CHEM 103
CHEMISTRY I

Chapter 2

ATOMS, MOLECULES, AND IONS

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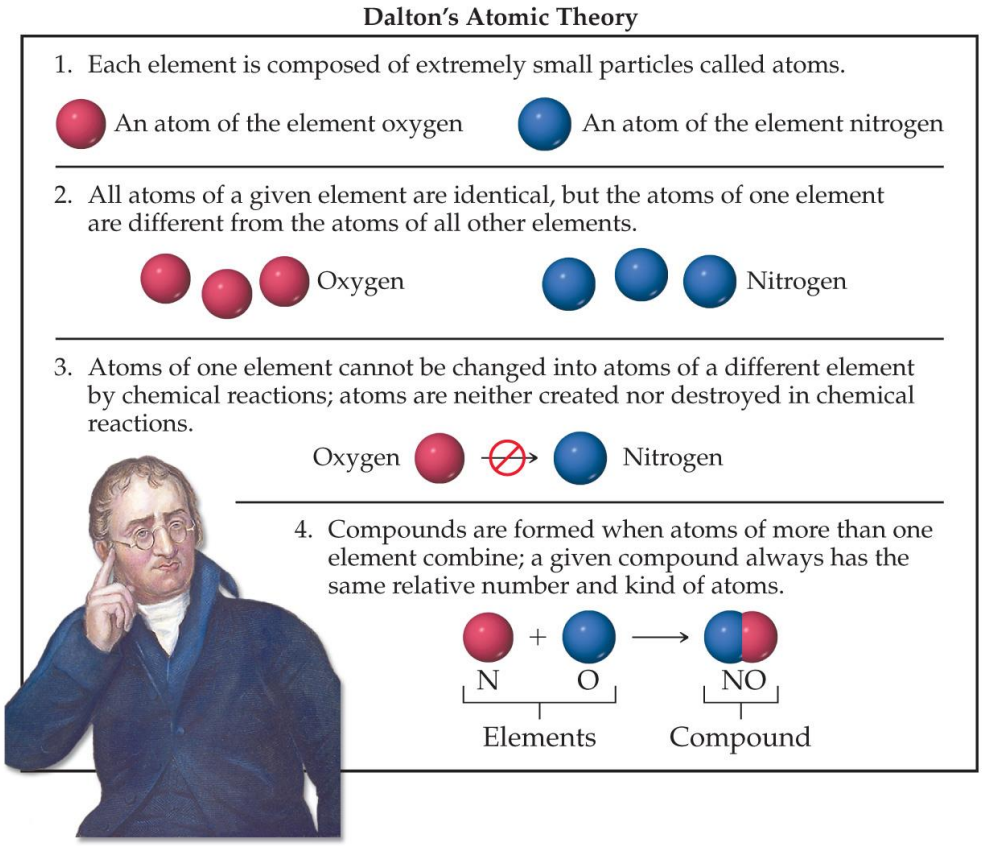
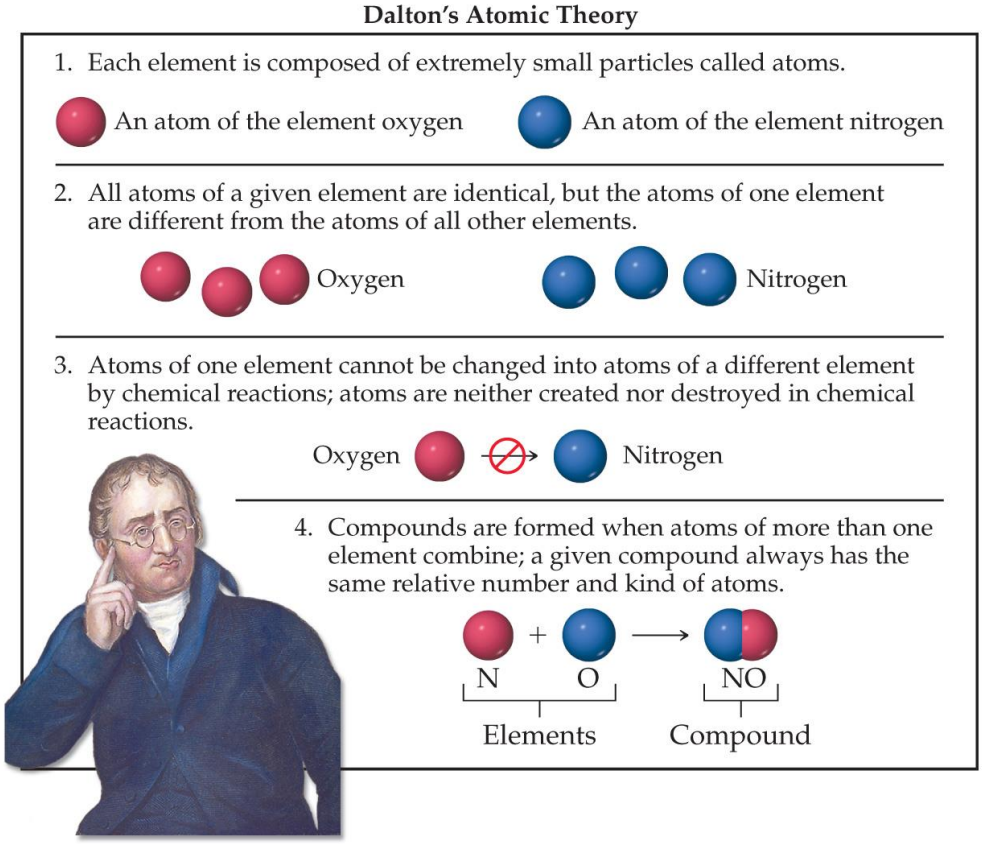
Atomic Theory of Matter



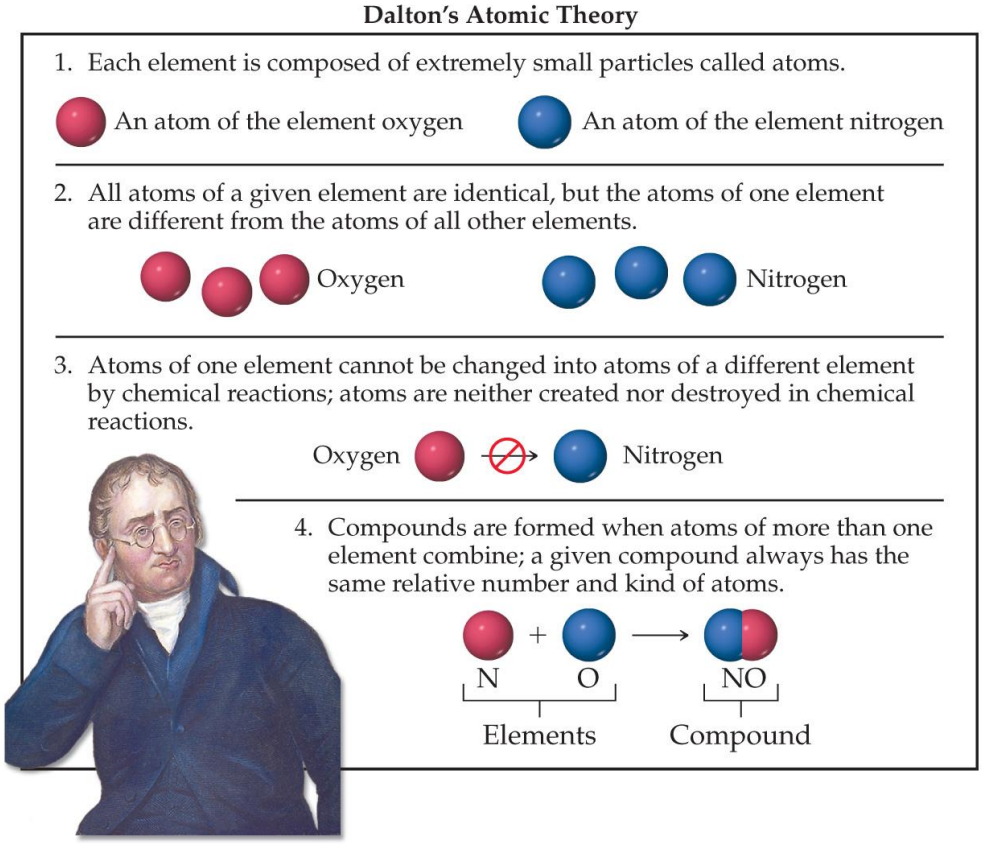
The theory that atoms are the fundamental building blocks of matter reemerged in the early nineteenth century, championed by John Dalton.

Dalton's Postulates



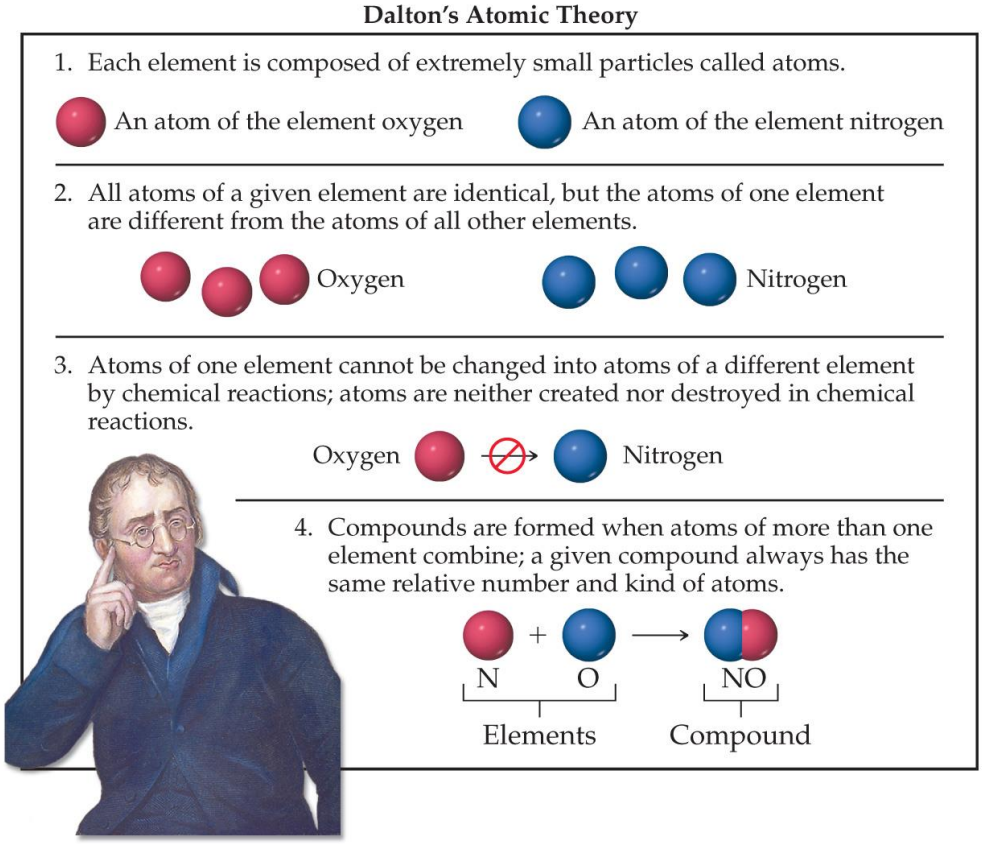
1) Each element is composed of extremely small particles called **atoms**.

