Chemistry, The Central Science, 10th edition
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and Bruce E. Bursten

Chapter 2
Atoms, Molecules, and Ions

Atomic Theory of Matter

The theory that atoms are the fundamental building blocks of matter reemerged in the early 19th 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. Compounds are formed when atoms of more than one element combine; a given compound always has the same relative number and kind of atoms.

Law of Constant Composition

Joseph Proust (1754–1826)

- Also known as the law of definite proportions.
- The elemental composition of a pure substance never varies.

Law of Multiple Proportions

- In chemisty the **law of multiple proportions** is one of the basic laws and a major tool of chemical measurement (stoichiometry)

- It states that when elements combine they do so in a ratio of small whole numbers. For example, carbon and oxygen react to form CO or CO_2, but not $CO_{1.8}$.

if two elements form more than one compound between them then the ratios of the masses of the second element combined with a fixed mass of the first element will also be in small whole numbers.

For example,

the oxygen compared between CO and CO_2 has a simple 1:2 ratio; one oxygen in the first compound, two oxygen in the second compound.

100 grams of carbon will react with either 133 grams of oxygen to produce carbon monoxide, or with 266 grams of oxygen to produce carbon dioxide

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.

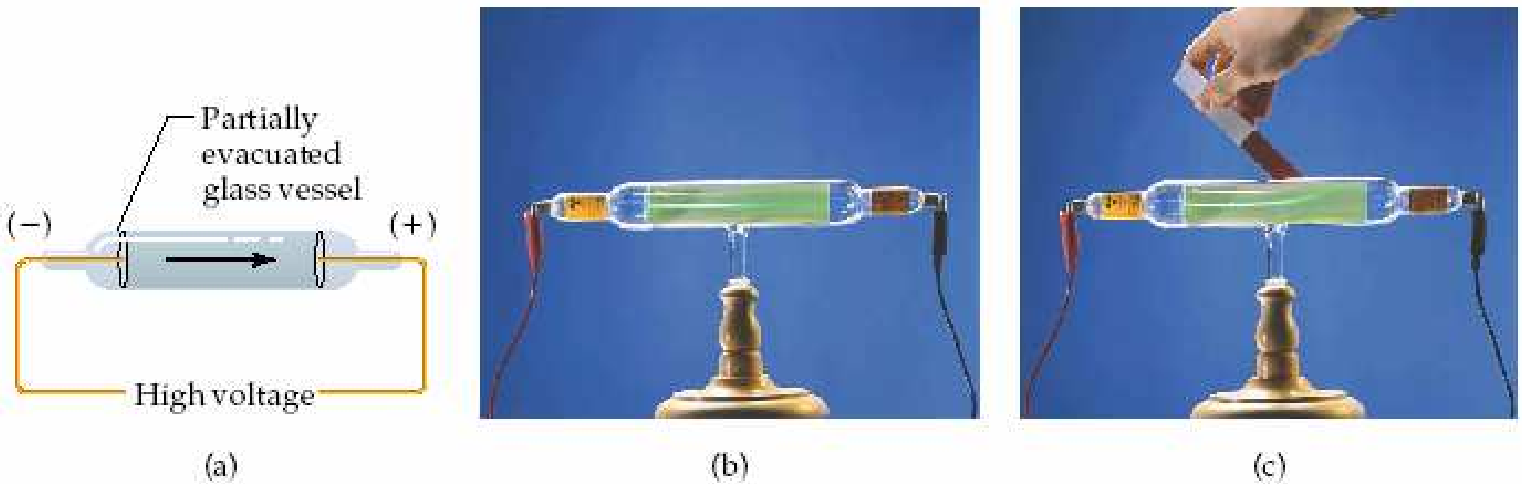
Atomic Structure

- Discovery of Electrons:

  J J Thomson (in 1897)

He gave the charge to mass ratio of electrons.

He also showed that the nature of the cathode ray did not depend on the material of the cathode.



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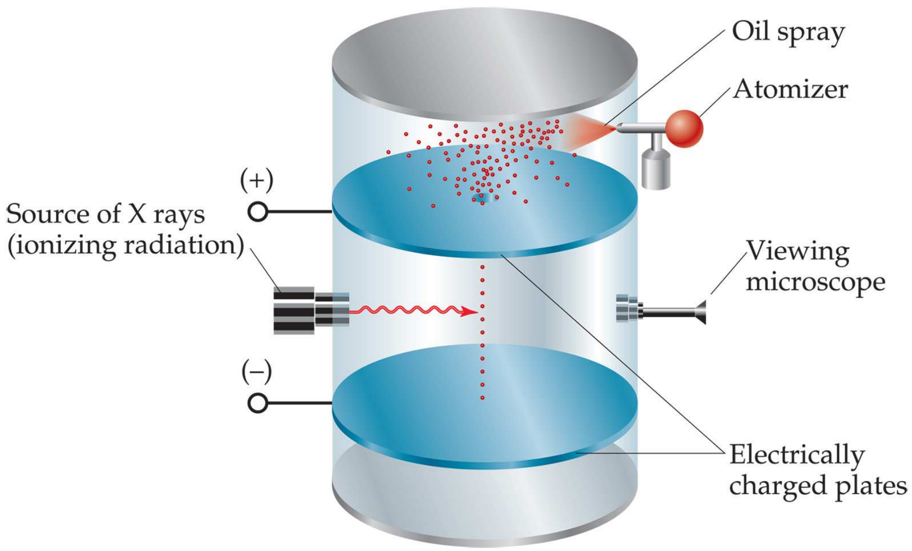
Conclusions drawn so far:

1. Cathode ray consists of negatively charged particles and electrons are constituents of all matter.
2. The charge on electrons is found to be 1.602×10^{-19} coulombs.

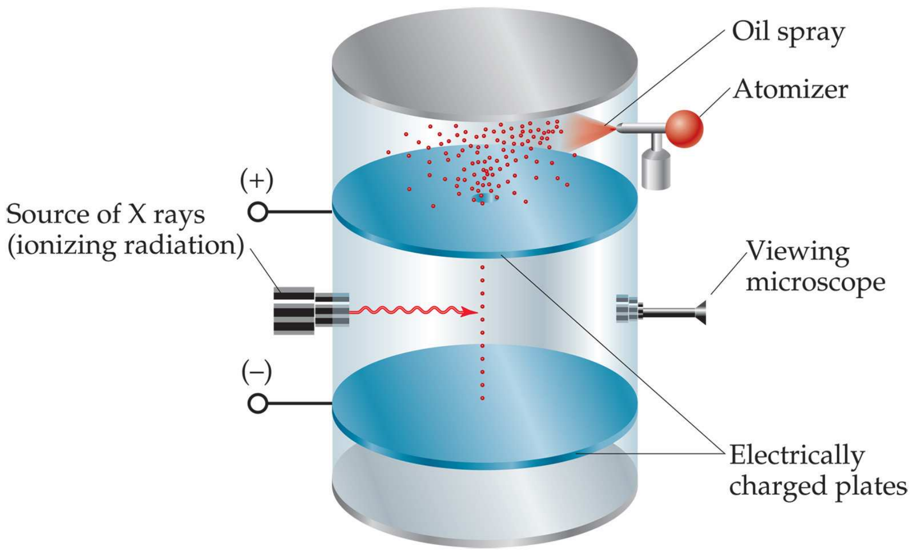
Millikan Oil Drop Experiment

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.

