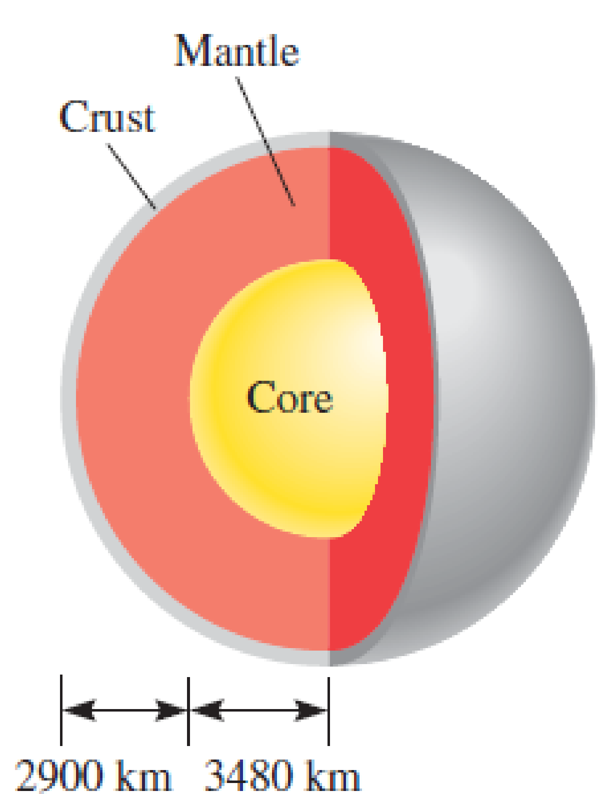
These things led to the development of **PERIODIC TABLE**

PERIODIC TABLE

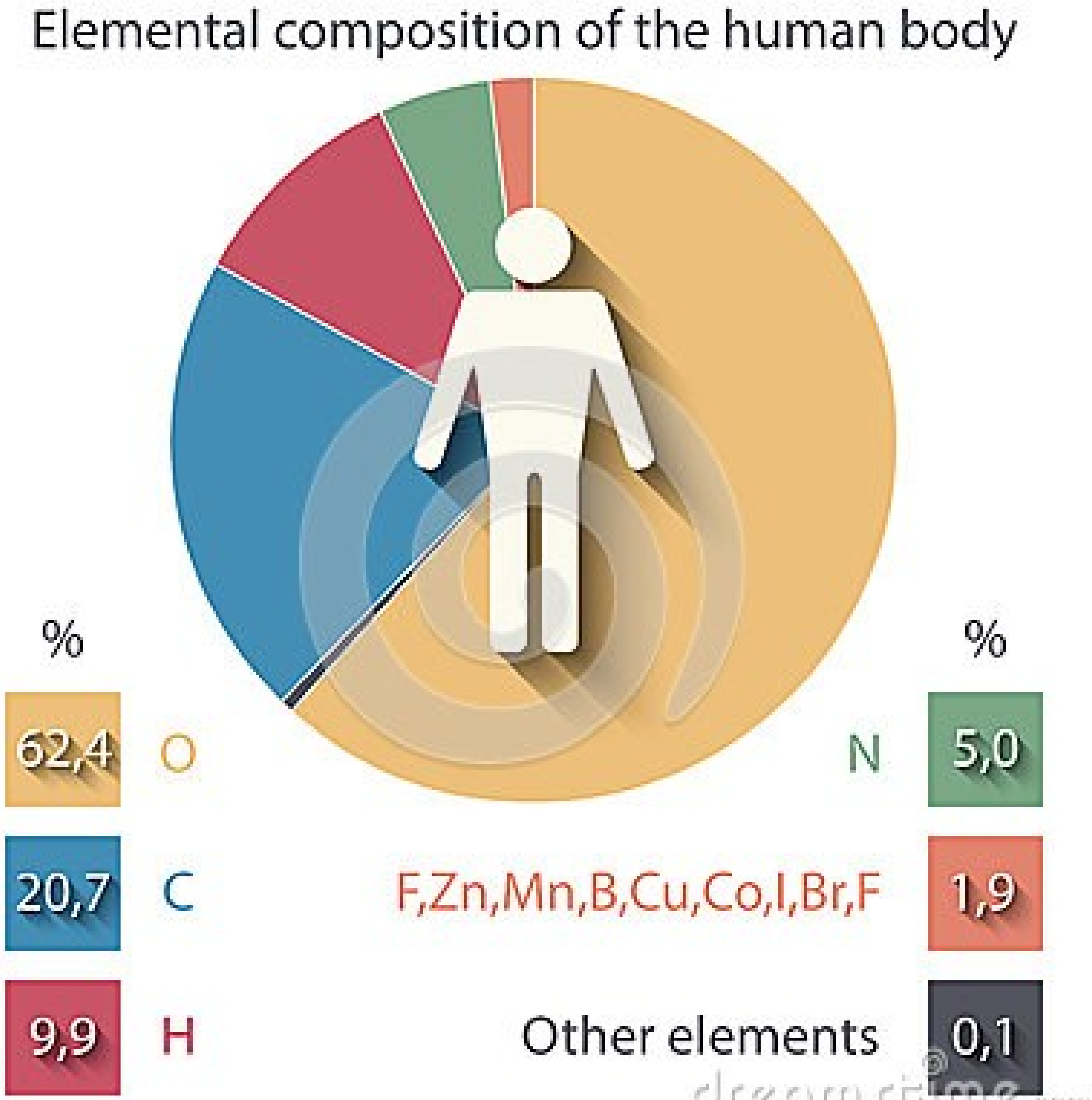


Chemical composition of the Earth`s crust





Structure of Earth's interior.