Dalton's Postulates



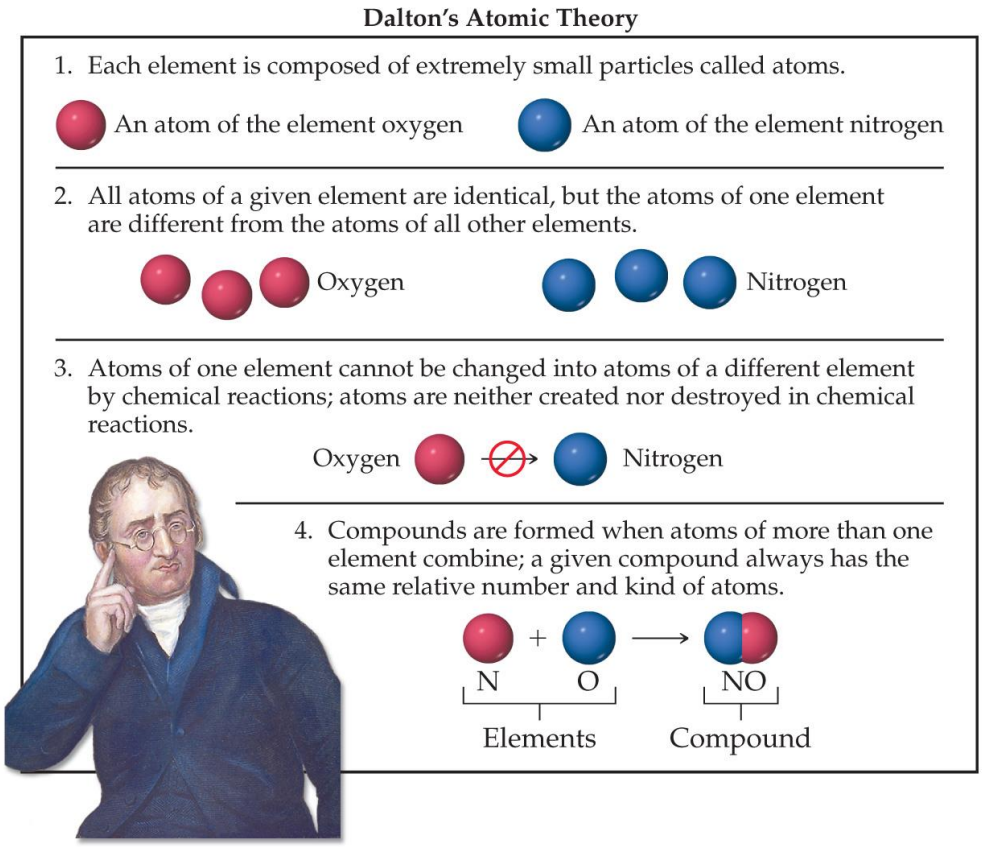
2) All atoms of a given element are identical to one another in mass and other properties, but the atoms of one element are different from the atoms of all other elements.

Dalton's Postulates



3) Atoms of an element are not changed into atoms of a different element by chemical reactions; atoms are neither created nor destroyed in chemical reactions.

Dalton's Postulates



4) Atoms of more than one element combine to form **compounds**; a given compound always has the same relative number and kind of atoms.

Law of Conservation of Mass

- The **total mass** of substances present at the end of a chemical process is the same as the mass of substances present before the process took place.
- This law was one of the laws on which Dalton's atomic theory was based.

Law of Multiple Proportions

- If two elements, A and B, form more than one compound, the masses of B that combine with a given mass of A are in the ratio of small whole numbers.
- Dalton predicted this law and observed it while developing his atomic theory.
- When two or more compounds exist from the same elements, they can *not* have the same relative number of atoms.

Discovery of Subatomic Particles

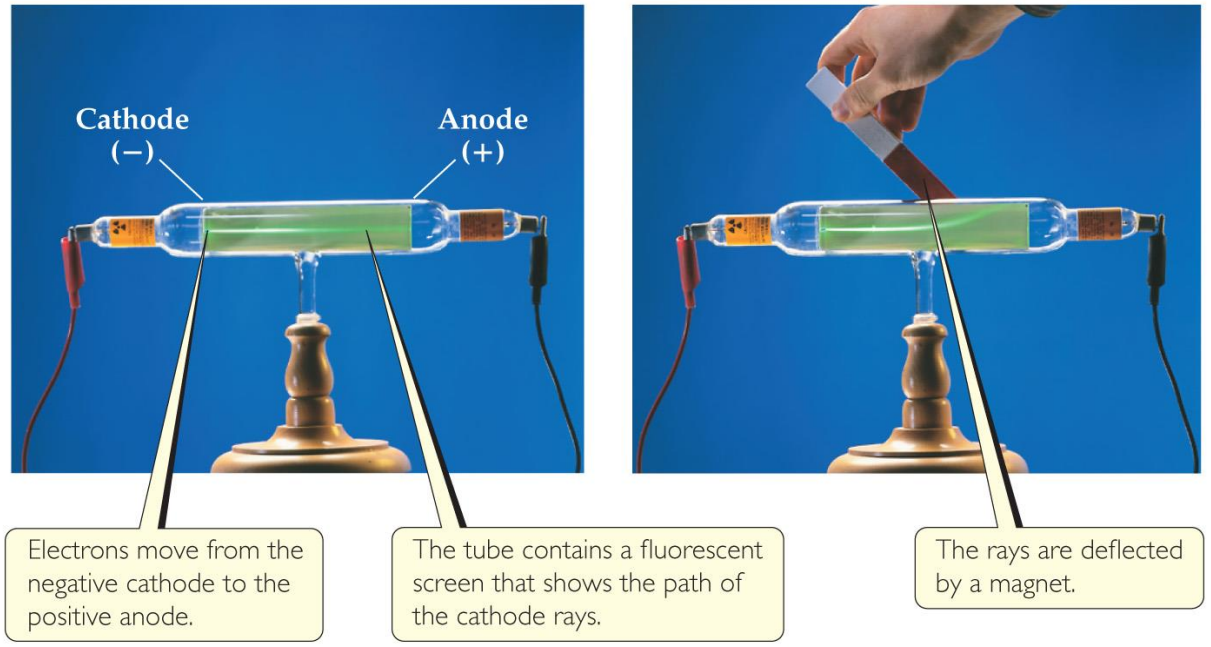
- In Dalton's view, the atom was the smallest particle possible. Many discoveries led to the fact that the atom itself was made up of smaller particles.

➢ Electrons and cathode rays

➢ Radioactivity

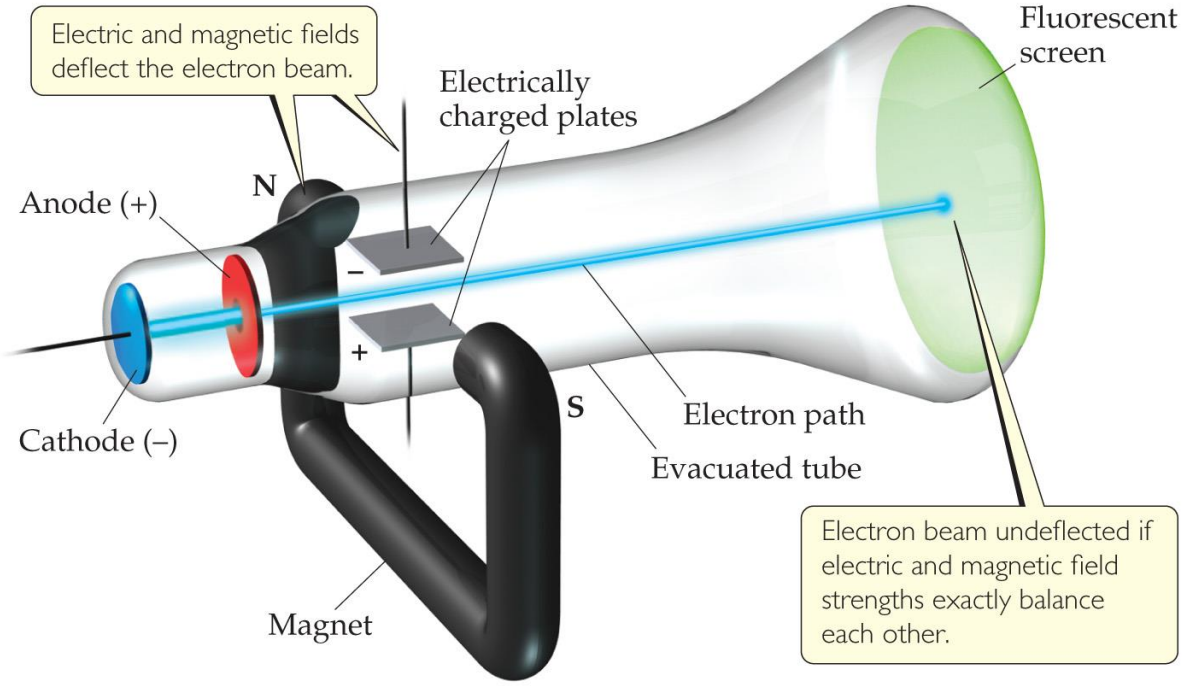
➢ Nucleus, protons, and neutrons

The Electron (Cathode Rays)



- Streams of negatively charged particles were found to emanate from cathode tubes, causing fluorescence.
- J. J. Thomson is credited with their discovery (1897).