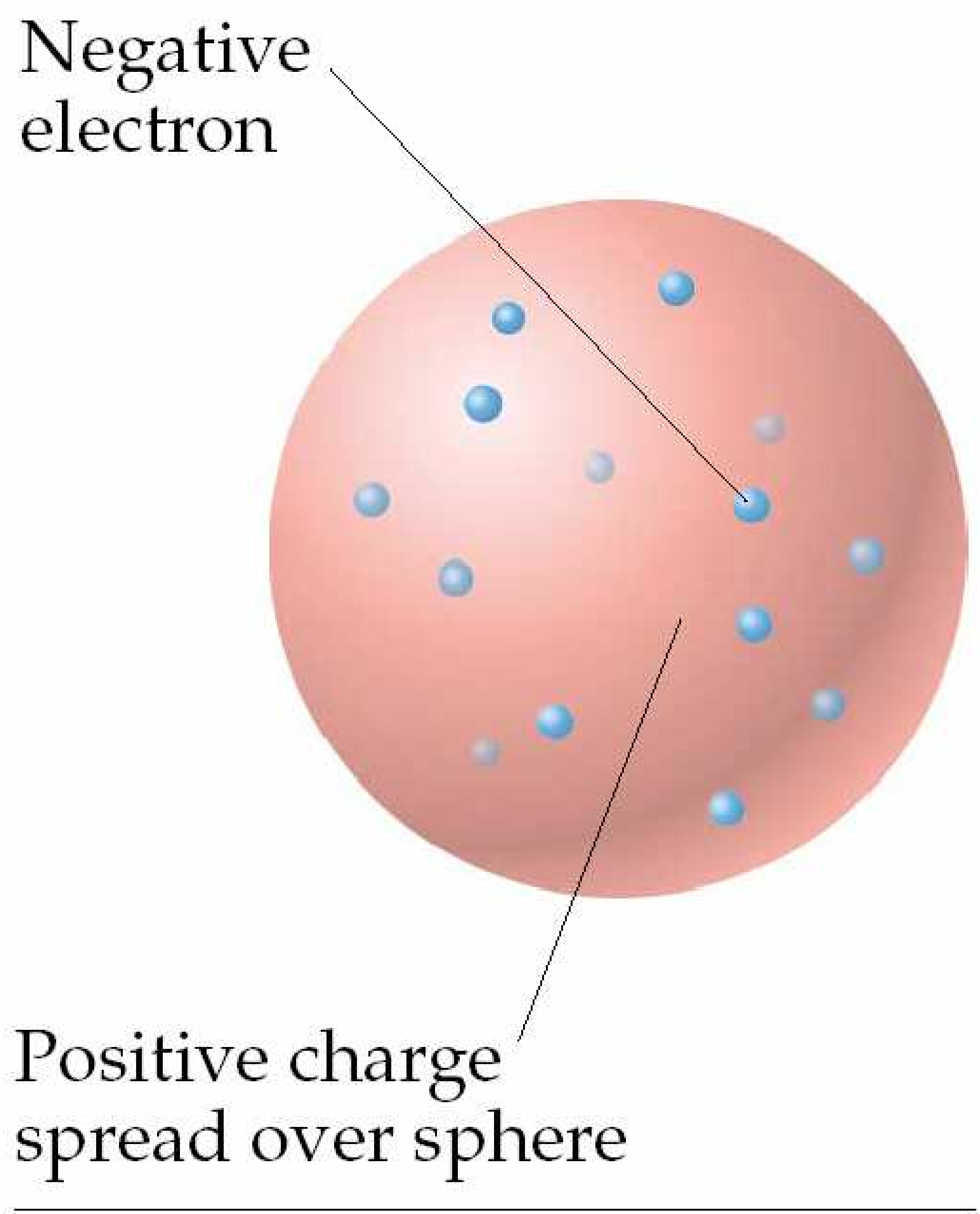


Millikan Oil Drop Experiment

Robert Millikan (University of Chicago) determined the charge on the electron in 1909.



- Now since a negative particle was discovered it was definite that the atom would also have an equal positive charge.
- Then at the time the most reasonable explanation seemed to be a plum pudding model



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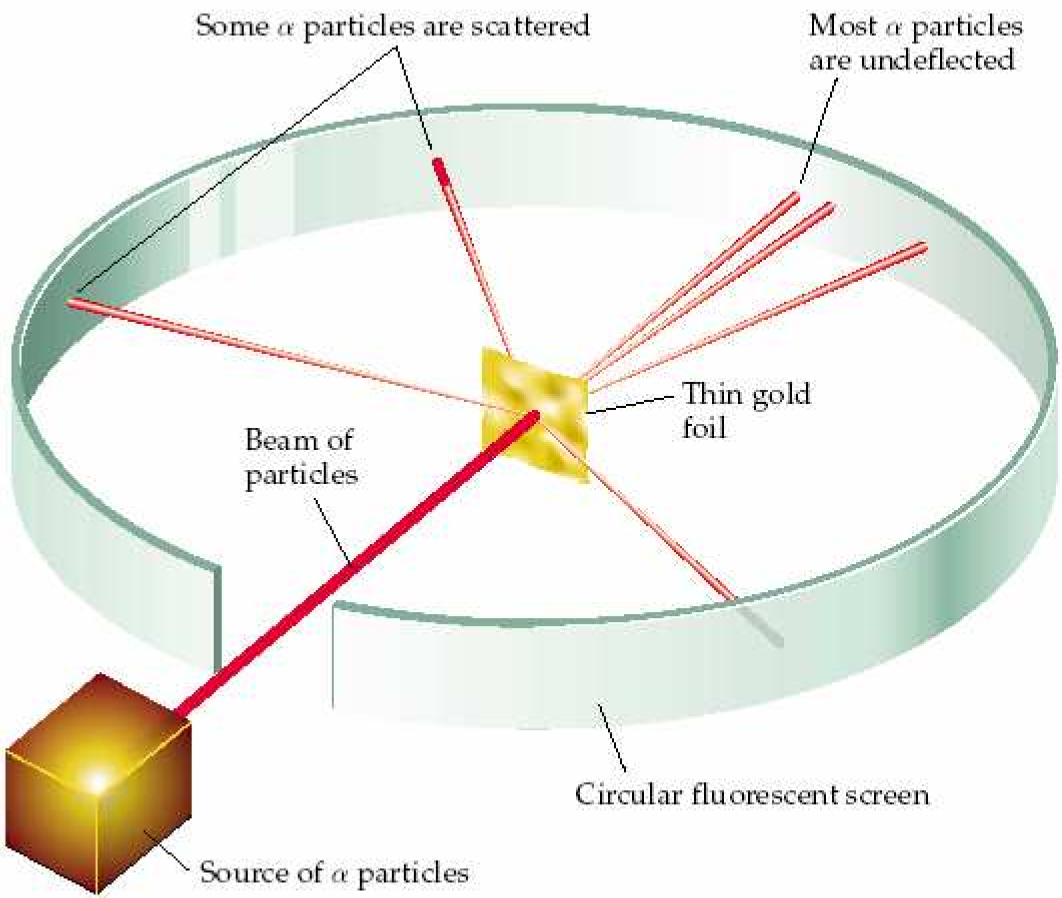
- Rutherford explained the existence of a focused positively charged nucleus in the atom.



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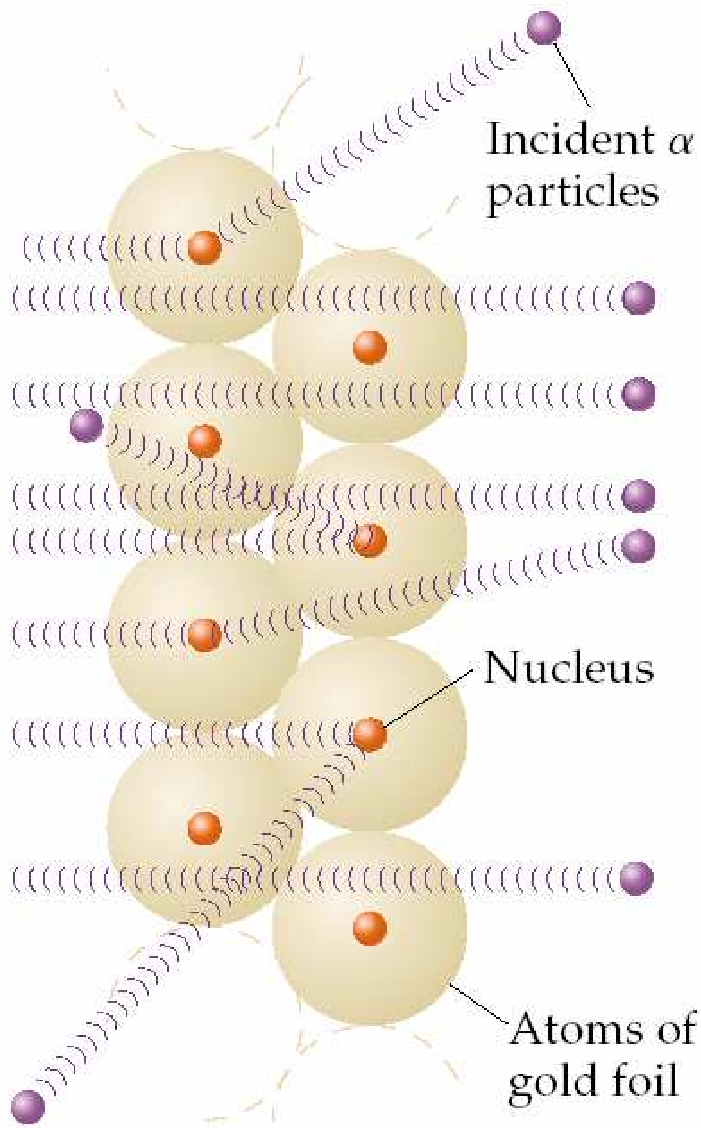