Elemental composition of the human body
%
62,4
O
20,7
C
9,9
H
%
N
5,0
F,Zn,Mn,B,Cu,Co,I,Br,F
1,9
Other elements
0,1

2.5. MOLECULES AND IONS

A MOLECULE: is an aggregate of at least two atoms in a definite arragement held together by chemical forces (also called chemical bonds)

A molecule is not necessarily a compound, which by definiton is made up of two or more elements

For instance, Hydrogen gas: H_2

MOLECULES

DIATOMIC MOLECULE

1. 1A : H_2
5A : N_2
6A: O_2
7A: F_2, Cl_2, Br_2, I_2

2. or can contain different elements

for example: HCl, CO

POLYATOMIC MOLECULE

1. O_3
2. or can contain different elements

for example: H_2O, NH_3

IONS

AN ION: is an atom or a group of atoms that has a positive or negative charge

1. CATION (+)
2. ANION (-)

Charge of ion: number of protons - number of electron

IONS

Monoatomic ions

Mg^{2+}

Fe^{3+}

S^{2-}

N^{3-}

Polyatomic ions

OH^{-}

CN^{-}

NH_4^{+}

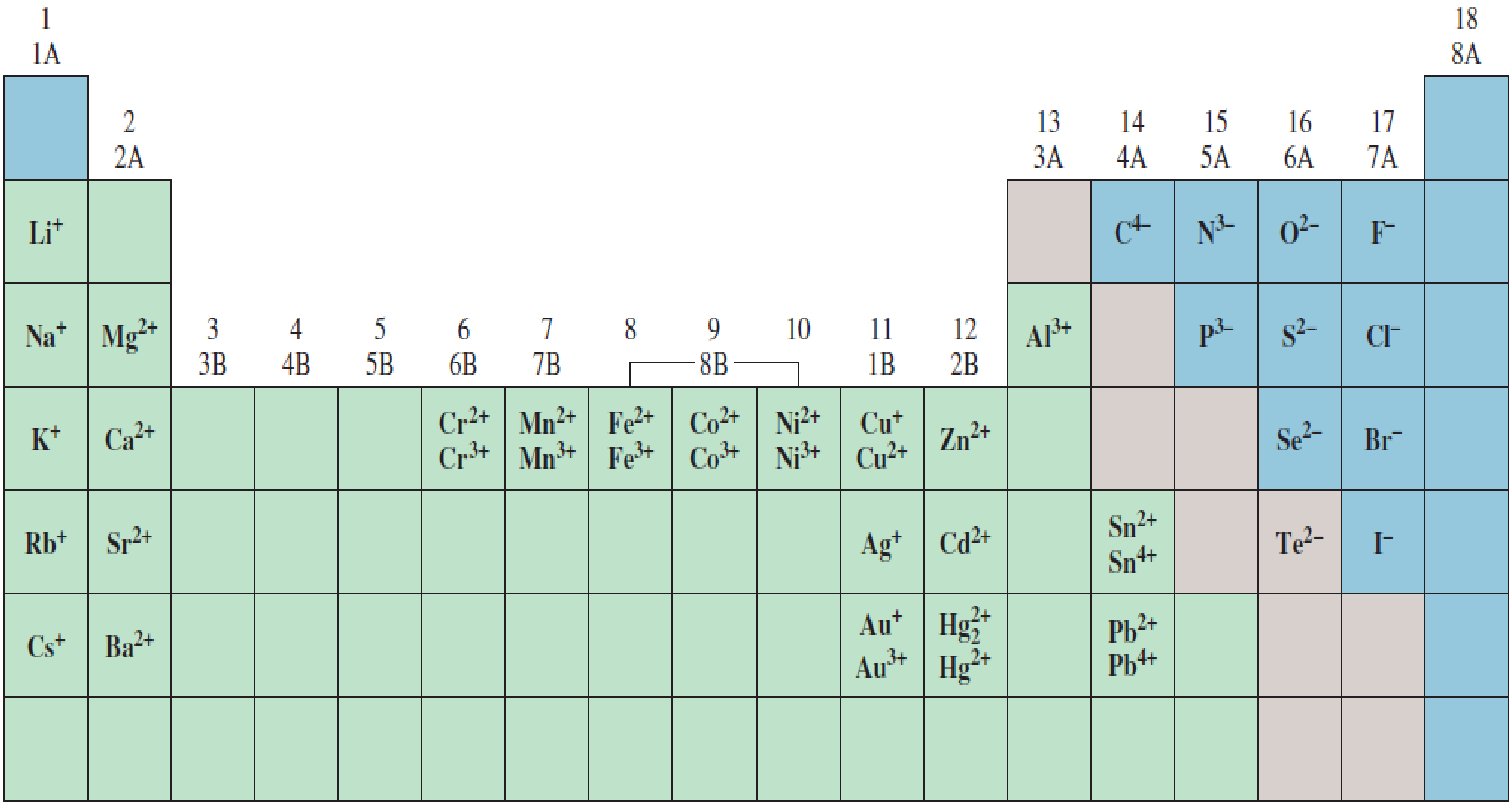


Figure 2.11 *Common monatomic ions arranged according to their positions in the periodic table. Note that the* Hg_2^{2+} *ion contains two atoms.*