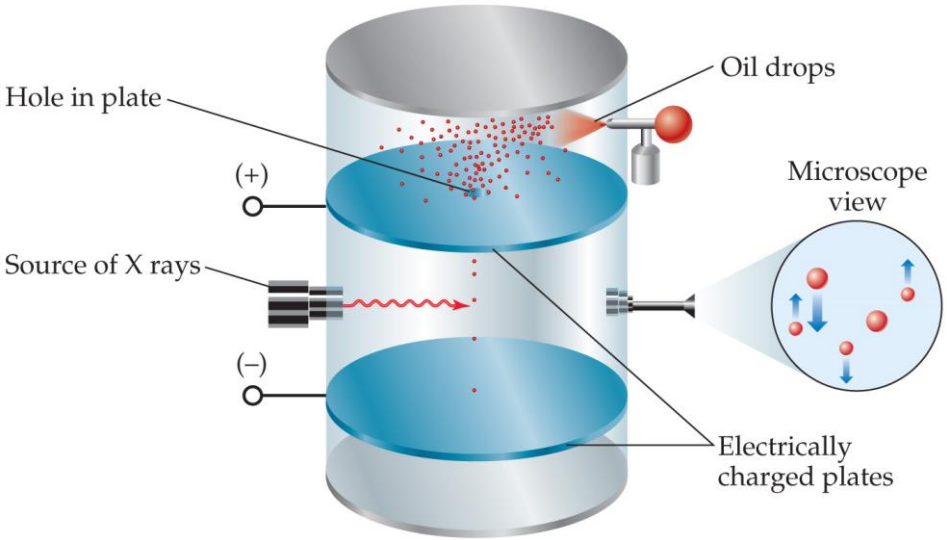
The Electron



Thomson measured the charge/mass ratio of the electron to be 1.76×10^8 coulombs/gram (C/g).

Millikan Oil-Drop Experiment (Electrons)

- Once the charge/mass ratio of the electron was known, determination of either the charge or the mass of an electron would yield the other.
- Robert Millikan determined the charge on the electron in 1909.

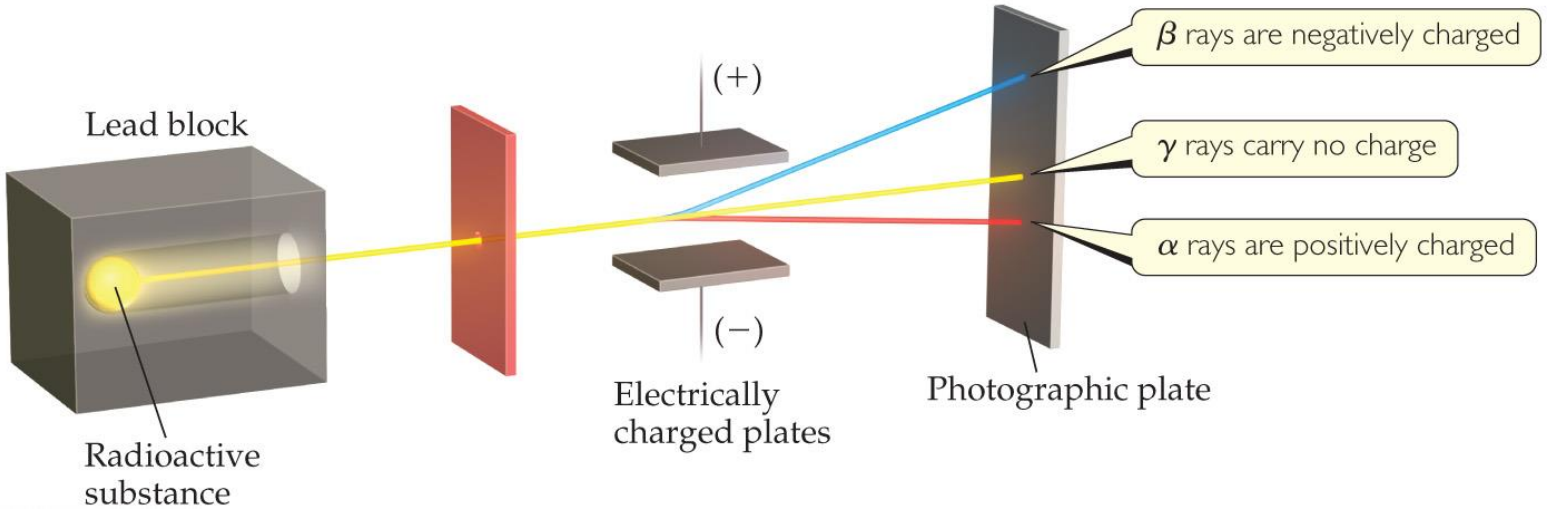


Radioactivity

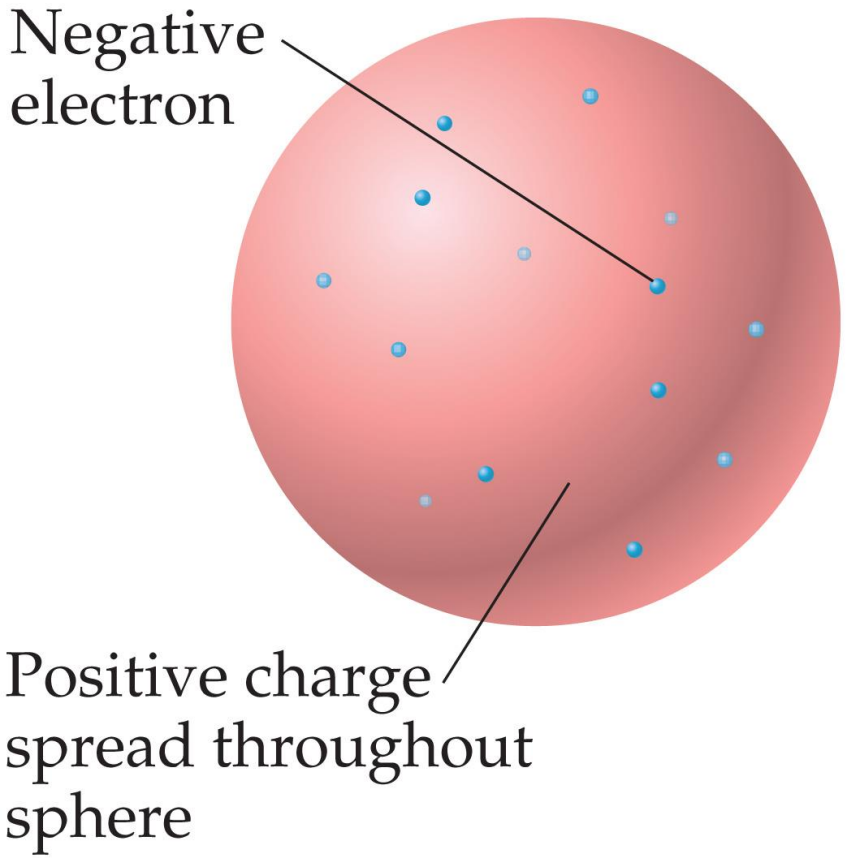
- **Radioactivity** is the spontaneous emission of high-energy radiation by an atom.
- It was first observed by Henri Becquerel.
- Marie and Pierre Curie also studied it.
- Its discovery showed that the atom had more subatomic particles and energy associated with it.

Radioactivity

- Three types of radiation were discovered by Ernest Rutherford:
  - α particles (positively charged)
  - β particles (negatively charged, like electrons)
  - γ rays (uncharged)

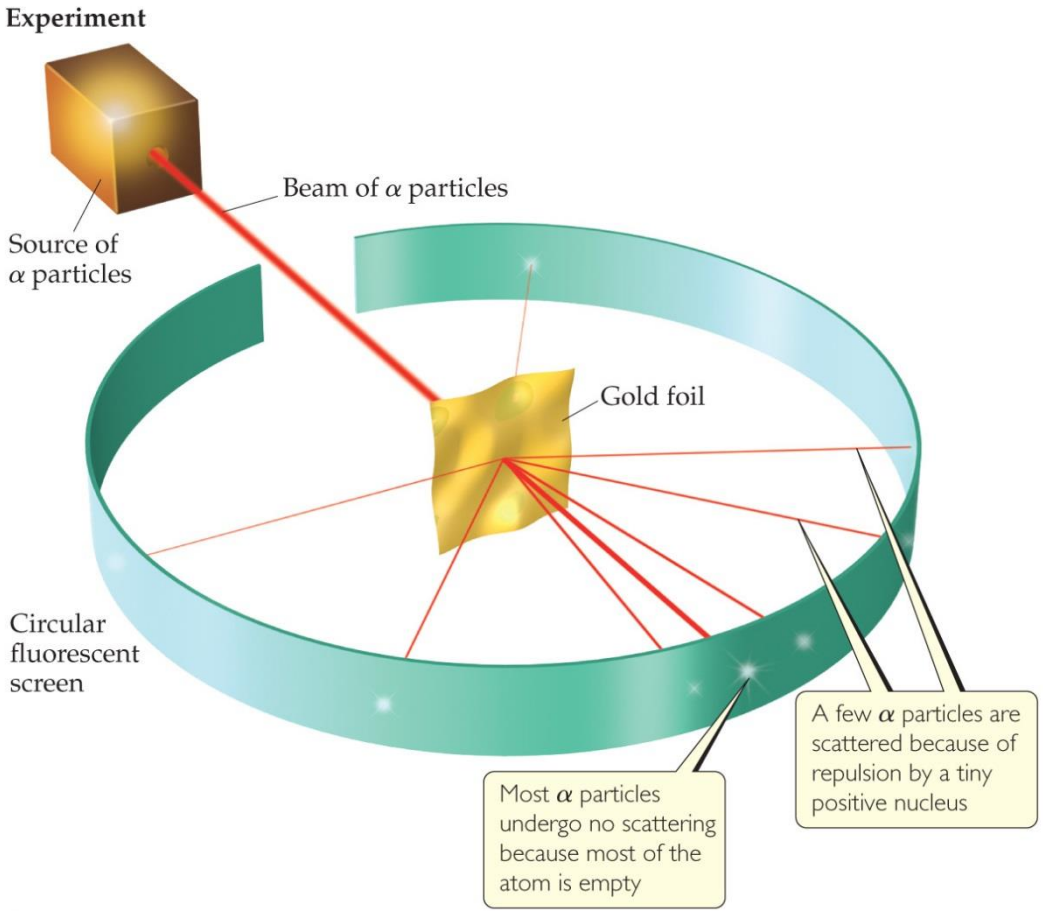


The Atom, circa 1900



- The prevailing theory was that of the “plum pudding” model, put forward by Thomson.
- It featured a positive sphere of matter with negative electrons embedded in it.