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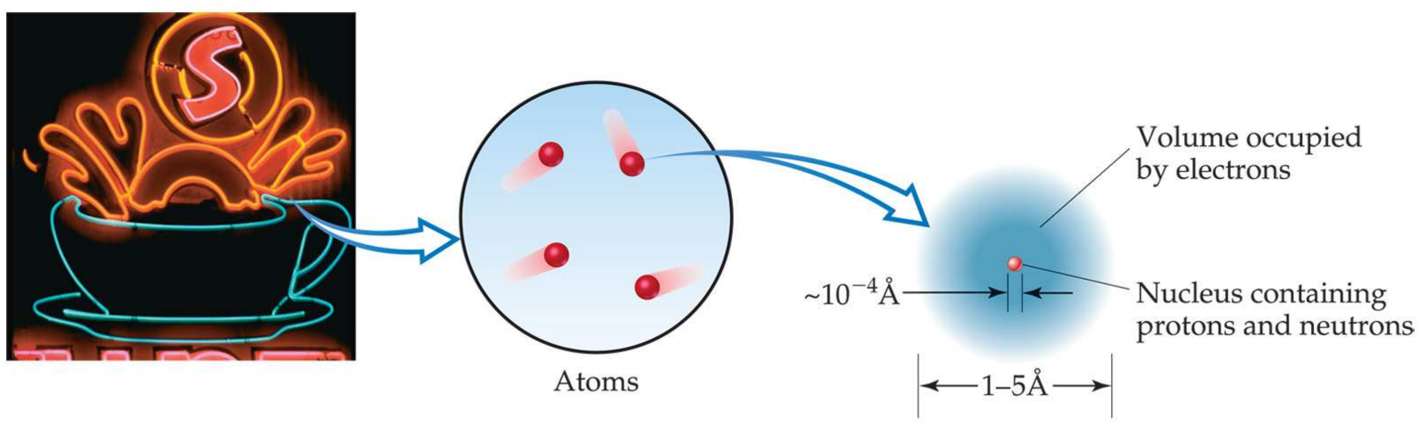
The Nuclear Atom

- Rutherford postulated a very small, dense nucleus with the electrons around the outside of the atom.
- Most of the volume of the atom is empty space.



Other Subatomic Particles

- Protons were discovered by Rutherford in 1919.
- Neutrons were discovered by James Chadwick in 1932.

Subatomic Particles

- Protons and electrons are the only particles that have a charge.
- Protons and neutrons have essentially the same mass.
- The mass of an electron is so small we ignore it.

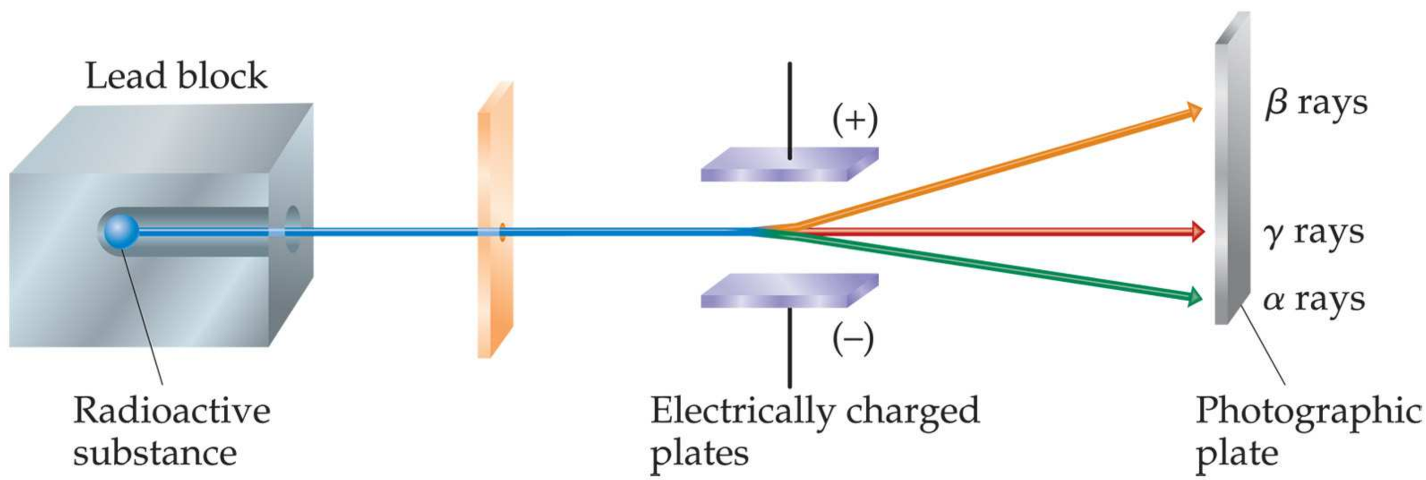
Particle	Charge	Mass (amu)
Proton	Positive (1+)	1.0073
Neutron	None (neutral)	1.0087
Electron	Negative (1−)	5.486×10^{-4}

Radioactivity:

- The spontaneous emission of radiation by an atom.
- First observed by Henri Becquerel.
- Also studied by Marie and Pierre Curie.

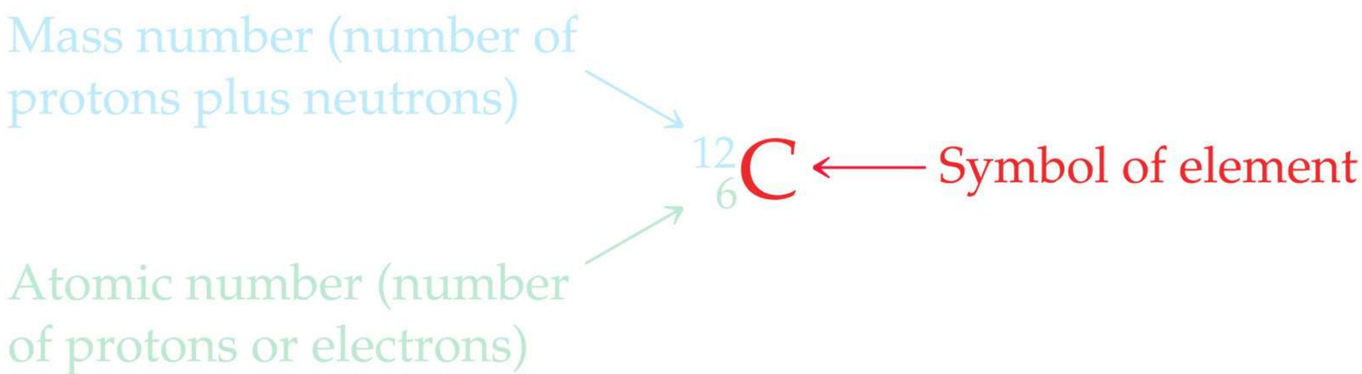
Radioactivity

- Three types of radiation were discovered by Ernest Rutherford:
  - α particles
  - β particles
  - γ rays



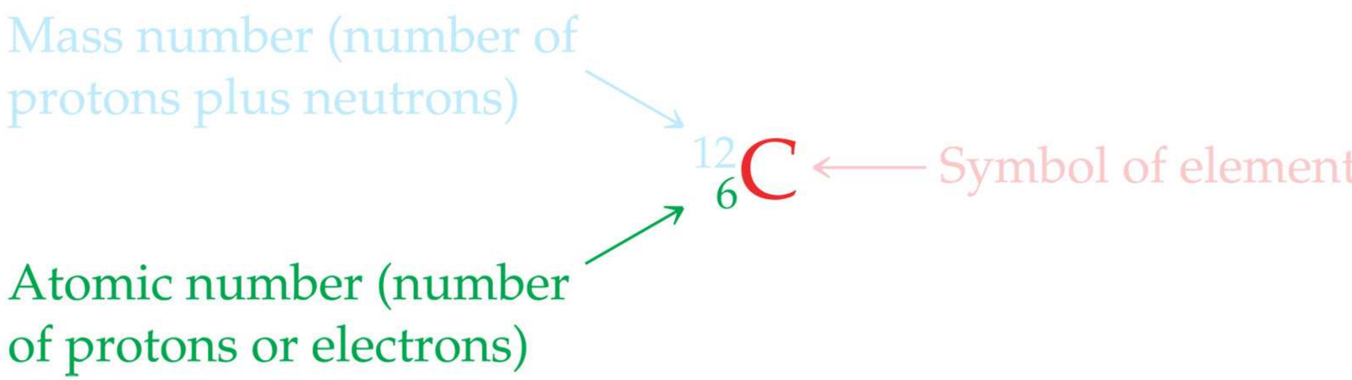
Atoms, Molecules, and Ions

Symbols of Elements



Elements are symbolized by one or two letters.

