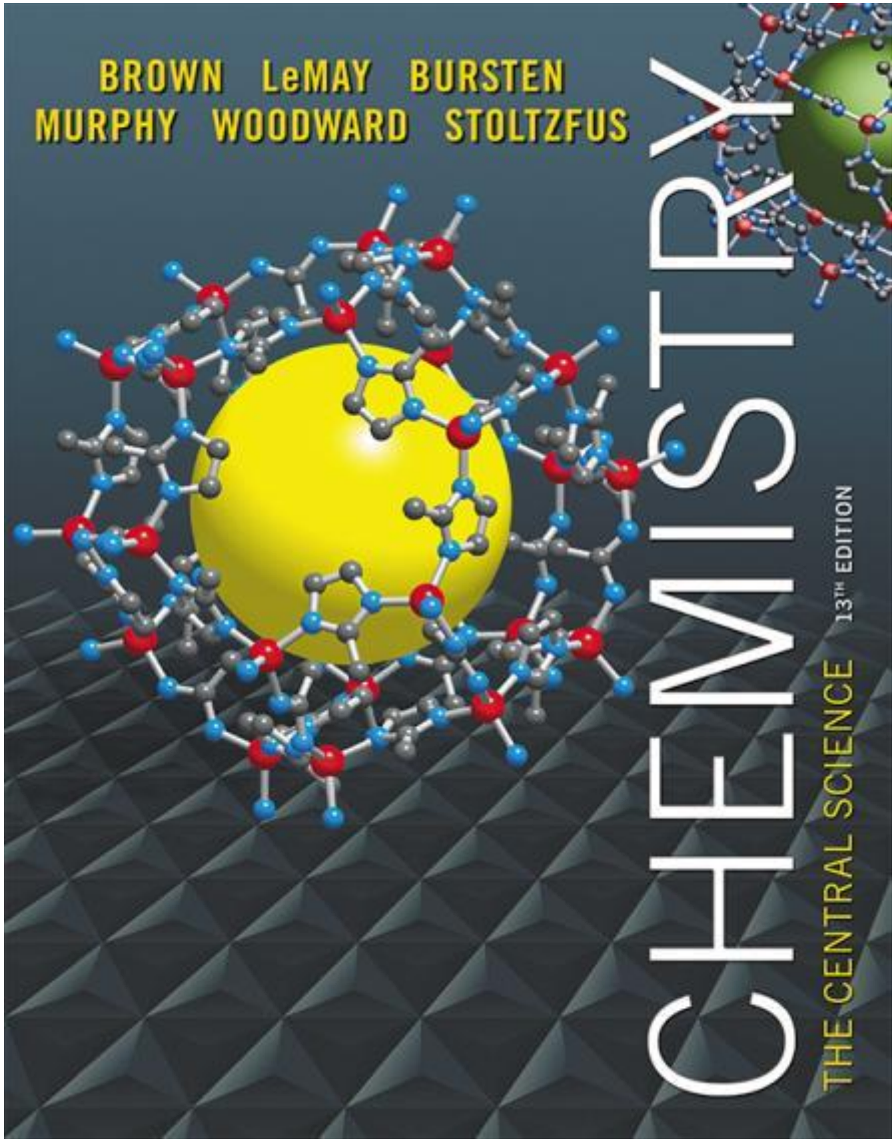

Lecture Presentation

Chapter 2

Atoms, Molecules, and Ions

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Atomic Theory of Matter

Dalton's Atomic Theory

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

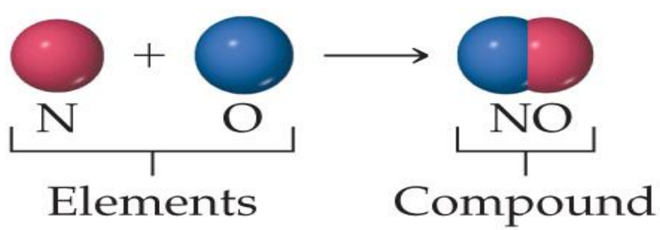

An atom of the element oxygen

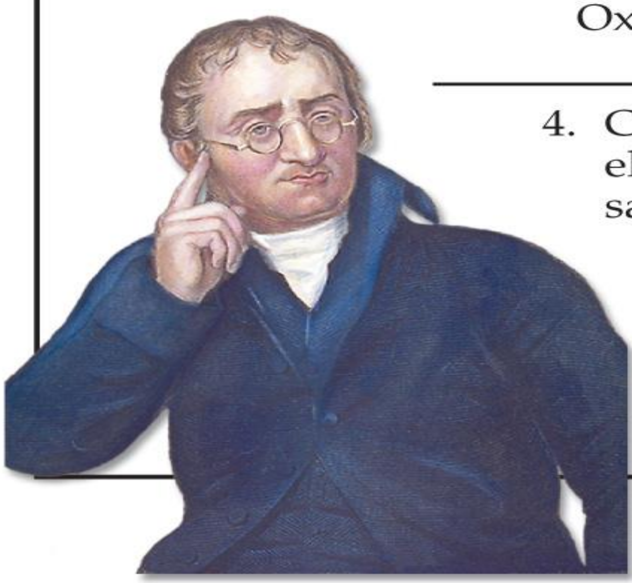

An atom of the element nitrogen

2. All atoms of a given element are identical, but the atoms of one element are different from the atoms of all other elements.

3. Atoms of one element cannot be changed into atoms of a different element by chemical reactions; atoms are neither created nor destroyed in chemical reactions.

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 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.