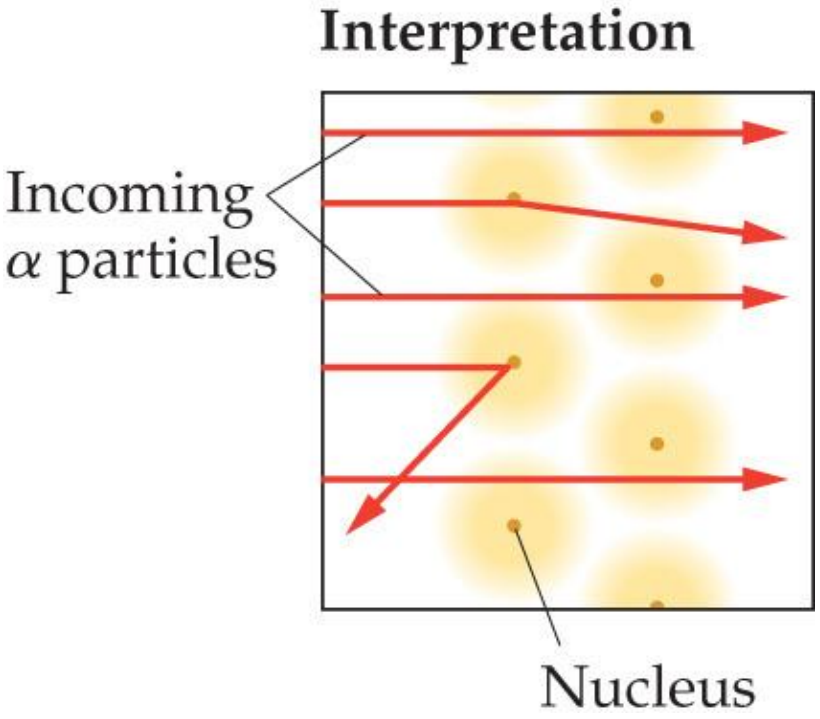
Discovery of the Nucleus



Ernest Rutherford shot α particles at a thin sheet of gold foil and observed the pattern of scatter of the particles.

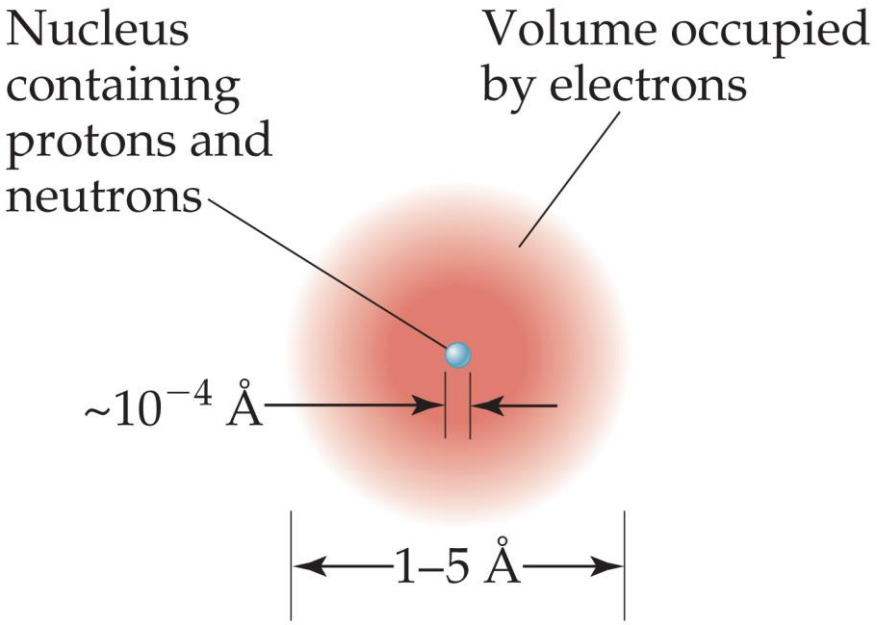
The Nuclear Atom

Since some particles were deflected at large angles, Thomson's model could not be correct.



The Nuclear Atom

- Rutherford postulated a very small, dense nucleus with the electrons around the outside of the atom.
- Most of the volume is empty space.
- Atoms are very small; 1 – 5 Å or 100 – 500 pm.
- Other subatomic particles (protons and neutrons) were discovered.



Subatomic Particles

- Protons (+1) and electrons (–1) have a charge; neutrons are neutral.
- Protons and neutrons have essentially the same mass (relative mass 1). The mass of an electron is so small we ignore it (relative mass 0).
- Protons and neutrons are found in the nucleus; electrons travel around the nucleus.

Table 2.1 Comparison of the Proton, Neutron, and Electron

Particle	Charge	Mass (amu)
Proton	Positive (1+)	1.0073
Neutron	None (neutral)	1.0087
Electron	Negative (1−)	5.486×10^{-4}

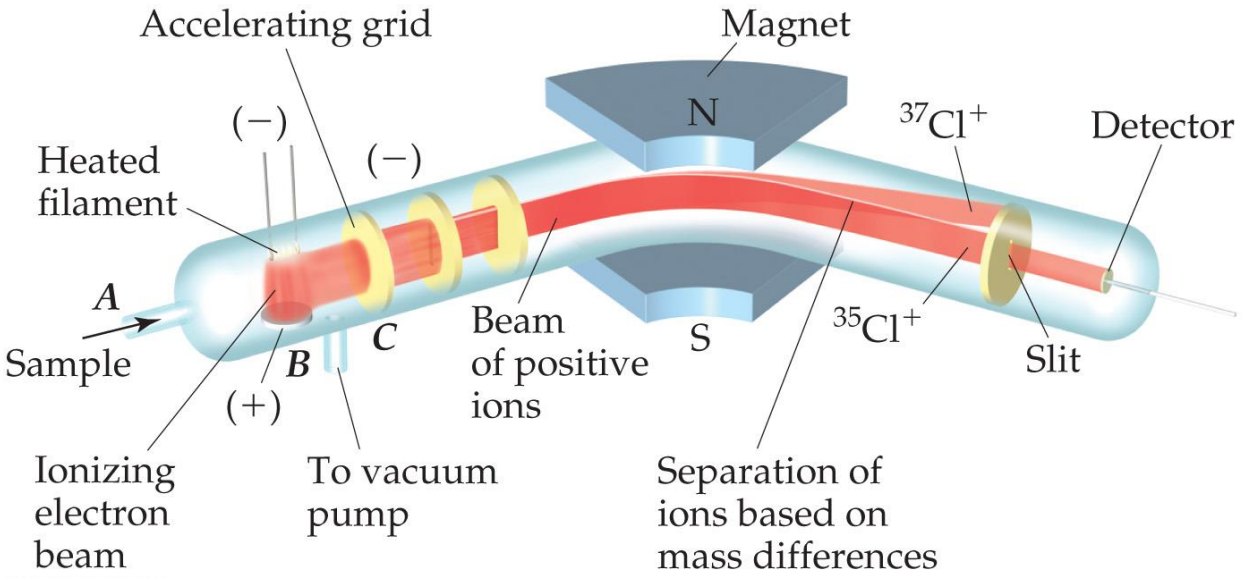
Atomic Mass

- Atoms have extremely small masses.
- The heaviest known atoms have a mass of approximately 4×10^{-22} g.
- A mass scale on the atomic level is used, where an atomic mass unit (amu) is the base unit.

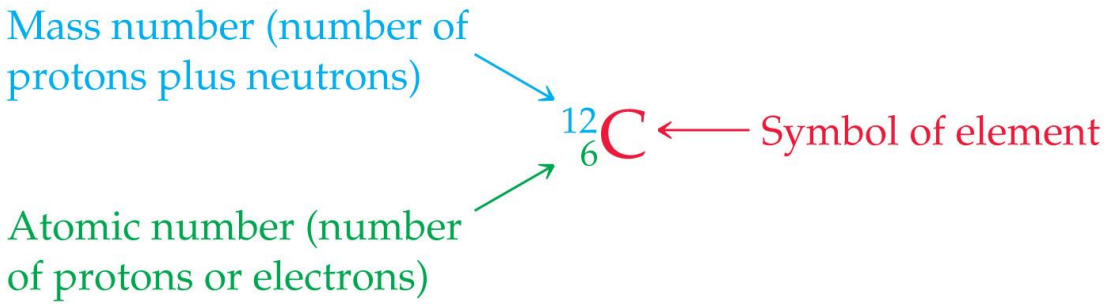
➢ $1 \text{ amu} = 1.66054 \times 10^{-24}$ g

Atomic Weight Measurement

- Atomic and molecular weight can be measured with great accuracy using a mass spectrometer.
- Masses of atoms are compared to the carbon atom with 6 protons and 6 neutrons (C-12).



Symbols of Elements



- Elements are represented by a one or two letter **symbol**. This is the symbol for carbon.
- All atoms of the same element have the same number of protons, which is called the **atomic number**, *Z*. It is written as a subscript BEFORE the symbol.
- The **mass number** is the total number of protons and neutrons in the nucleus of an atom. It is written as a superscript BEFORE the symbol.

Isotopes

- **Isotopes** are atoms of the same element with different masses.
- Isotopes have different numbers of neutrons, but the same number of protons.