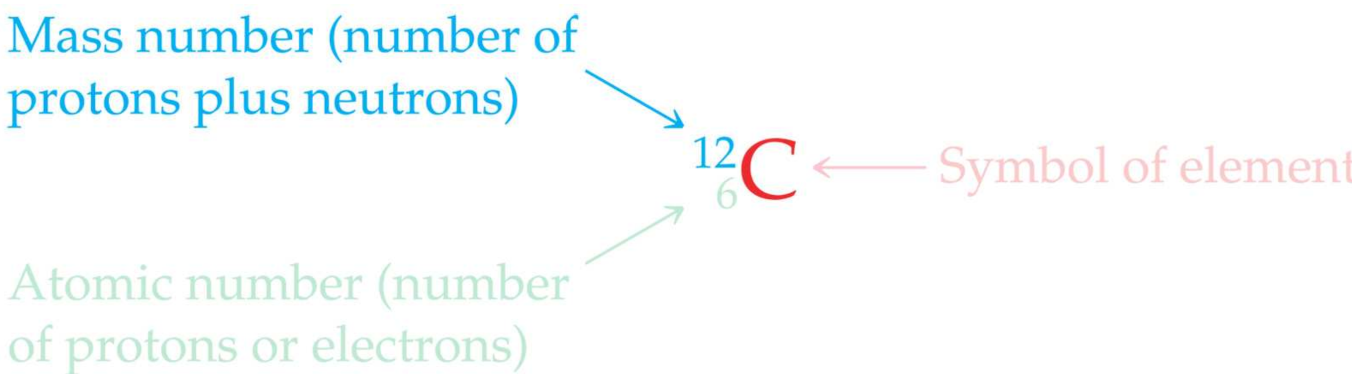
Atomic Number



All atoms of the same element have the same number of protons:

The atomic number (Z)

Atomic Mass



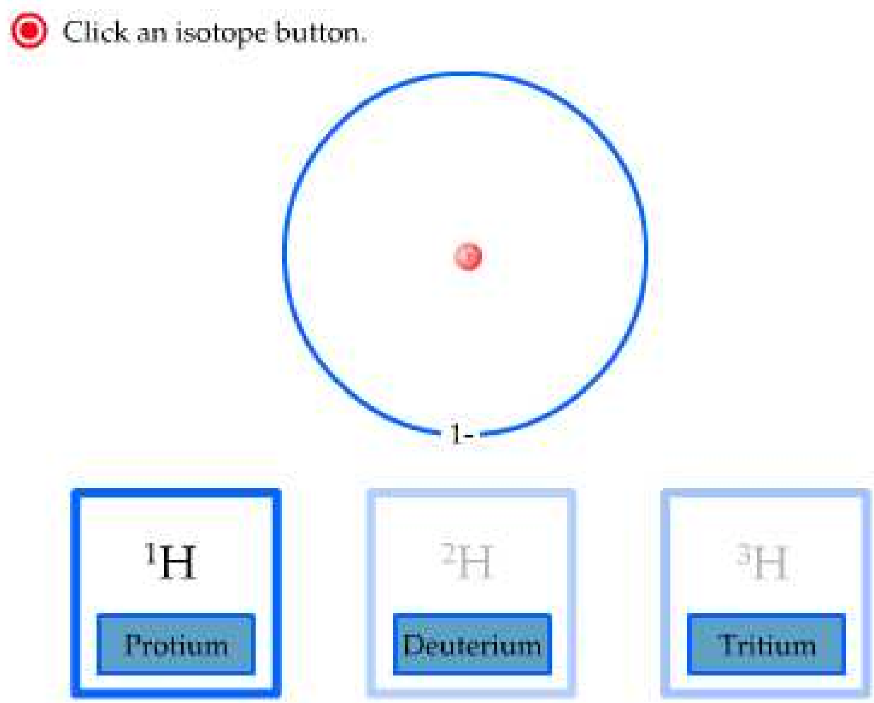
The mass of an atom in atomic mass units (amu) is the total number of protons and neutrons in the atom.

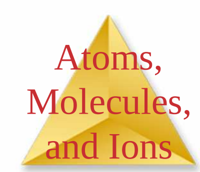
Isotopes:

- Atoms of the same element with different masses.
- Isotopes have different numbers of neutrons.

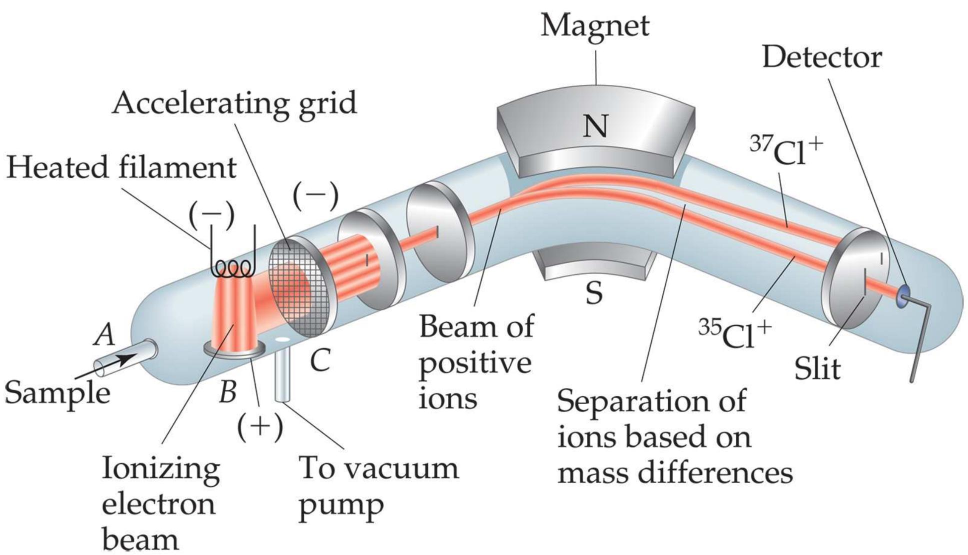
$^{11}_{6}C$ $^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$

Isotopes of Hydrogen





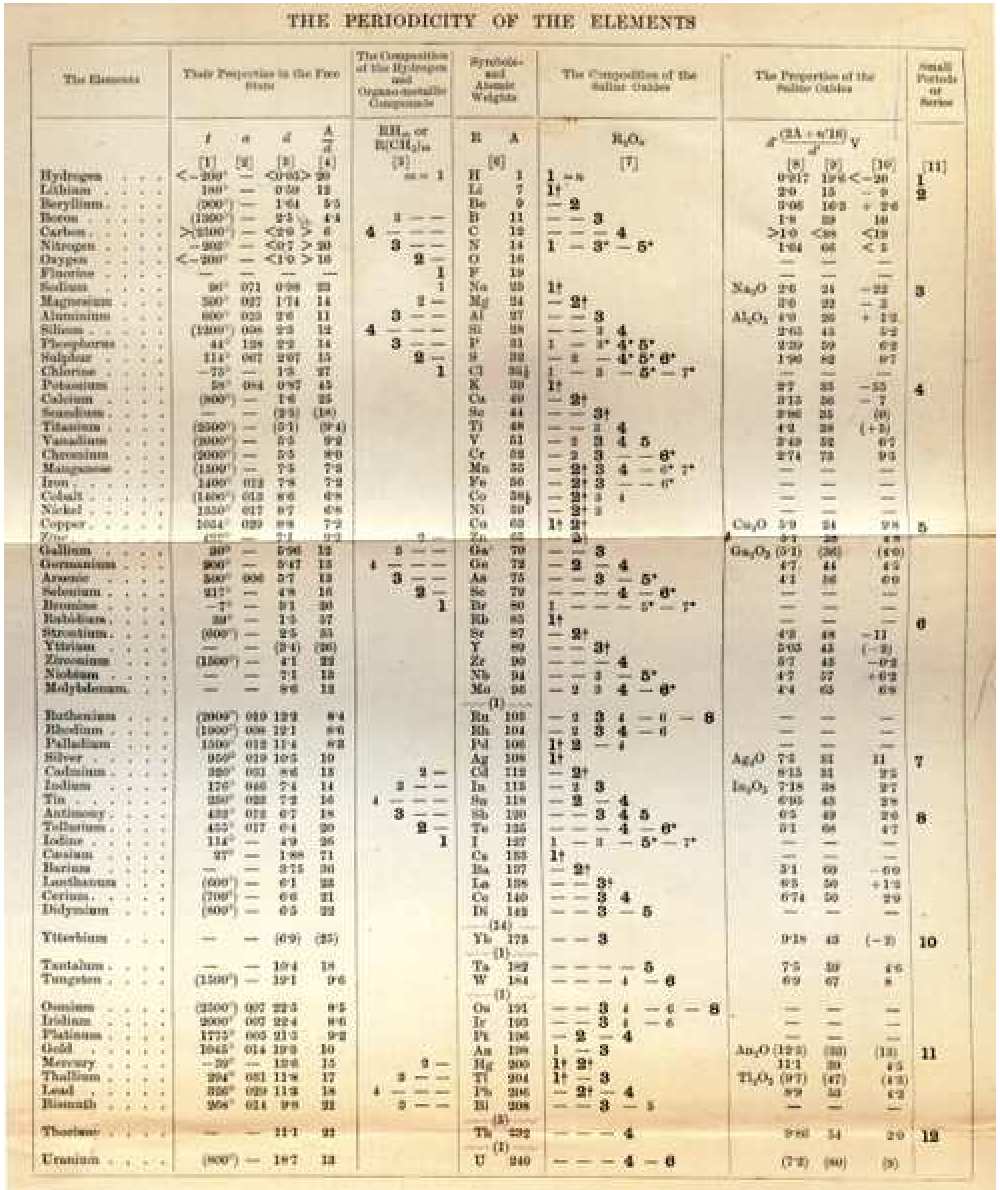
Atomic Mass



Atomic and molecular masses can be measured with great accuracy with a mass spectrometer.

Average Mass

- The unit for atomic mass is amu
- Because in the real world we use large amounts of atoms and molecules, we use average masses in calculations.
- Average mass is calculated from the isotopes of an element weighted by their relative abundances.