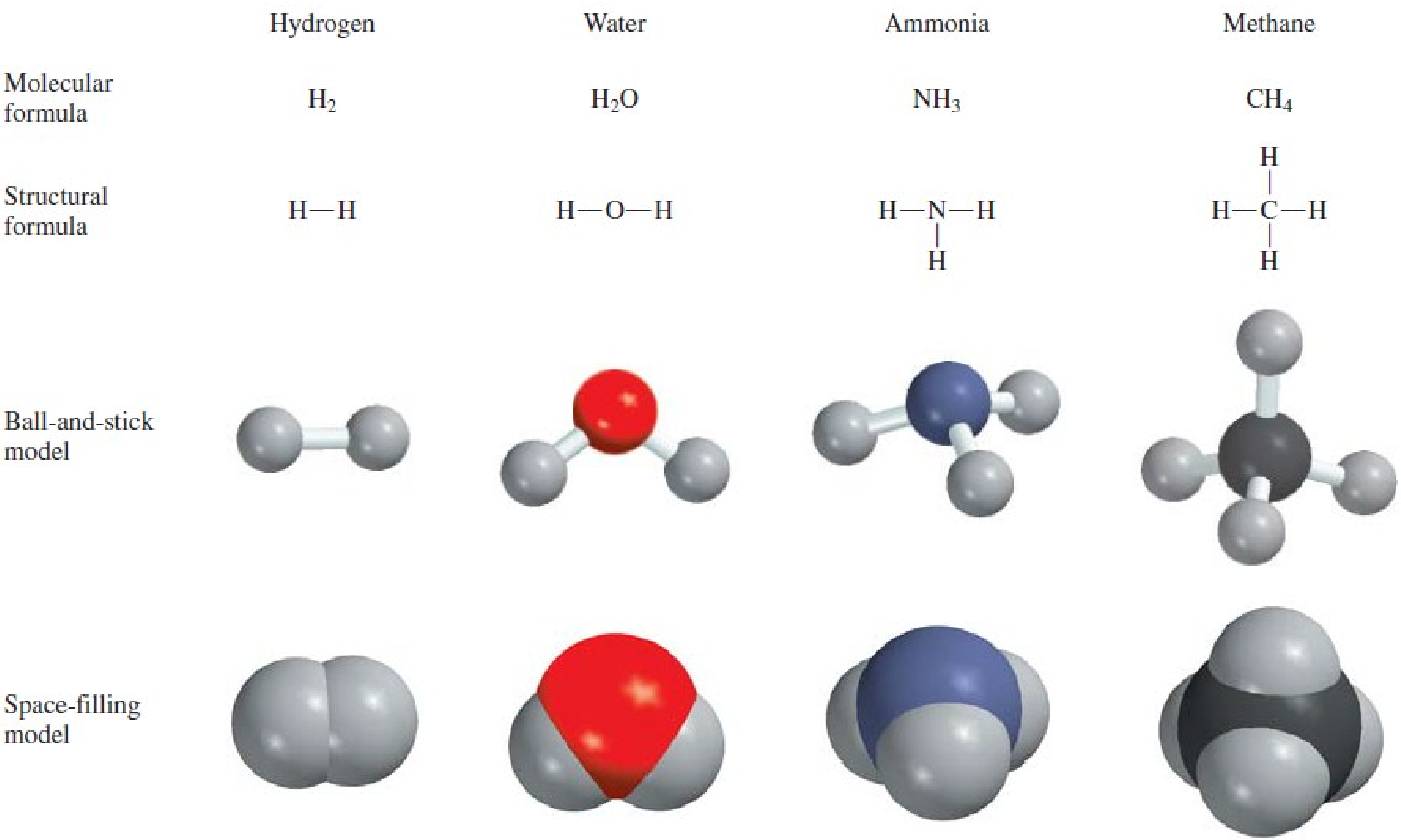
CHEMICAL FORMULAS

A- Molecular formulas

H_2O
NH_3,
CH_4

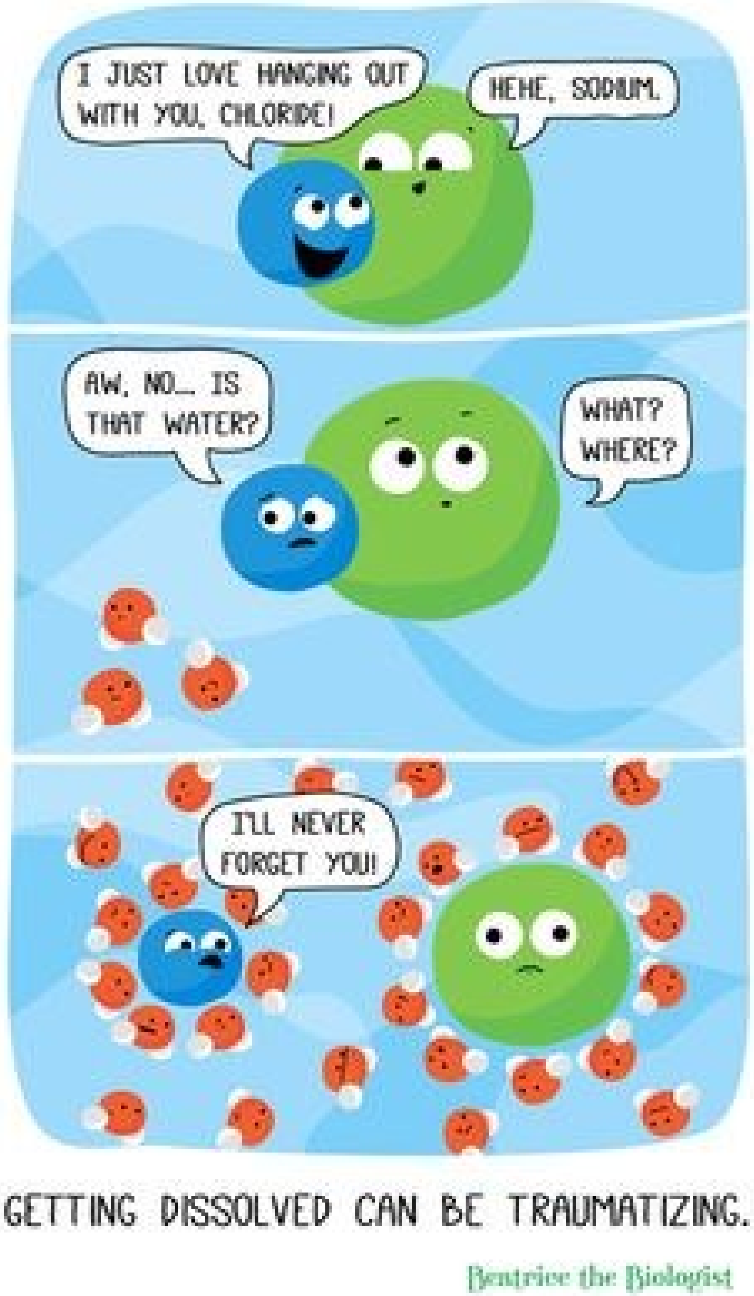
B- Emprical formulas

H_2O_2 : HO
N_2H_4 : NH_2

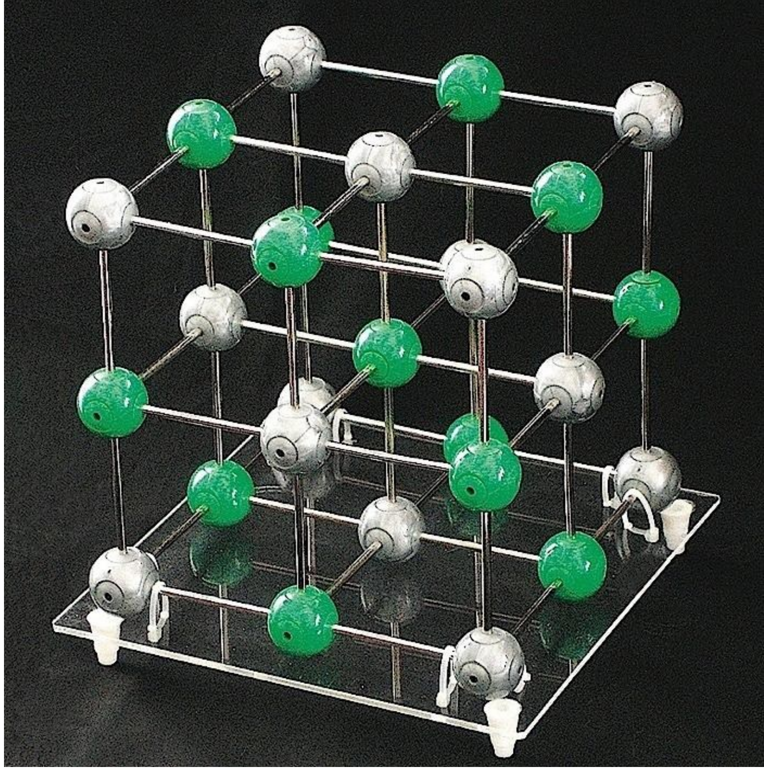


ure 2.12 *Molecular and structural formulas and molecular models of four common molecules.*

FORMULA OF IONIC COMPOUNDS



NaCl



Grey: chlorine
Green: sodium

The subscript of the cation is numerically equal to the charge on the anion, and the subscript of the anion is numerically equal to the charge of the cation