Table 2.2 Some Isotopes of Carbon[a]

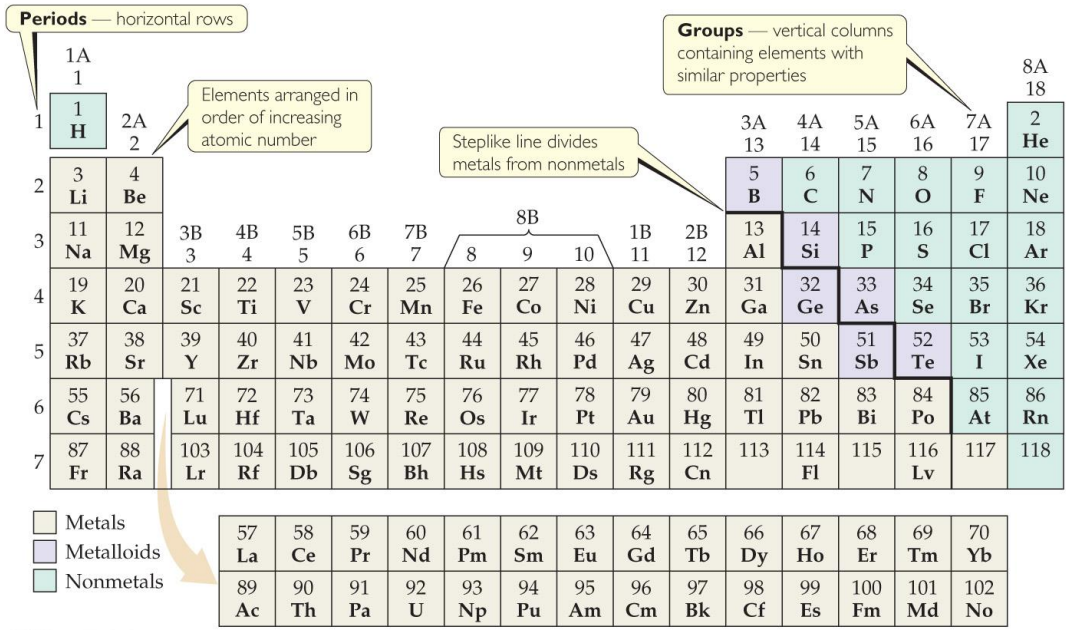
Symbol	Number of Protons	Number of Electrons	Number of Neutrons
^{11}C	6	6	5
^{12}C	6	6	6
^{13}C	6	6	7
^{14}C	6	6	8

[a]Almost 99% of the carbon found in nature is ^{12}C.

Atomic Weight

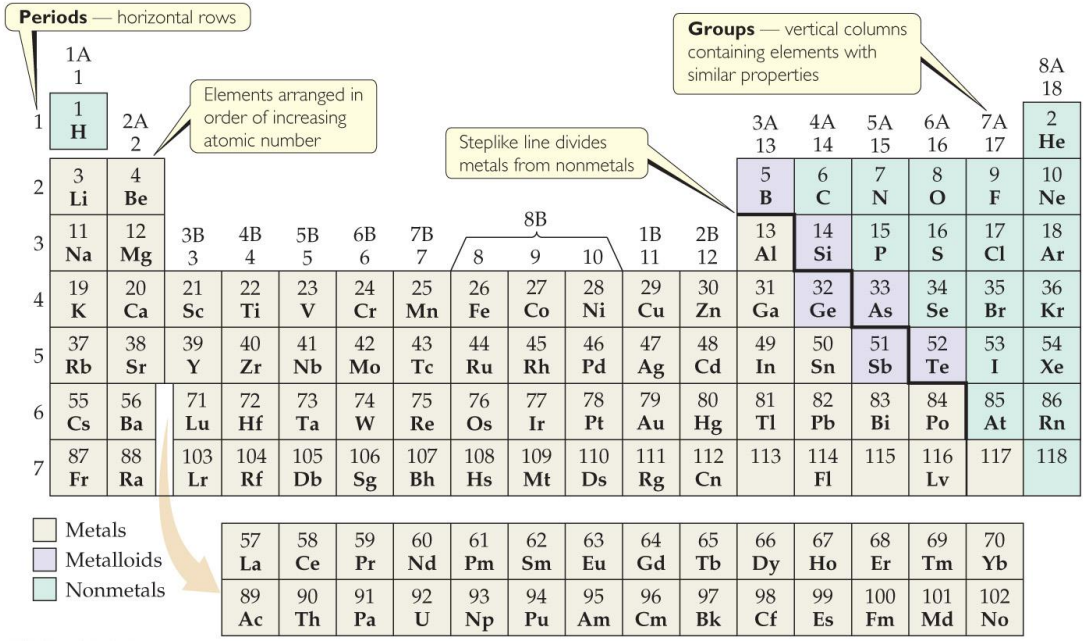
- Because in the real world we use large amounts of atoms and molecules, we use average masses in calculations.
- An average mass is found using all isotopes of an element weighted by their relative abundances. This is the element's **atomic weight**.
- That is, Atomic Weight = Σ [(isotope mass) × (fractional natural abundance)]. Note: the sum is for ALL isotopes of an element.

Periodic Table



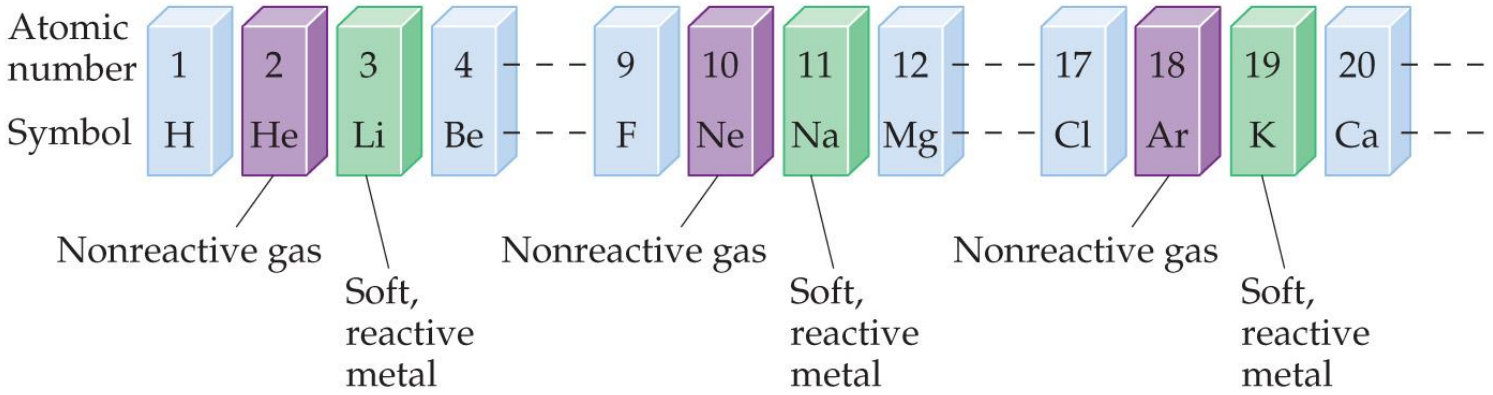
- The **periodic table** is a systematic organization of the elements.
- Elements are arranged in order of atomic number.
- Unlike the way we write isotopes, the atomic number is at the TOP of a box in the periodic table.
- The atomic weight of an element appears at the BOTTOM of the box. (They are not shown on this version of the Periodic Table.)

Periodic Table



- The rows on the periodic table are called **periods**.
- Columns are called **groups**.
- Elements in the same group have similar chemical properties.

Periodicity



When one looks at the chemical properties of elements, one notices a repeating pattern of reactivities.

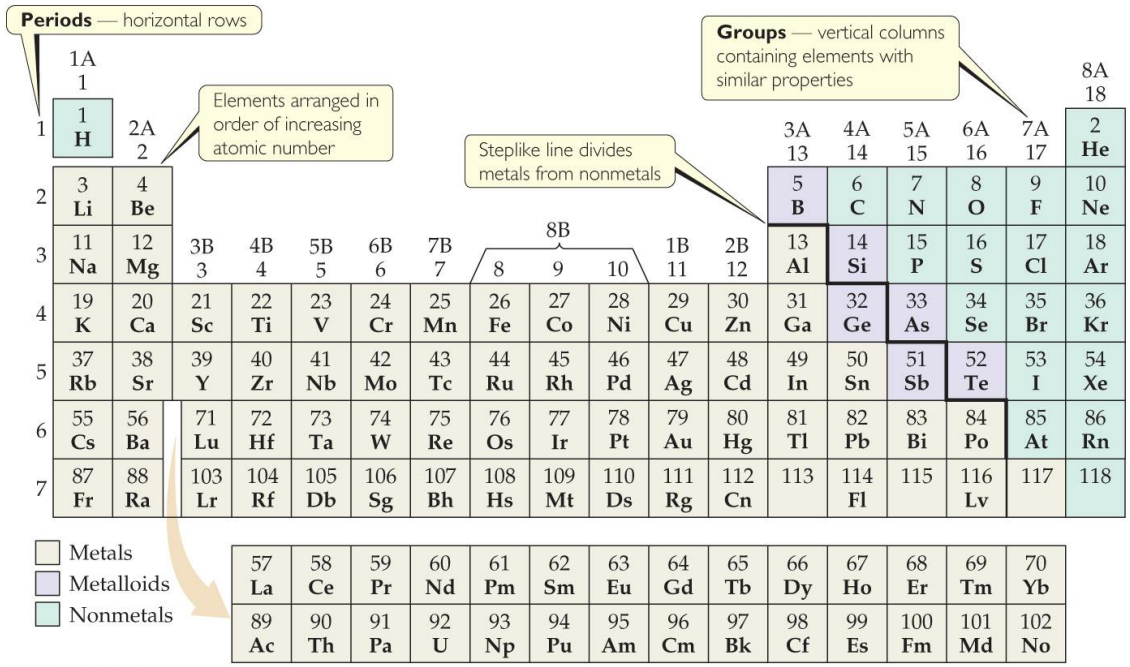
Groups

Table 2.3 Names of Some Groups in the Periodic Table

Group	Name	Elements
1A	Alkali metals	Li, Na, K, Rb, Cs, Fr
2A	Alkaline earth metals	Be, Mg, Ca, Sr, Ba, Ra
6A	Chalcogens	O, S, Se, Te, Po
7A	Halogens	F, Cl, Br, I, At
8A	Noble gases (or rare gases)	He, Ne, Ar, Kr, Xe, Rn