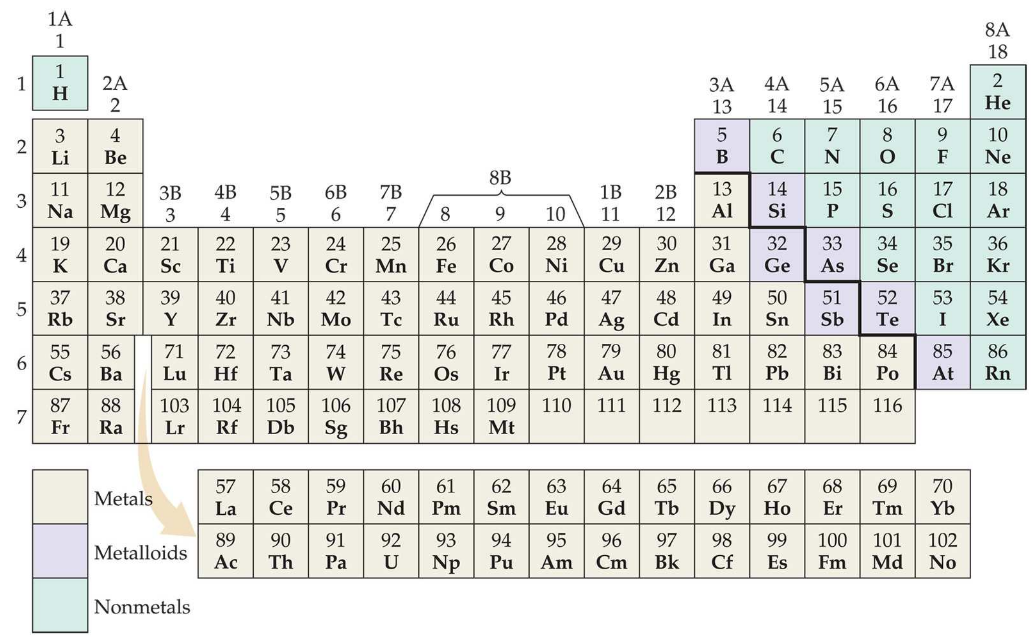


THE PERIODICITY OF THE ELEMENTS

The Elements	Symbols and Atomic Weights (R)	(A)	Small Periods or Series
Hydrogen	H	1	1
Lithium	Li	7	2
Beryllium	Be	9	
Boron	B	11	
Carbon	C	12	
Nitrogen	N	14	
Oxygen	O	16	
Fluorine	F	19	
Sodium	Na	23	3
Magnesium	Mg	24	
Aluminium	Al	27	
Silicon	Si	28	
Phosphorus	P	31	
Sulphur	S	32	
Chlorine	Cl	35½	
Potassium	K	39	4
Calcium	Ca	40	
Scandium	Sc	44	
Titanium	Ti	48	
Vanadium	V	51	
Chromium	Cr	52	
Manganese	Mn	55	
Iron	Fe	56	
Cobalt	Co	58½	
Nickel	Ni	59	
Copper	Cu	63	5
Zinc	Zn	65	
Gallium	Ga	70	
Germanium	Ge	72	
Arsenic	As	75	
Selenium	Se	79	
Bromine	Br	80	
Rubidium	Rb	85	6
Strontium	Sr	87	
Yttrium	Y	89	
Zirconium	Zr	90	
Niobium	Nb	94	
Molybdenum	Mo	96	
Ruthenium	Ru	103	
Rhodium	Rh	104	
Palladium	Pd	106	
Silver	Ag	108	7
Cadmium	Cd	112	
Indium	In	113	
Tin	Sn	119	
Antimony	Sb	120	
Tellurium	Te	125	8
Iodine	I	127	
Cæsium	Cs	133	
Barium	Ba	137	
Lanthanum	La	138	
Cerium	Ce	140	
Didymium	Di	142	
Ytterbium	Yb	173	10
Tantalum	Ta	182	
Tungsten	W	184	
Osmium	Os	191	
Iridium	Ir	193	
Platinum	Pt	196	
Gold	Au	198	11
Mercury	Hg	200	
Thallium	Tl	204	
Lead	Pb	206	
Bismuth	Bi	208	
Thorium	Th	232	12
Uranium	U	240	

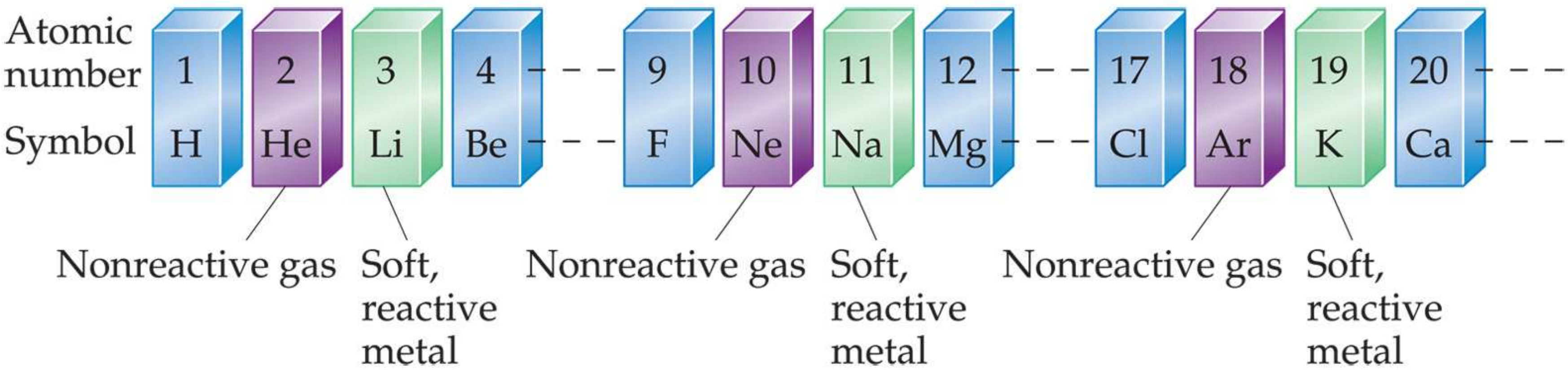
Atoms, Molecules, and Ions

Periodic Table:



- A systematic catalog of elements.
- Elements are arranged in order of atomic number.