KBr

ZnI_2

Al_2O_3

NAMING COMPOUND

ORGANIC COMPOUNDS

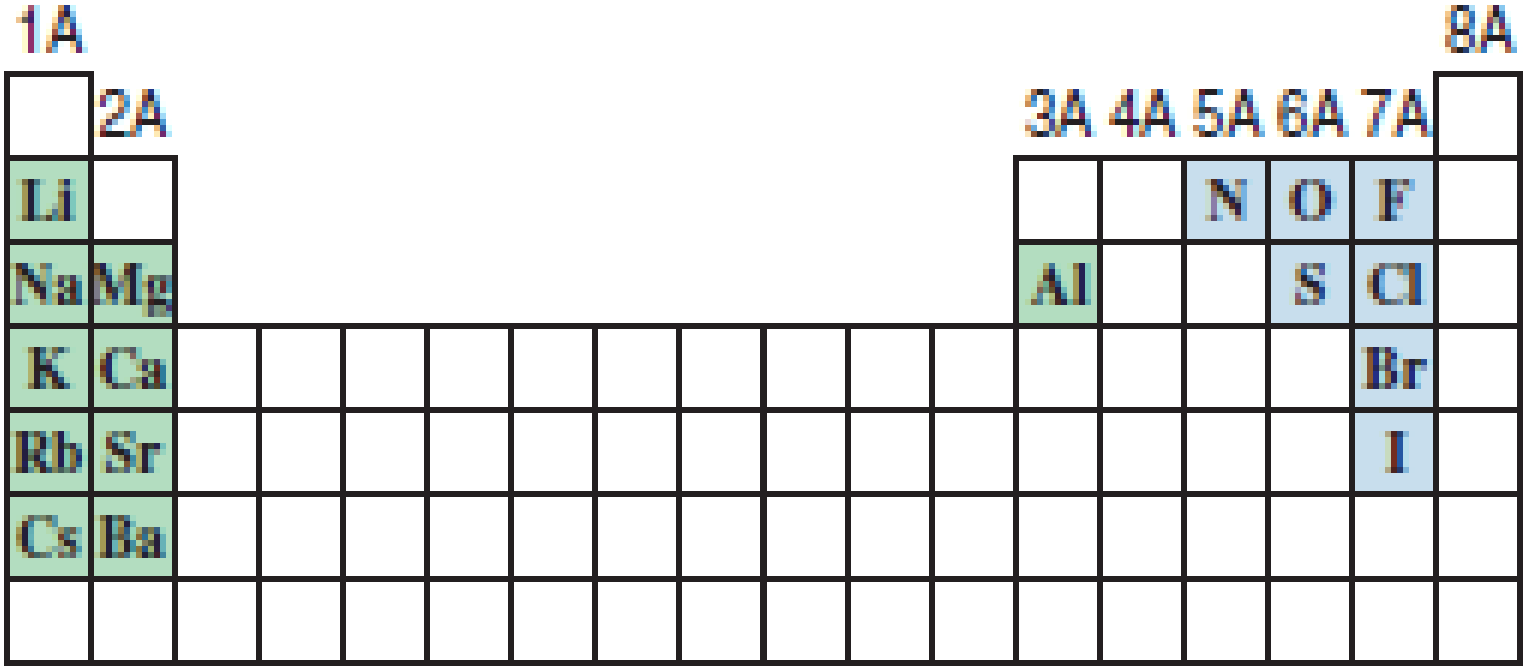
INORGANIC COMPOUNDS

1. Ionic compounds
2. Molecular compounds
3. Acids and bases
4. Hydrates

1. IONIC COMPOUNDS

Some metal cations

Element			Name of Cation
Na	sodium	Na^+	sodium ion (or sodium cation)
K	potassium	K^+	potassium ion (or potassium cation)
Mg	magnesium	Mg^{2+}	magnesium ion (or magnesium cation)
Al	aluminum	Al^{3+}	aluminum ion (or aluminum cation)



The most reactive metals (green) and the most reactive nonmetals (blue) combine to form ionic compounds.

Many ionic compounds are binary compounds;

or compounds formed from just two elements

NOMENCLATURE OF IONIC COMPOUNDS

A) For binary ionic compounds

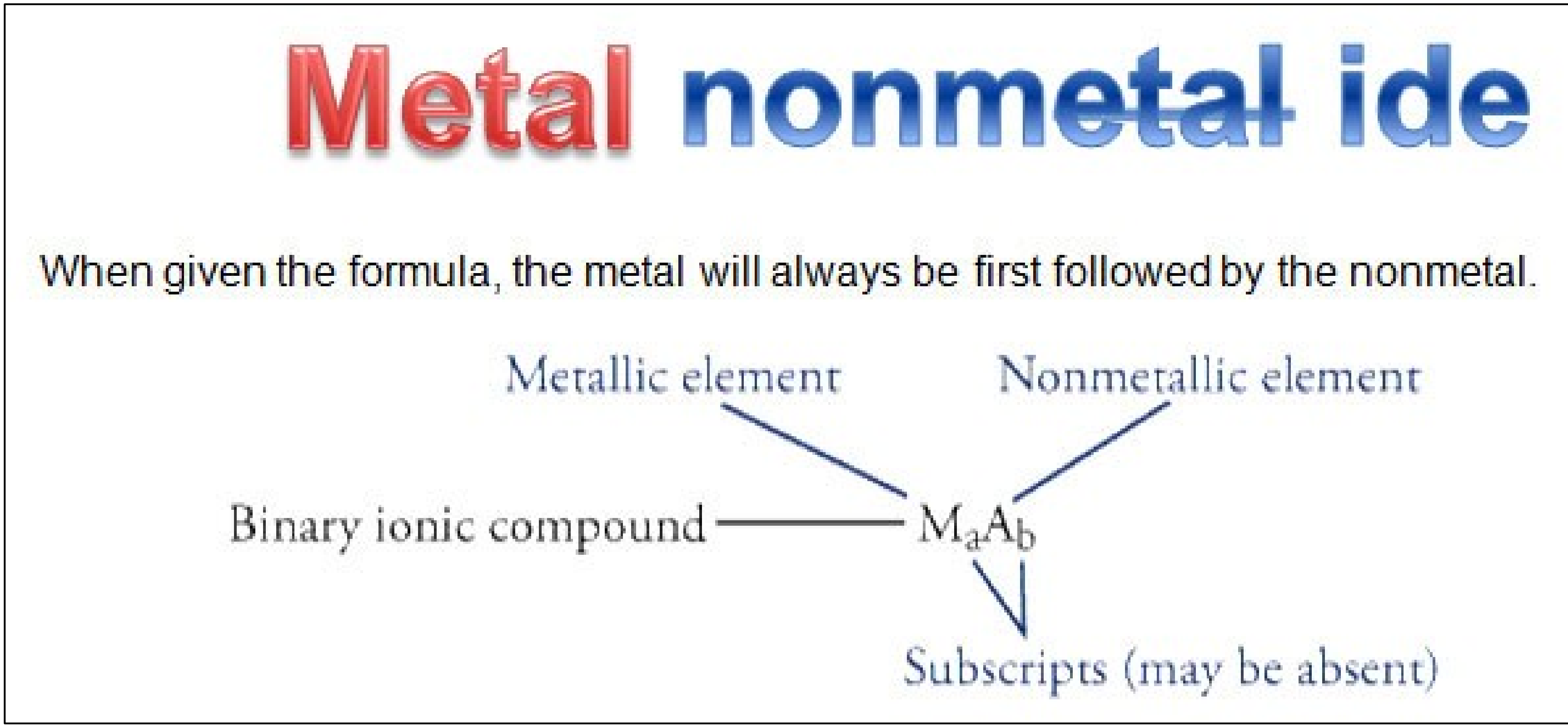


TABLE 2.2 **The "-ide" Nomenclature of Some Common Monatomic Anions According to Their Positions in the Periodic Table**

Group 4A	Group 5A	Group 6A	Group 7A
C carbide (C^{4-})*	N nitride (N^{3-})	O oxide (O^{2-})	F fluoride (F^-)
Si silicide (Si^{4-})	P phosphide (P^{3-})	S sulfide (S^{2-})	Cl chloride (Cl^-)
		Se selenide (Se^{2-})	Br bromide (Br^-)
		Te telluride (Te^{2-})	I iodide (I^-)