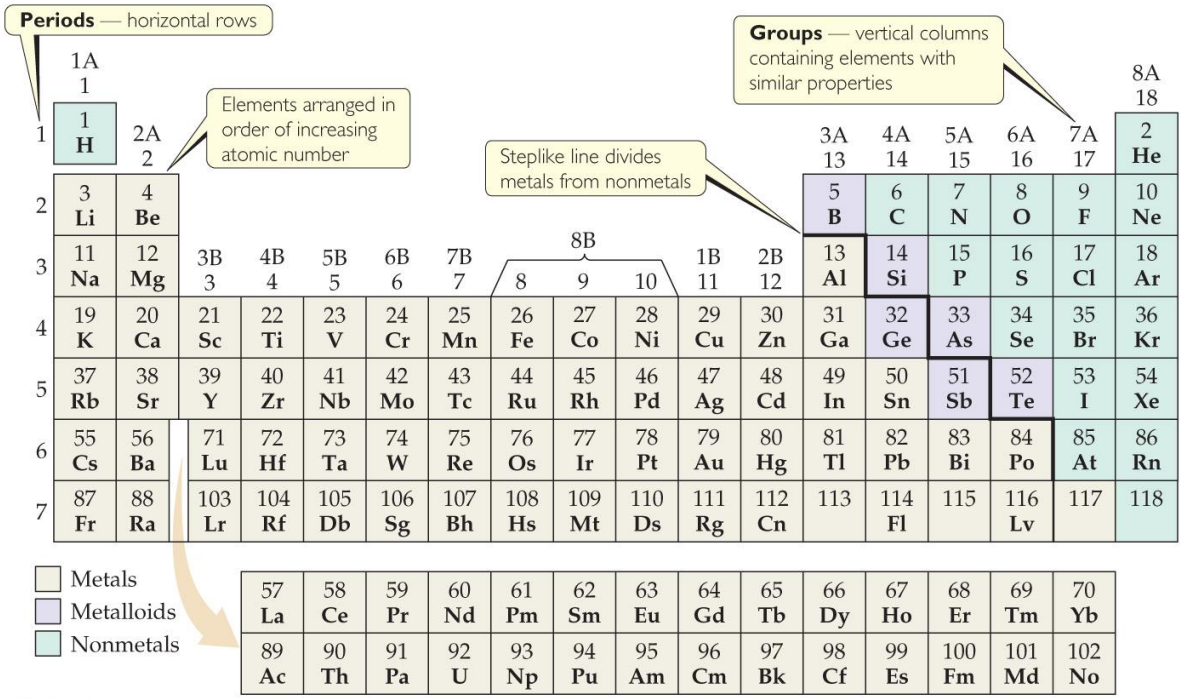
These five groups are known by their names.

Periodic Table



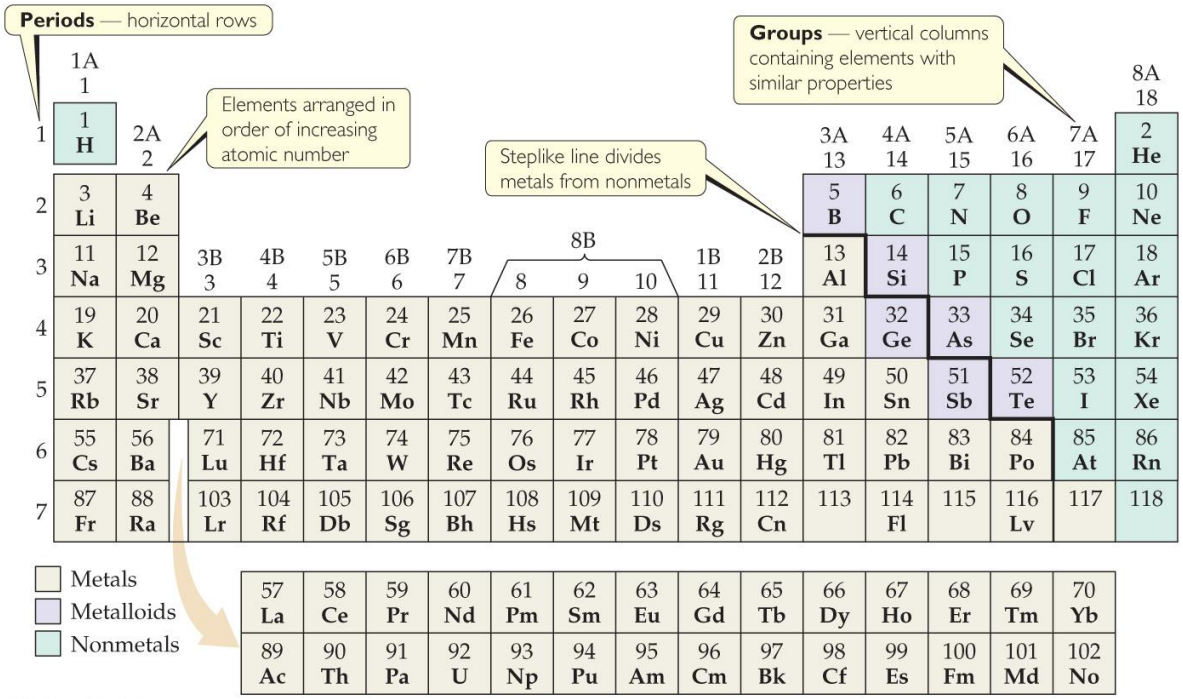
- Metals are on the left side of the periodic table.
- Some properties of metals include
  - shiny luster.
  - conducting heat and electricity.
  - solidity (except mercury).

Periodic Table



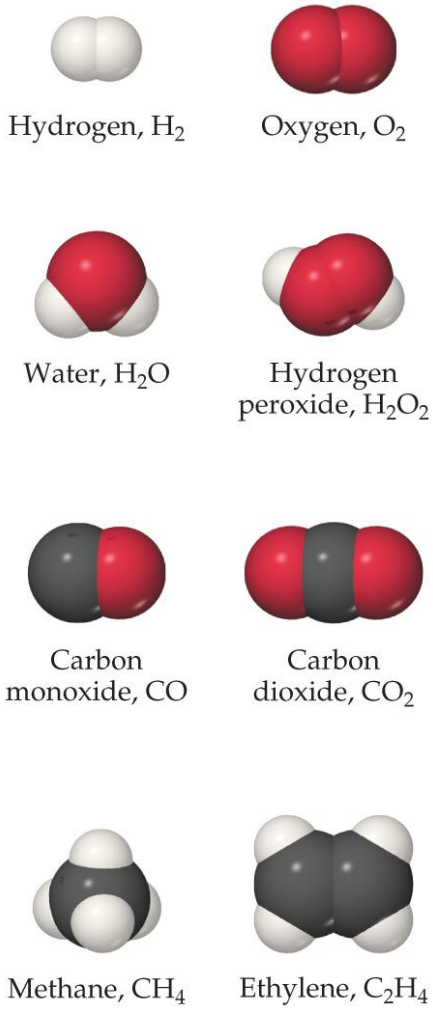
- Nonmetals are on the right side of the periodic table (with the exception of H).
- They can be solid (like carbon), liquid (like bromine), or gas (like neon) at room temperature.

Periodic Table



- Elements on the steplike line are metalloids (except Al, Po, and At).
- Their properties are sometimes like metals and sometimes like nonmetals.

Chemical Formulas



- The subscript to the right of the symbol of an element tells the number of atoms of that element in one molecule of the compound.
- **Molecular compounds** are composed of molecules and almost always contain only nonmetals.

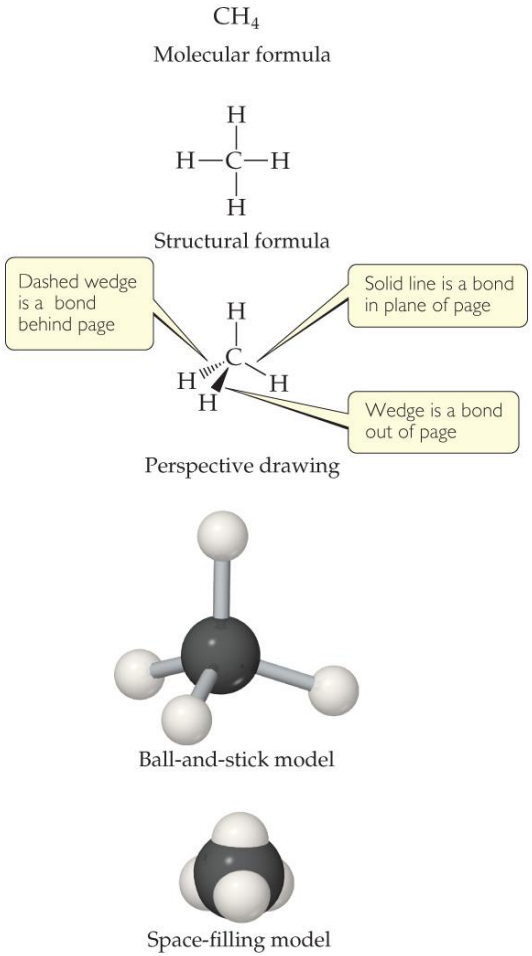
Diatomic Molecules

- These seven elements occur naturally as molecules containing two atoms:
  - Hydrogen
  - Nitrogen
  - Oxygen
  - Fluorine
  - Chlorine
  - Bromine
  - Iodine