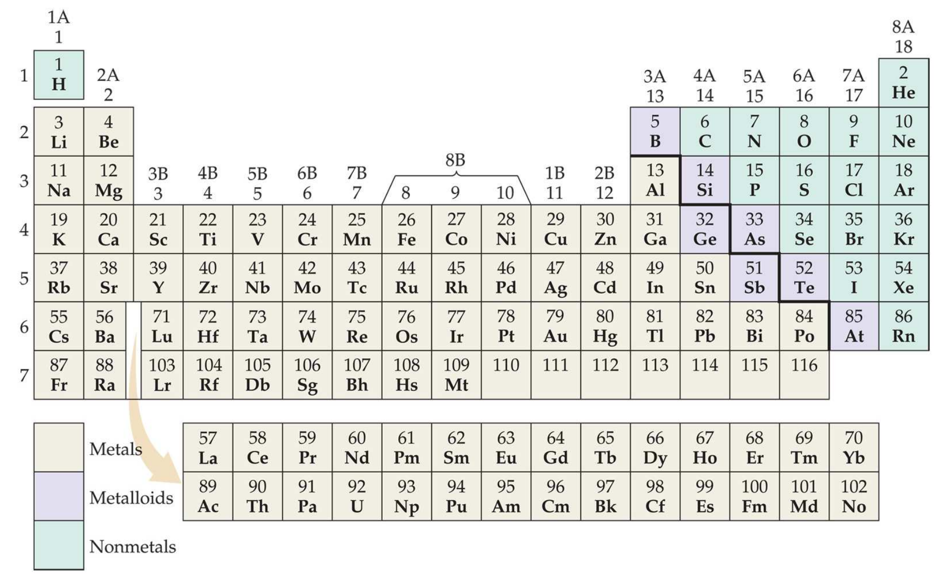
Periodicity



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

Periodic Table

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

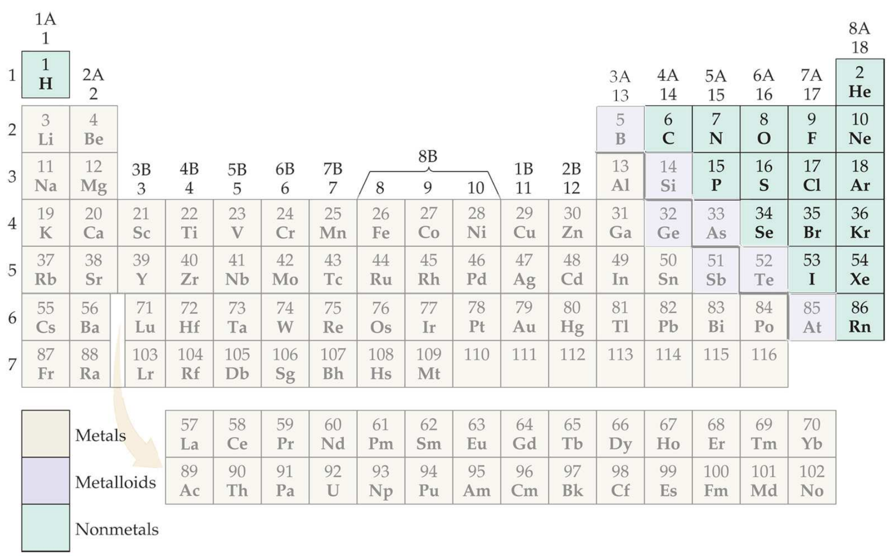


Groups

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

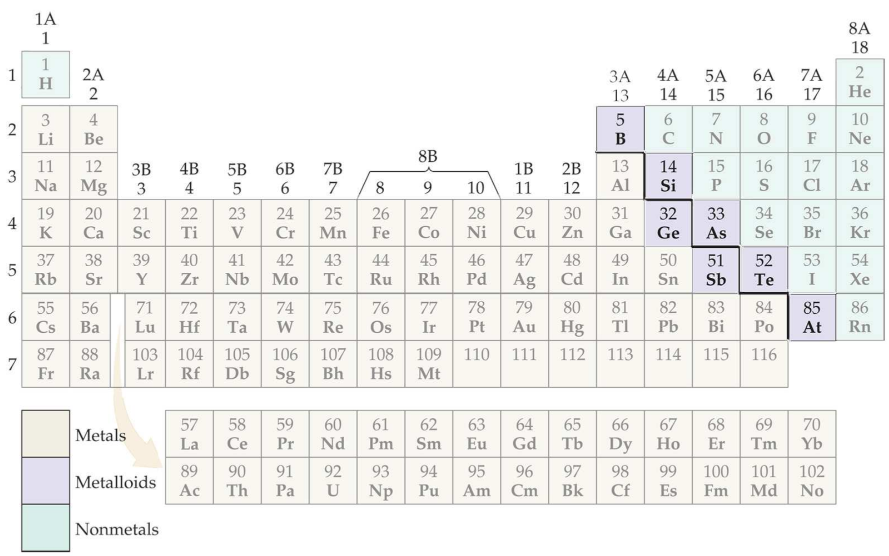
These five groups are known by their names.

Periodic Table



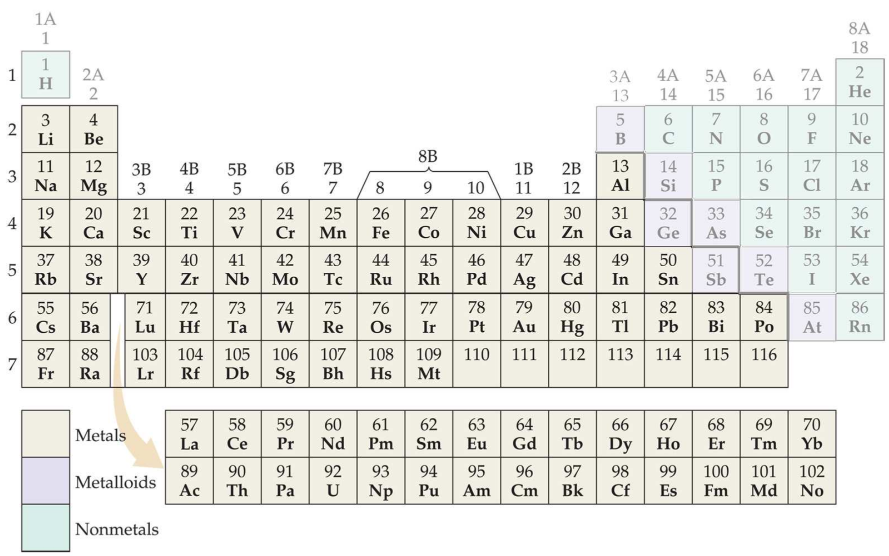
Nonmetals are on the right side of the periodic table (with the exception of H).

Periodic Table



Metalloids border the stair-step line (with the exception of Al and Po).

Periodic Table

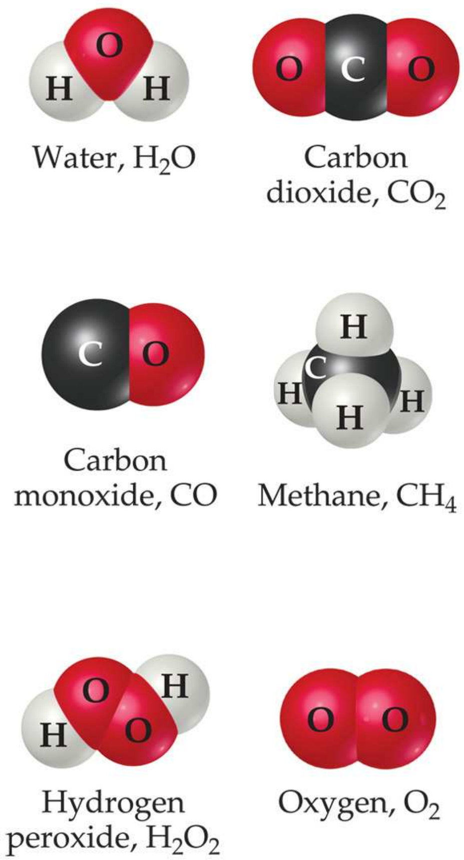


Metals are on the left side of the chart.

Note that there are more metals than nonmetals

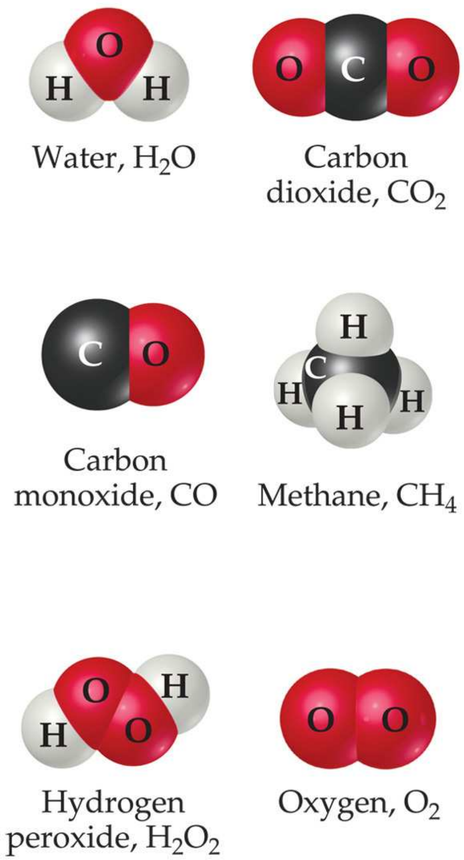
Atoms, Molecules, and Ions

Chemical Formulas



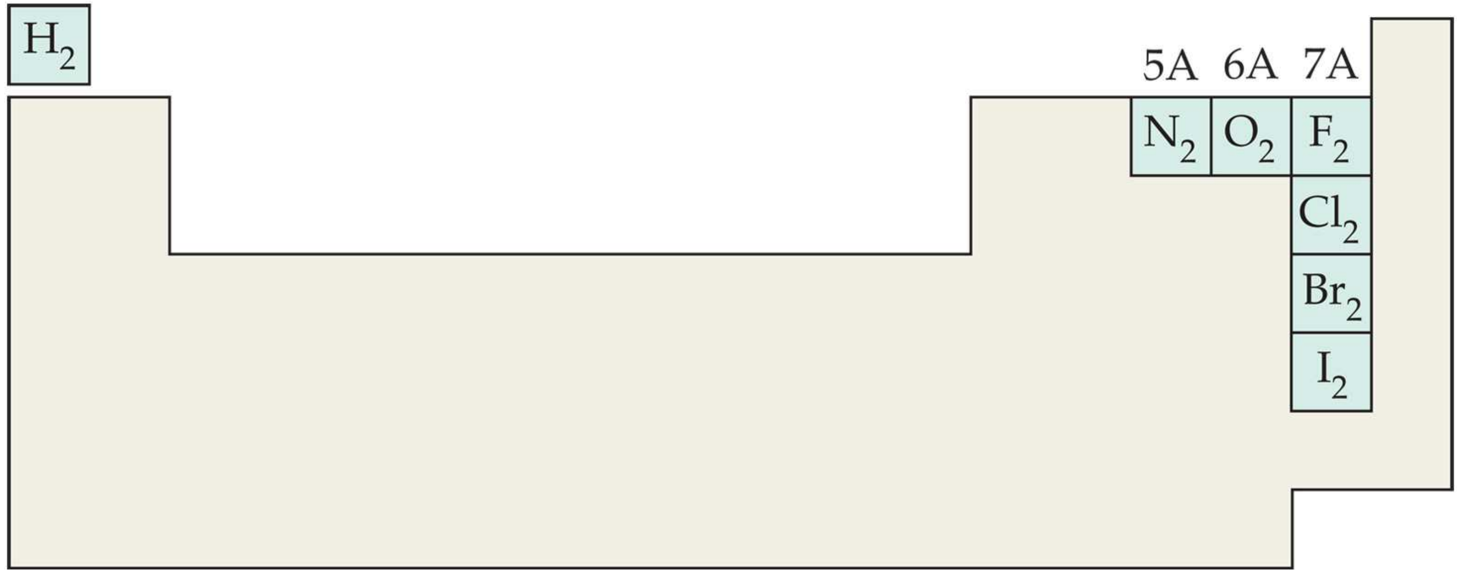
The subscript to the right of the symbol of an element tells the number of atoms of that element in one molecule of the compound.