Cation	Anion
aluminum (Al^{3+})	bromide (Br^-)
ammonium (NH_4^+)	carbonate (CO_3^{2-})
barium (Ba^{2+})	chlorate (ClO_3^-)
cadmium (Cd^{2+})	chloride (Cl^-)
calcium (Ca^{2+})	chromate (CrO_4^{2-})
cesium (Cs^+)	cyanide (CN^-)
chromium(III) or chromic (Cr^{3+})	dichromate ($Cr_2O_7^{2-}$)
cobalt(II) or cobaltous (Co^{2+})	dihydrogen phosphate ($H_2PO_4^-$)
copper(I) or cuprous (Cu^+)	fluoride (F^-)
copper(II) or cupric (Cu^{2+})	hydride (H^-)
hydrogen (H^+)	hydrogen carbonate or bicarbonate (HCO_3^-)
iron(II) or ferrous (Fe^{2+})	hydrogen phosphate (HPO_4^{2-})
iron(III) or ferric (Fe^{3+})	hydrogen sulfate or bisulfate (HSO_4^-)
lead(II) or plumbous (Pb^{2+})	hydroxide (OH^-)
lithium (Li^+)	iodide (I^-)

cations	anions
magnesium (Mg^{2+})	nitrate (NO_3^-)
manganese(II) or manganous (Mn^{2+})	nitride (N^{3-})
mercury(I) or mercurous (Hg_2^{2+})*	nitrite (NO_2^-)
mercury(II) or mercuric (Hg^{2+})	oxide (O^{2-})
potassium (K^+)	permanganate (MnO_4^-)
rubidium (Rb^+)	peroxide (O_2^{2-})
silver (Ag^+)	phosphate (PO_4^{3-})
sodium (Na^+)	sulfate (SO_4^{2-})
strontium (Sr^{2+})	sulfide (S^{2-})
tin(II) or stannous (Sn^{2+})	sulfite (SO_3^{2-})
zinc (Zn^{2+})	thiocyanate (SCN^-)

Examples: KBr, ZnI_2, Al_2O_3

B) Ternary compounds: consisting of three elements

-»ide» ending is also used for anion groups containing different elements :

OH^-
CN^-

LiOH
KCN

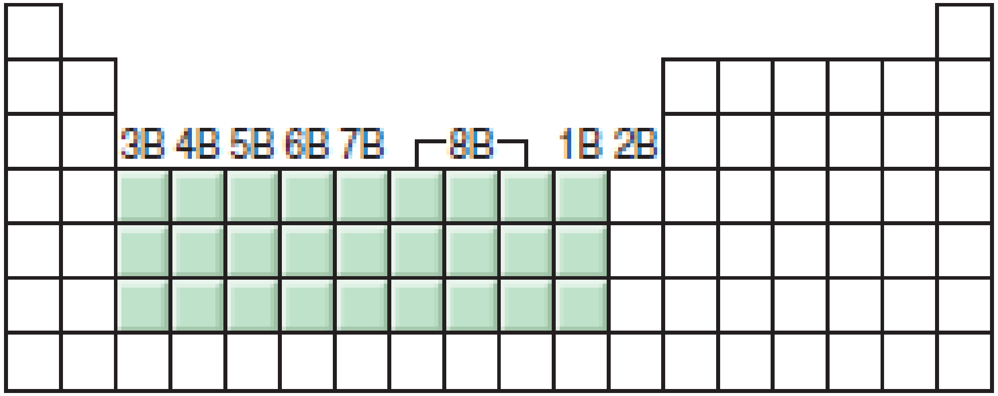
IONIC COMPOUNDS

Metal - Nonmetal

*If it is a **transition metal**: designate the cations with Roman numbers! It is called STOCK system*

MnO
Mn_2O_3
MnO_2

$FeCl_2$
$FeCl_3$



The transition metals are the elements in Groups 1B and 3B–8B (see Figure 2.10).

2. MOLECULAR COMPOUNDS

2.a- Nonmetalic-Nonmeta~~lic~~

-ide

HCl

HBr

SiC

2.b- It is quite common for one pair of elements to form several different compounds.