Types of Formulas

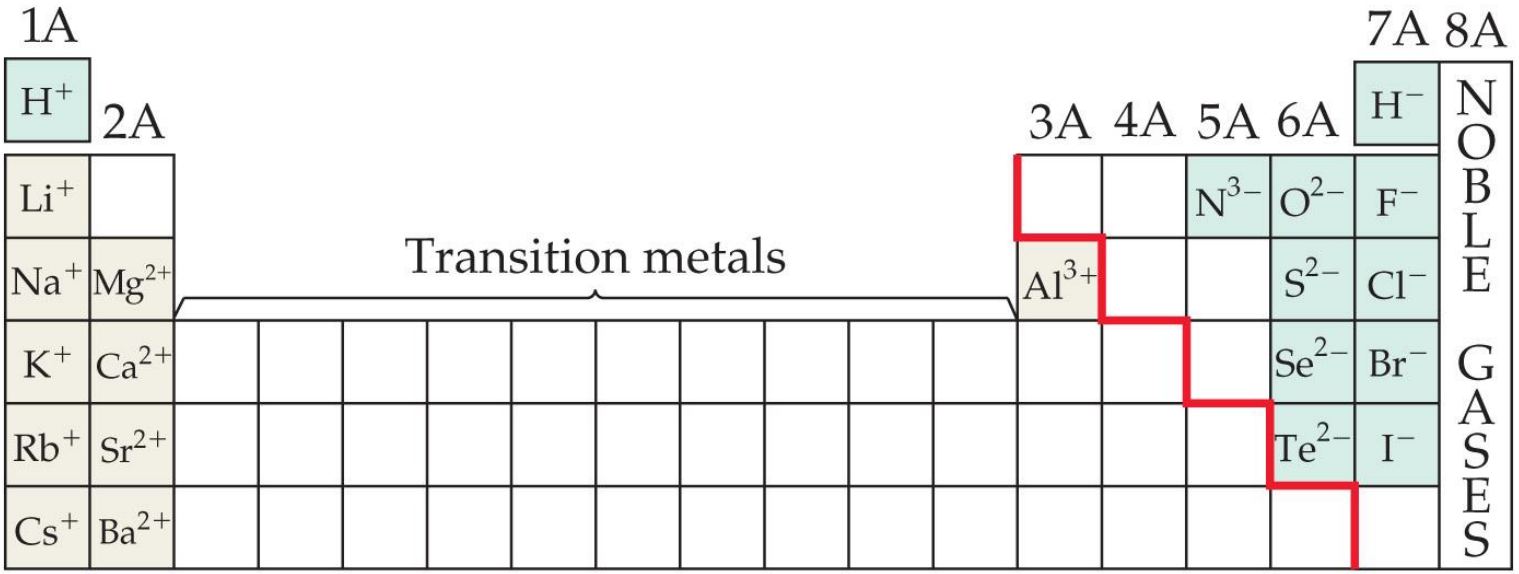
- **Empirical formulas** give the lowest whole-number ratio of atoms of each element in a compound.
- **Molecular formulas** give the exact number of atoms of each element in a compound.
- If we know the molecular formula of a compound, we can determine its empirical formula. The converse is not true!

Types of Formulas



- **Structural formulas** show the order in which atoms are attached. They do NOT depict the three-dimensional shape of molecules.
- **Perspective drawings** also show the three-dimensional order of the atoms in a compound. These are also demonstrated using **models**.

Ions



- When an atom of a group of atoms loses or gains electrons, it becomes an **ion**.
- **Cations** are formed when at least one electron is lost. Monatomic cations are formed by metals.
- **Anions** are formed when at least one electron is gained. Monatomic anions are formed by nonmetals.

Common Cations

Table 2.4 Common Cations[a]

Charge	Formula	Name	Formula	Name
1+	**H^+**	**hydrogen ion**	**NH_4^+**	**ammonium ion**
	Li^+	lithium ion	Cu^+	copper(I) or cuprous ion
	Na^+	**sodium ion**		
	K^+	**potassium ion**		
	Cs^+	cesium ion		
	Ag^+	**silver ion**		
2+	**Mg^{2+}**	**magnesium ion**	Co^{2+}	cobalt(II) or cobaltous ion
	Ca^{2+}	**calcium ion**	**Cu^{2+}**	**copper(II)** or cupric ion
	Sr^{2+}	strontium ion	**Fe^{2+}**	**iron(II)** or ferrous ion
	Ba^{2+}	barium ion	Mn^{2+}	manganese(II) or manganous ion
	Zn^{2+}	**zinc ion**	Hg_2^{2+}	mercury(I) or mercurous ion
	Cd^{2+}	cadmium ion	**Hg^{2+}**	**mercury(II)** or mercuric ion
			Ni^{2+}	nickel(II) or nickelous ion
			Pb^{2+}	**lead(II)** or plumbous ion
			Sn^{2+}	tin(II) or stannous ion
3+	**Al^{3+}**	**aluminum ion**	Cr^{3+}	chromium(III) or chromic ion
			Fe^{3+}	**iron(III)** or ferric ion

[a]The ions we use most often in this course are in boldface. Learn them first.

Common Anions

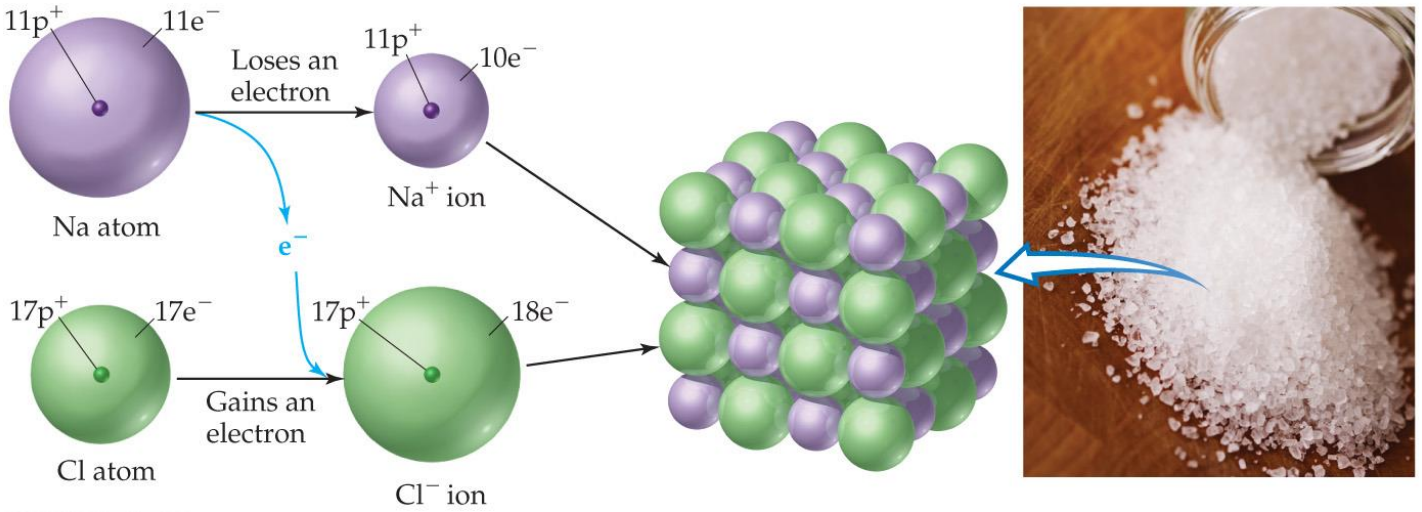
Table 2.5 Common Anions[a]

Charge	Formula	Name	Formula	Name
1−	H^-	hydride ion	**CH_3COO^-** (or $C_2H_3O_2^-$)	**acetate ion**
	F^-	**fluoride ion**	ClO_3^-	chlorate ion
	Cl^-	**chloride ion**	**ClO_4^-**	**perchlorate ion**
	Br^-	**bromide ion**	**NO_3^-**	**nitrate ion**
	I^-	**iodide ion**	MnO_4^-	permanganate ion
	CN^-	cyanide ion		
	OH^-	**hydroxide ion**		
2−	**O^{2-}**	**oxide ion**	**CO_3^{2-}**	**carbonate ion**
	O_2^{2-}	peroxide ion	CrO_4^{2-}	chromate ion
	S^{2-}	**sulfide ion**	$Cr_2O_7^{2-}$	dichromate ion
			SO_4^{2-}	**sulfate ion**
3−	N^{3-}	nitride ion	**PO_4^{3-}**	**phosphate ion**

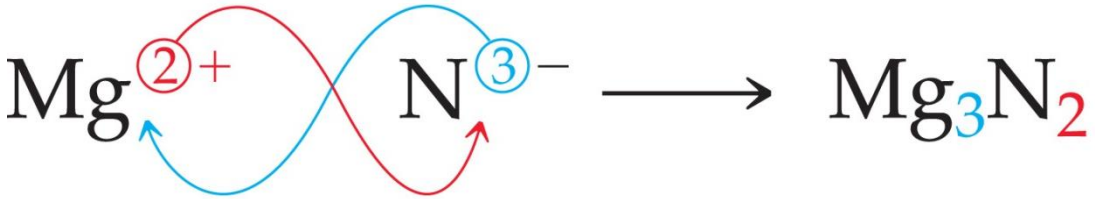
[a]The ions we use most often are in boldface. Learn them first.

Ionic Compounds

- **Ionic compounds** (such as NaCl) are generally formed between metals and nonmetals.
- Electrons are transferred from the metal to the nonmetal. The oppositely charged ions attract each other. Only empirical formulas are written.



Writing Formulas



- Because compounds are electrically neutral, one can determine the formula of a compound this way:
  - The charge on the cation becomes the subscript on the anion.
  - The charge on the anion becomes the subscript on the cation.
  - If these subscripts are not in the lowest whole-number ratio, divide them by the greatest common factor.

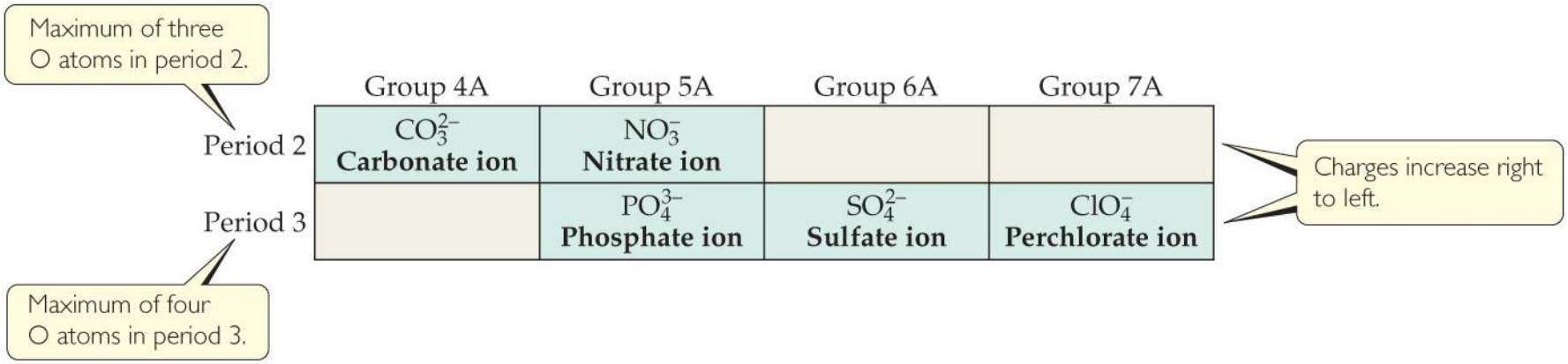
Inorganic Nomenclature

- Write the name of the cation. If the cation can have more than one possible charge, write the charge as a Roman numeral in parentheses.
- If the anion is an element, change its ending to ***-ide***; if the anion is a polyatomic ion, simply write the name of the polyatomic ion.