Molecular Compounds



Molecular compounds are composed of molecules and almost always contain only nonmetals.

Diatomic Molecules



These seven elements occur naturally as molecules containing two atoms.

Allotropes

- Many elements like C, O and S exist in more than one form in nature.

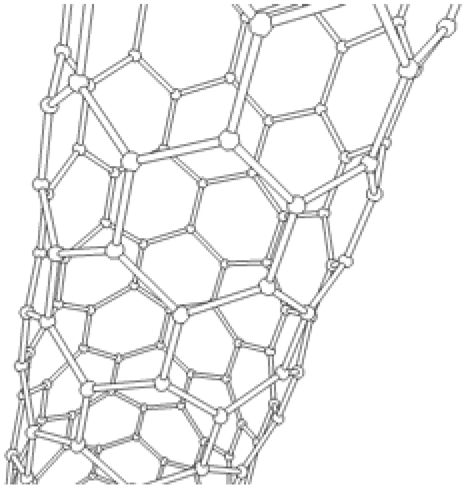
Oxygen :

dioxygen O_2 - colorless

ozone O_3 - blue

Carbon:

- Diamond - an extremely hard, transparent crystal, with the carbon atoms arranged in a tetrahedral lattice. A poor electrical conductor. An excellent thermal conductor.
- Graphite - a soft, black, flaky solid, a moderate electrical conductor. The C atoms are bonded in flat hexagonal lattices, which are then layered in sheets.
- amorphous carbon
- fullerenes including "buckyballs", such as C_{60}, and carbon nanotubes



Atoms, Molecules, and Ions

Phosphorus:

White phosphorus - crystalline solid P_4

Red phosphorus - polymeric solid

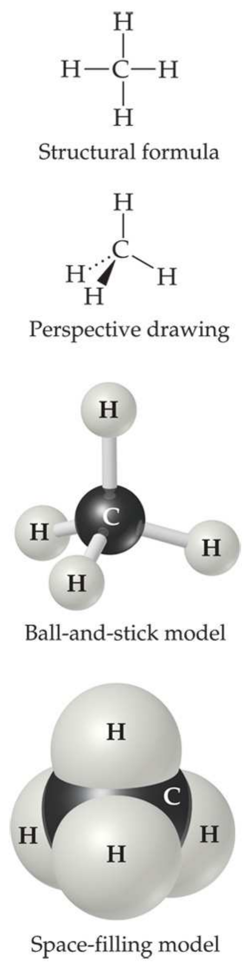
Sulfur

- Plastic (amorphous) sulfur - polymeric solid
- Rhombic sulfur - large crystals composed of S8 molecules
- Monoclinic sulfur - fine needle-like crystals
- Other ring molecules such as S7 and S12

Types of Formulas

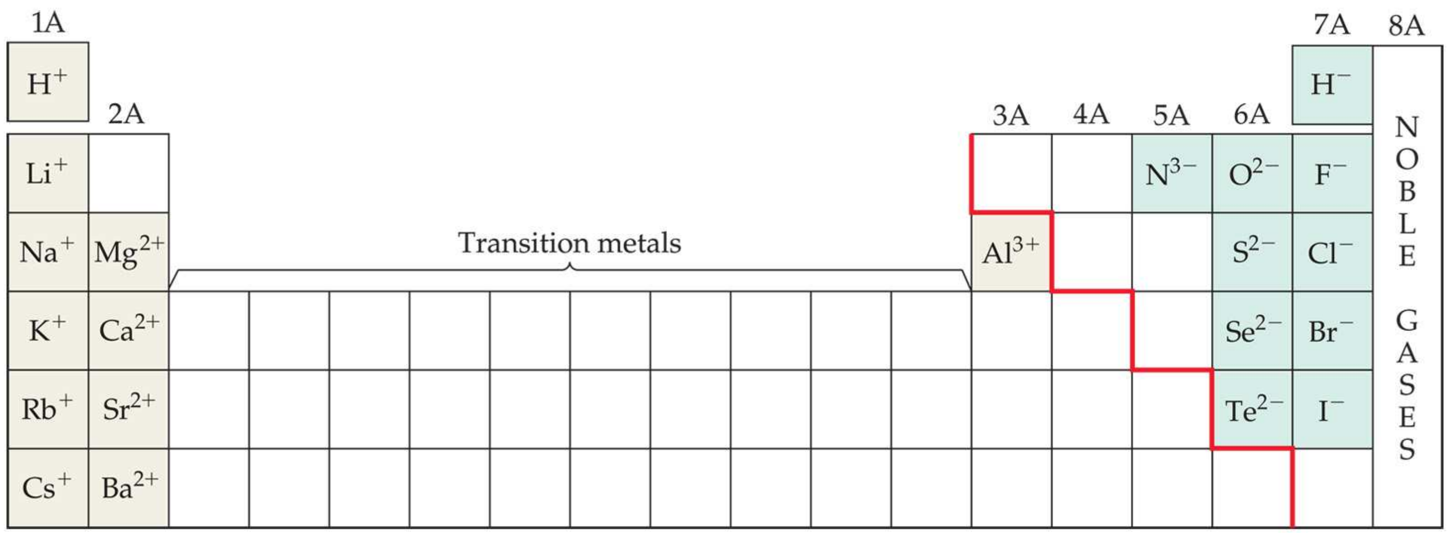
- Empirical formulas give the lowest whole-number ratio of atoms of each element in a compound.
- Molecular formulas give the exact number of atoms of each element in a compound.

Types of Formulas



- Structural formulas show the order in which atoms are bonded.
- Perspective drawings also show the three-dimensional array of atoms in a compound.

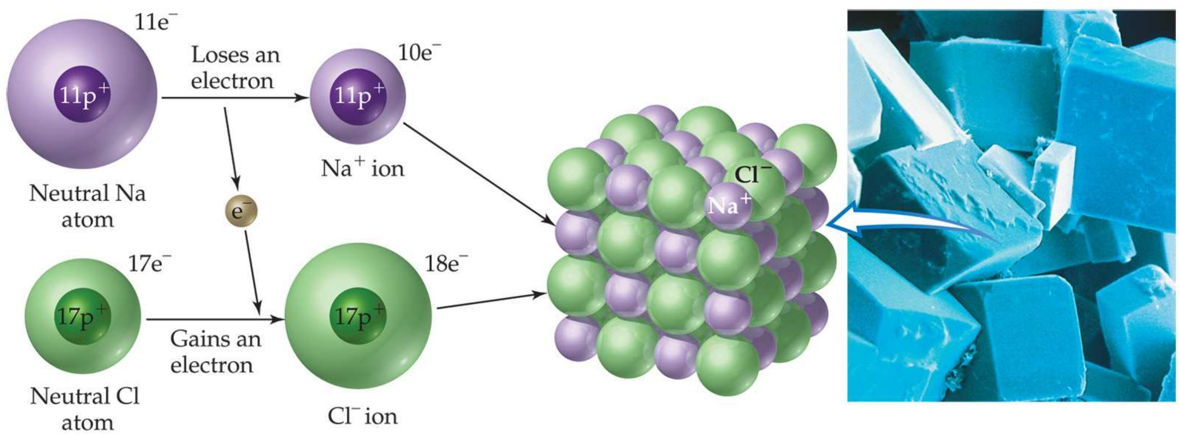
Ions



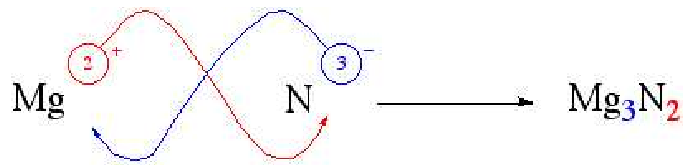
- When atoms lose or gain electrons, they become ions.
  - Cations are positive and are formed by elements on the left side of the periodic chart.
  - Anions are negative and are formed by elements on the right side of the periodic chart.

Ionic Bonds

Ionic compounds (such as NaCl) are generally formed between metals and nonmetals.



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.

Common Cations

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

*The most common ions are in boldface.

Common Anions

Charge	Formula	Name	Formula	Name
1−	H^-	Hydride ion	**$C_2H_3O_2^-$**	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**

*The most common ions are in boldface.