In these cases, use GREEK prefixes

CO

CO_2

SO_2

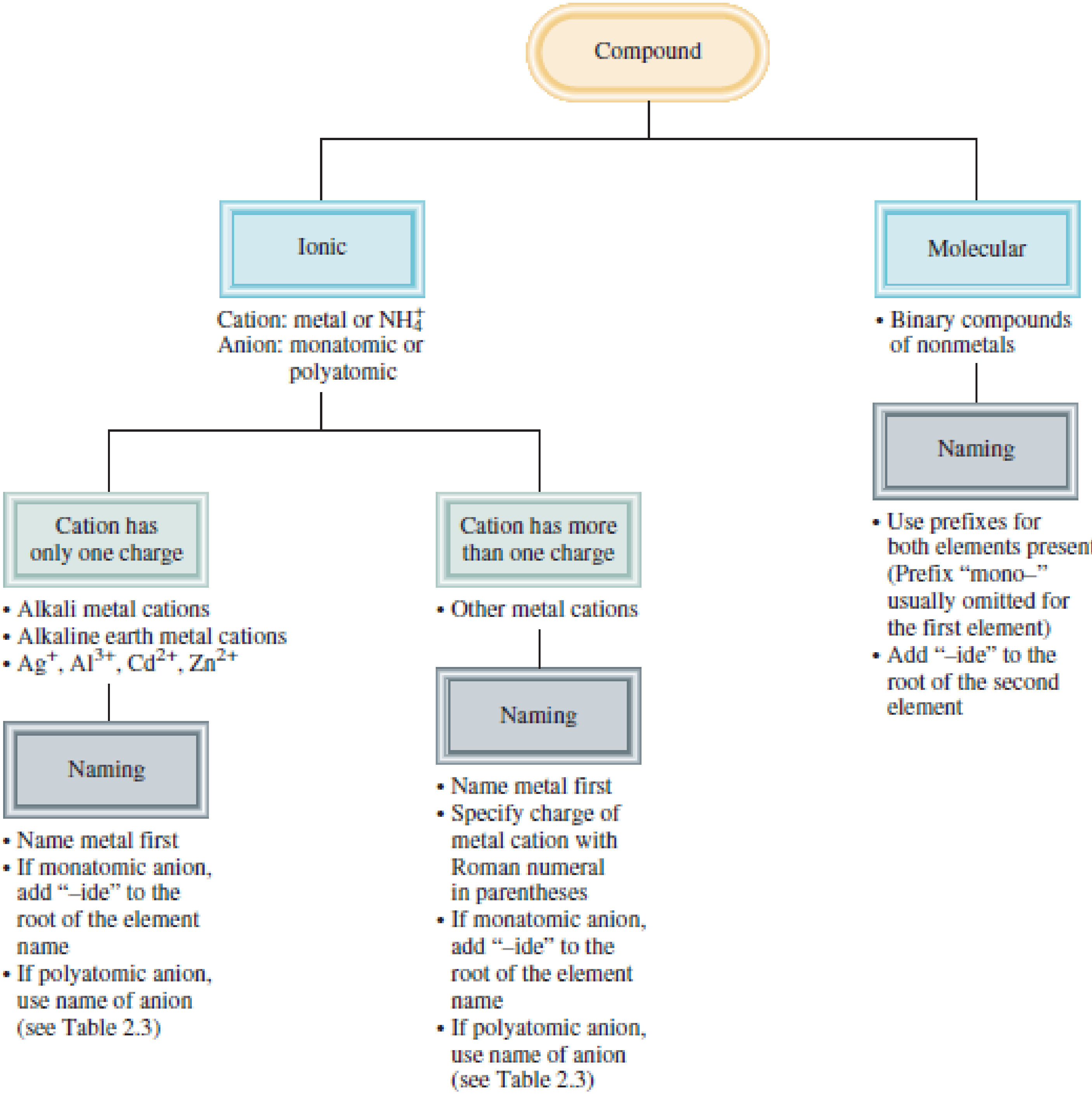
SO_3

NO_2

N_2O_4

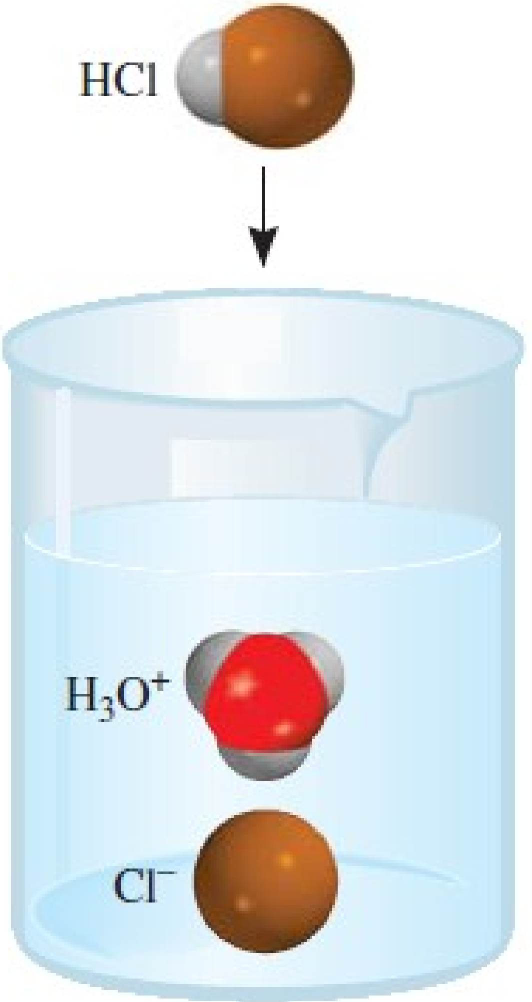
Greek Prefixes Used in Naming Molecular Compounds

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


Compound
Ionic
Cation: metal or NH_4^+
Anion: monatomic or polyatomic
Molecular
• Binary compounds of nonmetals
Cation has only one charge
• Alkali metal cations
• Alkaline earth metal cations
• Ag^+, Al^{3+}, Cd^{2+}, Zn^{2+}
Cation has more than one charge
• Other metal cations
Naming
• Name metal first
• If monatomic anion, add "–ide" to the root of the element name
• If polyatomic anion, use name of anion (see Table 2.3)
Naming
• Name metal first
• Specify charge of metal cation with Roman numeral in parentheses
• If monatomic anion, add "–ide" to the root of the element name
• If polyatomic anion, use name of anion (see Table 2.3)
Naming
• Use prefixes for both elements present (Prefix "mono–" usually omitted for the first element)
• Add "–ide" to the root of the second element

3. ACIDS AND BASES

Acid: can be desciribed as a substance that yields hydrogen ions (H^+) when dissolved in water



When dissolved in water, the HCl molecule is converted to the H^+ and Cl^- ions. The H^+ ion is associated with one or more water molecules, and is usually represented as H_3O^+.