Patterns in Oxyanion Nomenclature

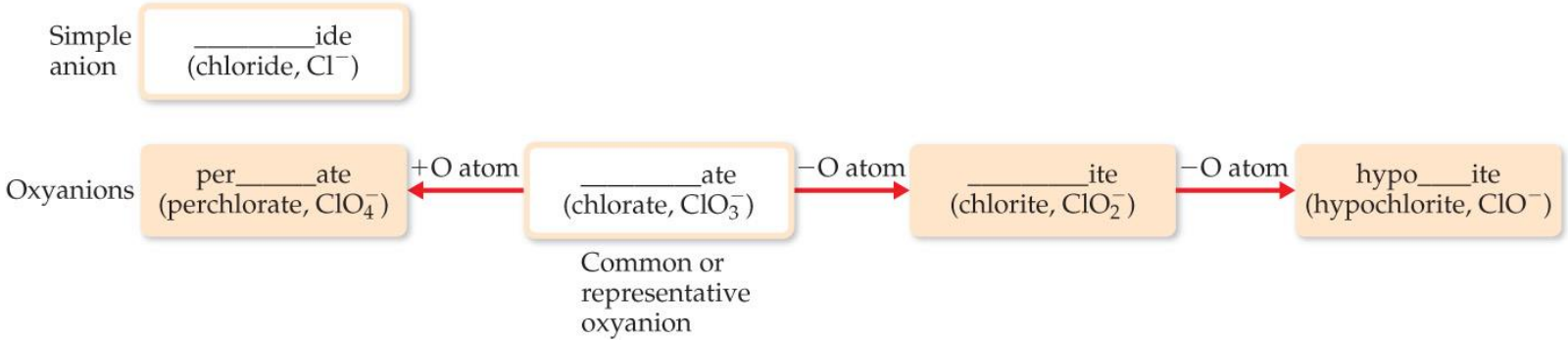
- When there are two oxyanions involving the same element
  - the one with fewer oxygens ends in ***-ite***.
  - the one with more oxygens ends in ***-ate***.
    - NO_2^- : nitrite; NO_3^- : nitrate
    - SO_3^{2-} : sulfite; SO_4^{2-} : sulfate

Patterns in Oxyanion Nomenclature



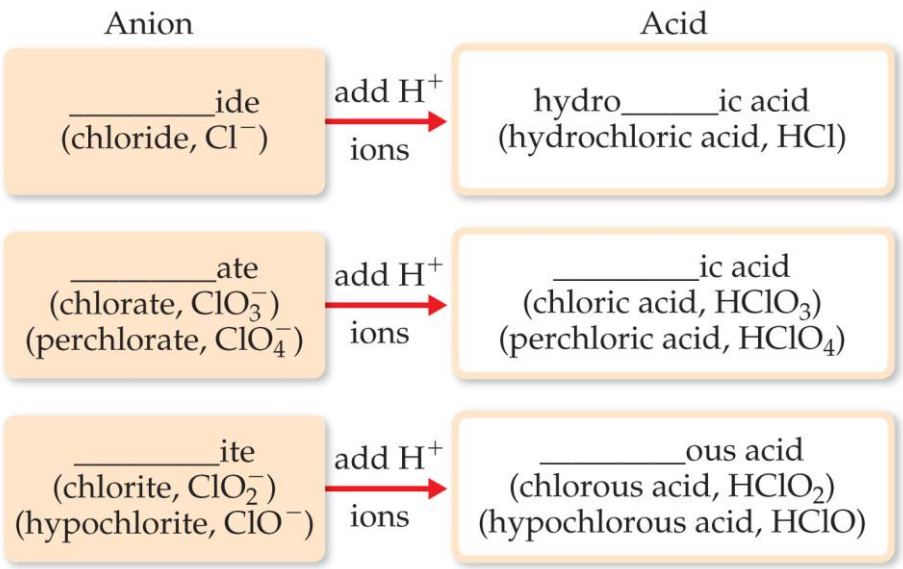
- Central atoms on the second row have a bond to, at most, three oxygens; those on the third row take up to four.
- Charges increase as you go from *right* to *left*.

Patterns in Oxyanion Nomenclature



- The one with the second fewest oxygens ends in ***-ite***: ClO_2^- is chlorite.
- The one with the second most oxygens ends in ***-ate***: ClO_3^- is chlorate.
- The one with the fewest oxygens has the prefix ***hypo-*** and ends in ***-ite***: ClO^- is hypochlorite.
- The one with the most oxygens has the prefix ***per-*** and ends in ***-ate***: ClO_4^- is perchlorate.

Acid Nomenclature



- If the anion in the acid ends in ***-ide***, change the ending to ***-ic acid*** and add the prefix ***hydro-***.
  - HCl: hydrochloric acid
  - HBr: hydrobromic acid
  - HI: hydroiodic acid
- If the anion ends in ***-ite***, change the ending to ***-ous acid***.
  - HClO: hypochlorous acid
  - $HClO_2$: chlorous acid
- If the anion ends in ***-ate***, change the ending to ***-ic acid.***
  - $HClO_3$: chloric acid
  - $HClO_4$: perchloric acid

Nomenclature of Binary Molecular Compounds

Table 2.6 Prefixes Used in Naming Binary Compounds Formed between Nonmetals

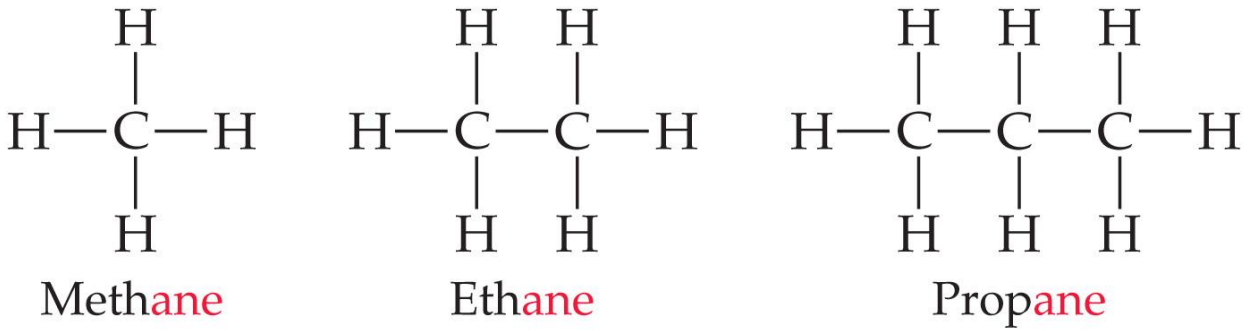
Prefix	Meaning
Mono-	*1*
Di-	*2*
Tri-	*3*
Tetra-	*4*
Penta-	*5*
Hexa-	*6*
Hepta-	*7*
Octa-	*8*
Nona-	*9*
Deca-	*10*

- The name of the element farther to the left in the periodic table (closer to the metals) or lower in the same group is usually written first.
- A prefix is used to denote the number of atoms of each element in the compound (***mono-*** is not used on the first element listed, however).

Nomenclature of Binary Compounds

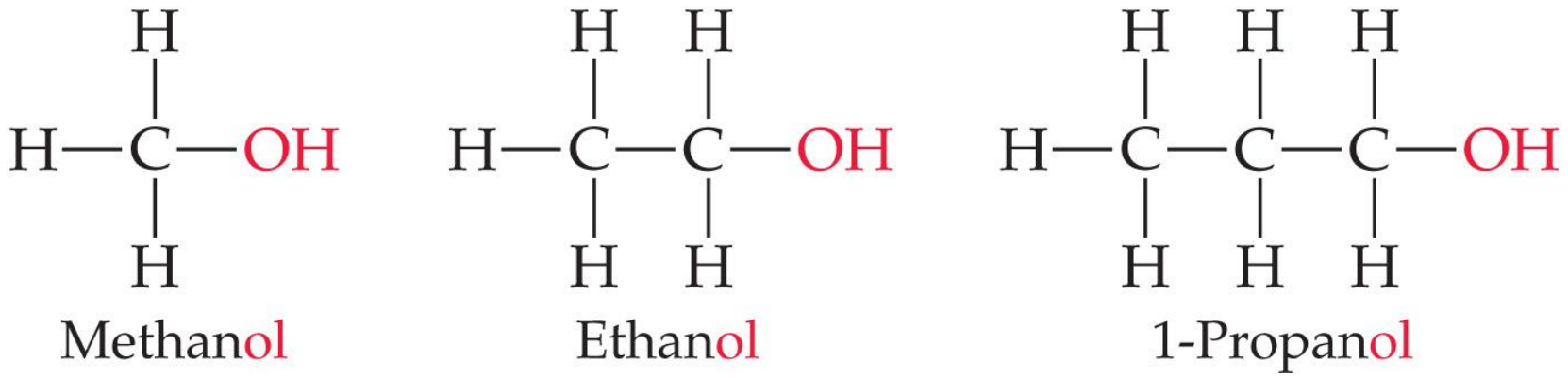
- The ending on the second element is changed to ***-ide***.
  - CO_2: carbon dioxide
  - CCl_4: carbon tetrachloride
- If the prefix ends with *a* or *o* and the name of the element begins with a vowel, the two successive vowels are often elided into one.
  - N_2O_5: dinitrogen pentoxide

Nomenclature of Organic Compounds



- **Organic chemistry** is the study of carbon.
- Organic chemistry has its own system of nomenclature.
- The simplest hydrocarbons (compounds containing only carbon and hydrogen) are **alkanes**.
- The first part of the names just listed correspond to the number of carbons (***meth-*** = 1, ***eth-*** = 2, ***prop-*** = 3, etc.)

Nomenclature of Organic Compounds



- When a hydrogen in an alkane is replaced with something else (a **functional group**, like -OH in the compounds above), the name is derived from the name of the alkane.
- The ending denotes the type of compound.
  - An **alcohol** ends in *-ol*.