Inorganic Nomenclature

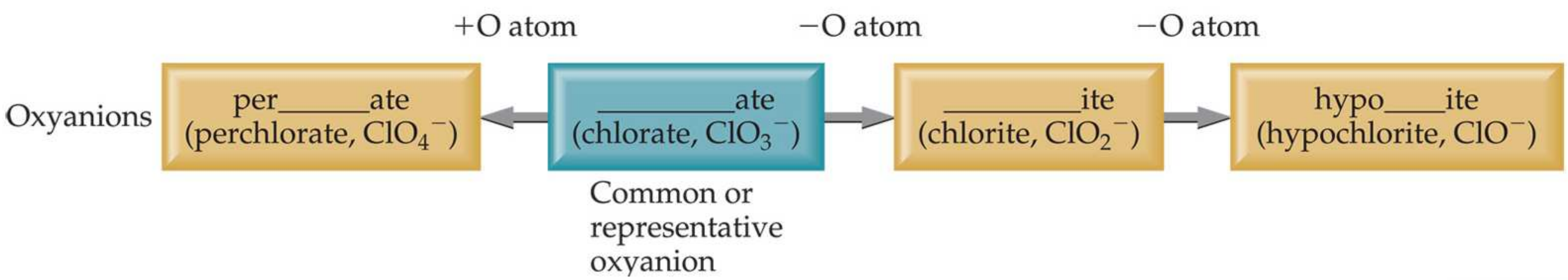
- Write the name of the cation.
- If the anion is an element, change its ending to -*ide*; if the anion is a polyatomic ion, simply write the name of the polyatomic ion.
- If the cation can have more than one possible charge, write the charge as a Roman numeral in parentheses.

Patterns in Oxyanion Nomenclature

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

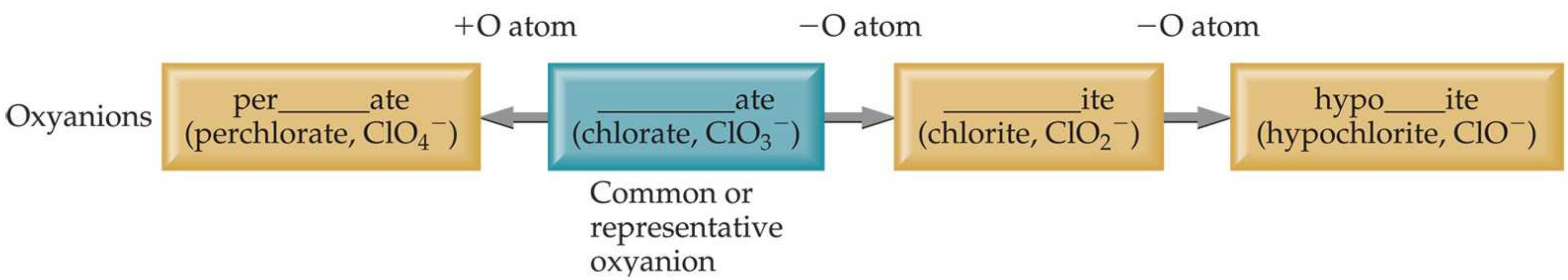
Patterns in Oxyanion Nomenclature

- The one with the second fewest oxygens ends in -*ite*
  - ➢ClO_2^- : chlorite
- The one with the second most oxygens ends in -*ate*
  - ➢ClO_3^- : chlorate

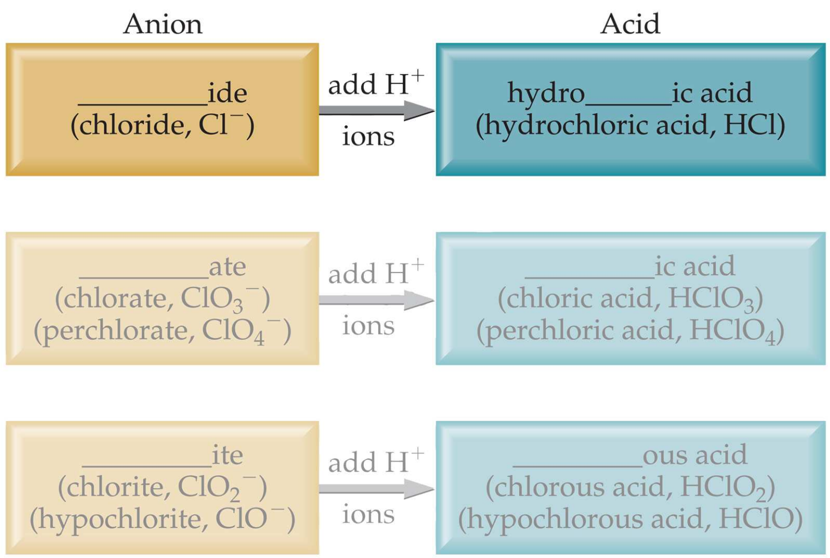


Patterns in Oxyanion Nomenclature

- The one with the fewest oxygens has the prefix *hypo*- and ends in -*ite*
  - ➢ClO^- : hypochlorite
- The one with the most oxygens has the prefix *per*- and ends in -*ate*
  - ➢ClO_4^- : perchlorate

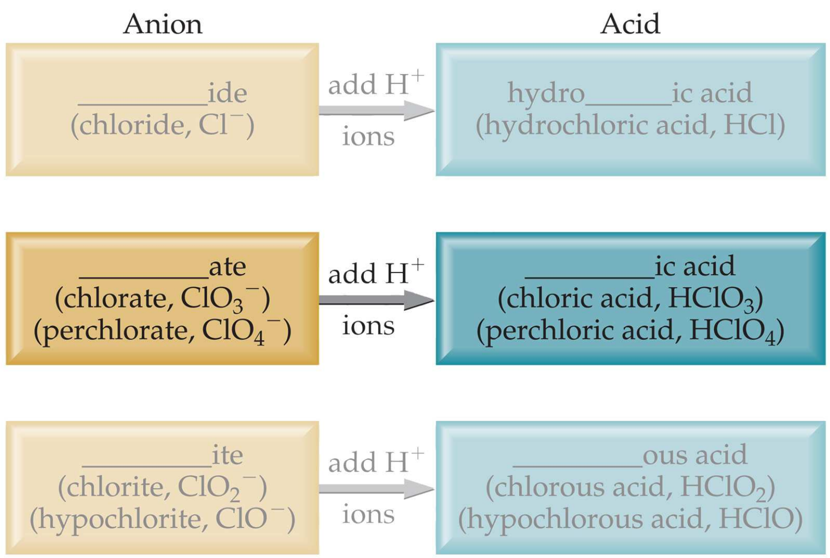


Acid Nomenclature



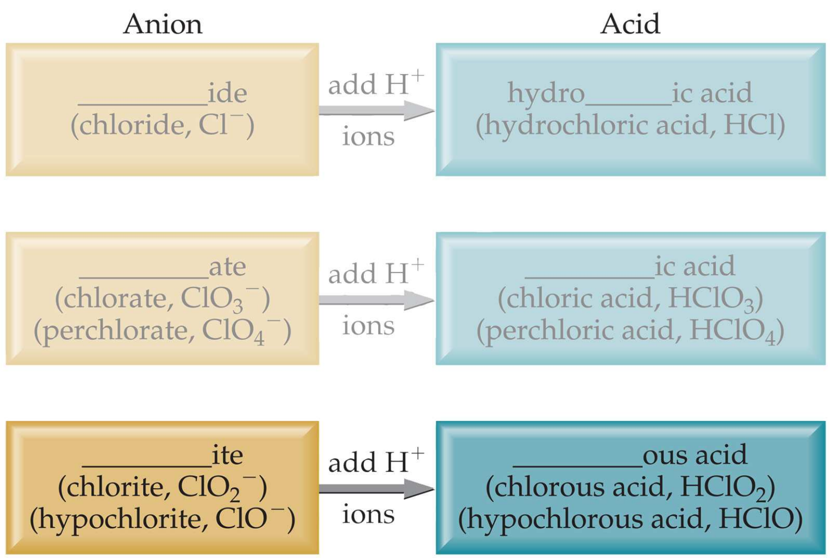
- If the anion in the acid ends in -*ide*, change the ending to -*ic acid* and add the prefix *hydro*- :
  - HCl: hydrochloric acid
  - HBr: hydrobromic acid
  - HI: hydroiodic acid

Acid Nomenclature



- If the anion in the acid ends in -*ate*, change the ending to -*ic acid:*
  - $HClO_3$: chloric acid
  - $HClO_4$: perchloric acid

Acid Nomenclature



- If the anion in the acid ends in *-ite*, change the ending to *-ous acid*:
  - HClO: hypochlorous acid
  - $HClO_2$: chlorous acid

Nomenclature of Binary Compounds

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

- The less electronegative atom is usually listed 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

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

- The ending on the more electronegative element is changed to -*ide*.

  - CO_2: carbon dioxide
  - CCl_4: carbon tetrachloride

Nomenclature of Binary Compounds

Prefix	*Meaning*
Mono-	*1*
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Hexa-	*6*
Hepta-	*7*
Octa-	*8*
Nona-	*9*
Deca-	*10*

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