HCl: hidrogen chloride (named as molecular compounds)

HCl: hydrochloric acid

prefix *ending*

TABLE 2.5 Some Simple Acids

Anion	Corresponding Acid
F^- (fluoride)	HF (hydrofluoric acid)
Cl^- (chloride)	HCl (hydrochloric acid)
Br^- (bromide)	HBr (hydrobromic acid)
I^- (iodide)	HI (hydroiodic acid)
CN^- (cyanide)	HCN (hydrocyanic acid)
S^{2-} (sulfide)	H_2S (hydrosulfuric acid)

Oxoacids: are acids that contain **hydrogen**, **oxygen** and **another element**

(the central element)

HNO_3

H_2CO_3

H_2SO_4

$HClO_3$

Naming of oxoacids

a) Addition of one O atom to the ……**ic acid**:

The acid called «**per ……-ic acid**»

$HClO_3$: chloric acid
$HClO_4$: perchloric acid

b) Removal of one O atom from the …-**ic acid**:

The acid called «**ous…..acid**»

HNO_3: nitric acid
HNO_2: nitrous acid

c) Removal of two O atoms from ….**ic acid**:

The acid is called «**hypo…..ous acid**»

$HBrO_3$: bromic acid
$HBrO$: hypobromous acid

NAMING OF OXOANIONS

1. When all the H ions are removed from ….**ic acid**
   The anion name ends with «**ate**»

H_2CO_3

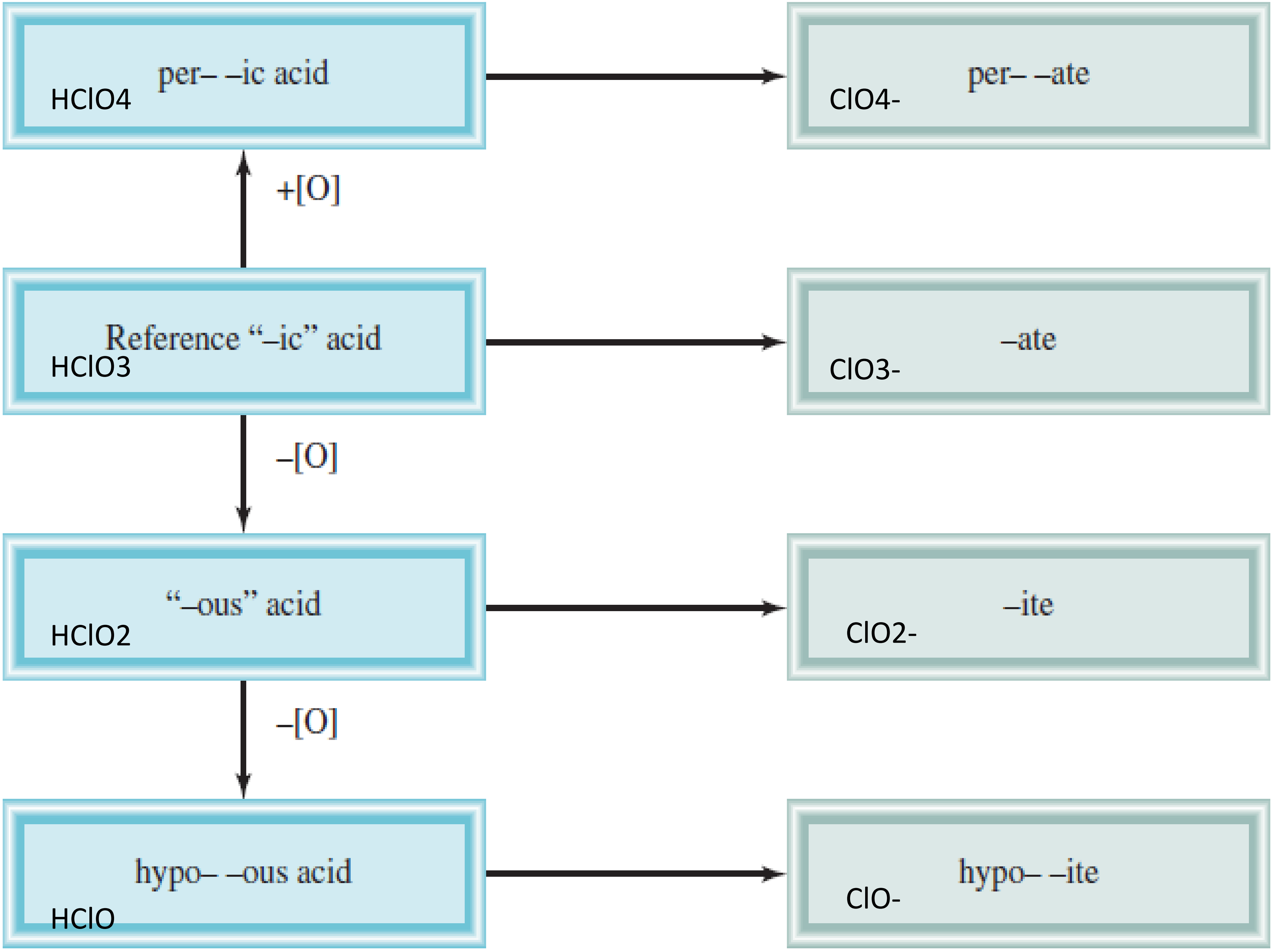
CO_3^{2-}

2. When all the H ions are removed from «**ous» acid**,
   the anions name ends with –**ite**

$HClO_3$

$HClO_2$

ClO_2^-



per– –ic acid
HClO4
per– –ate
ClO4-
+[O]
Reference "–ic" acid
HClO3
–ate
ClO3-
–[O]
"–ous" acid
HClO2
–ite
ClO2-
–[O]
hypo– –ous acid
HClO
hypo– –ite
ClO-

Naming bases

Base: A substancce that yields hydroxide ions (OH-) when dissolved in water.

NaOH

KOH

$Ba(OH)_2$

4. HYDRATES

Figure 2.16 *$CuSO_4 \cdot 5H_2O$ (left) is blue; $CuSO_4$ (right) is white.*