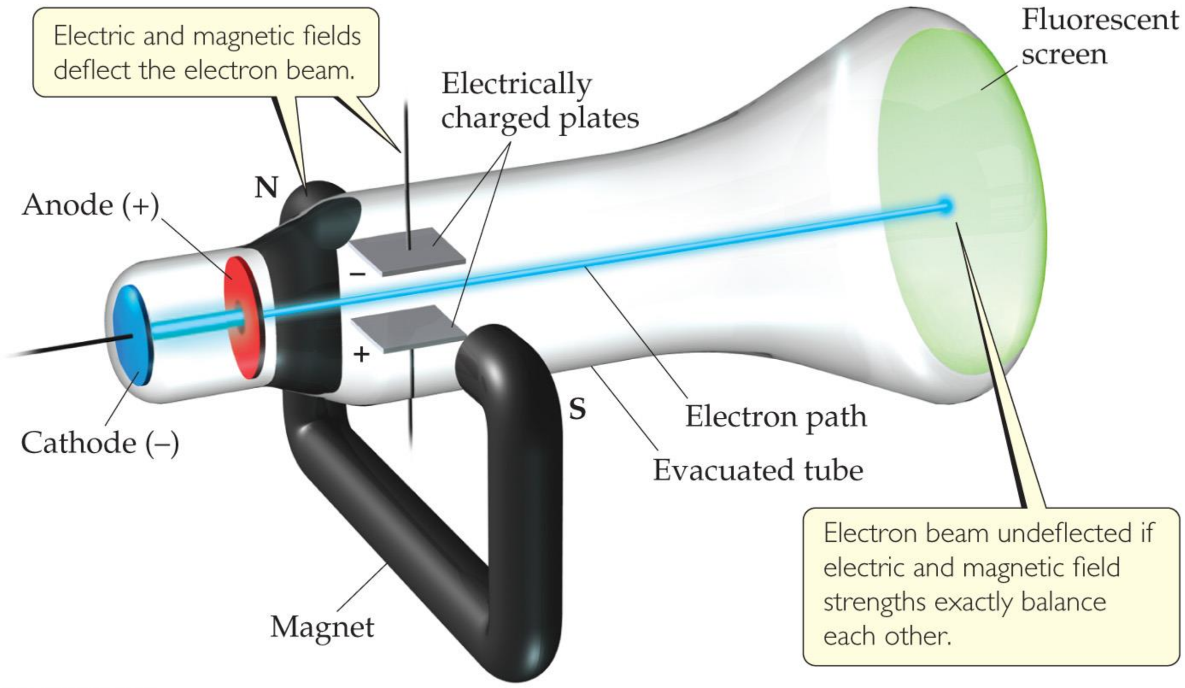
Law of Multiple Proportions

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.

When two or more compounds exist from the same elements, they can *not* have the same relative number of atoms.

Ex. H_2O and H_2O_2 or CO_2 and CO

The Electron

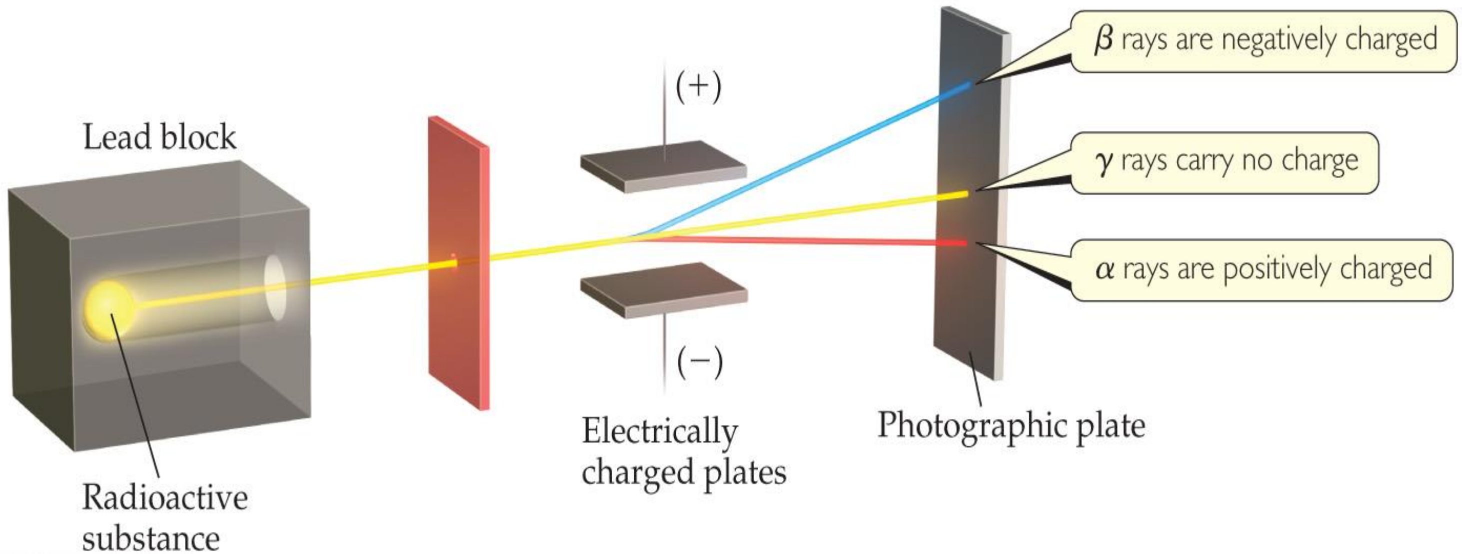


- Streams of negatively charged particles were found to emanate from cathode tubes, causing fluorescence.
- J. J. Thomson is credited with their discovery (1897).

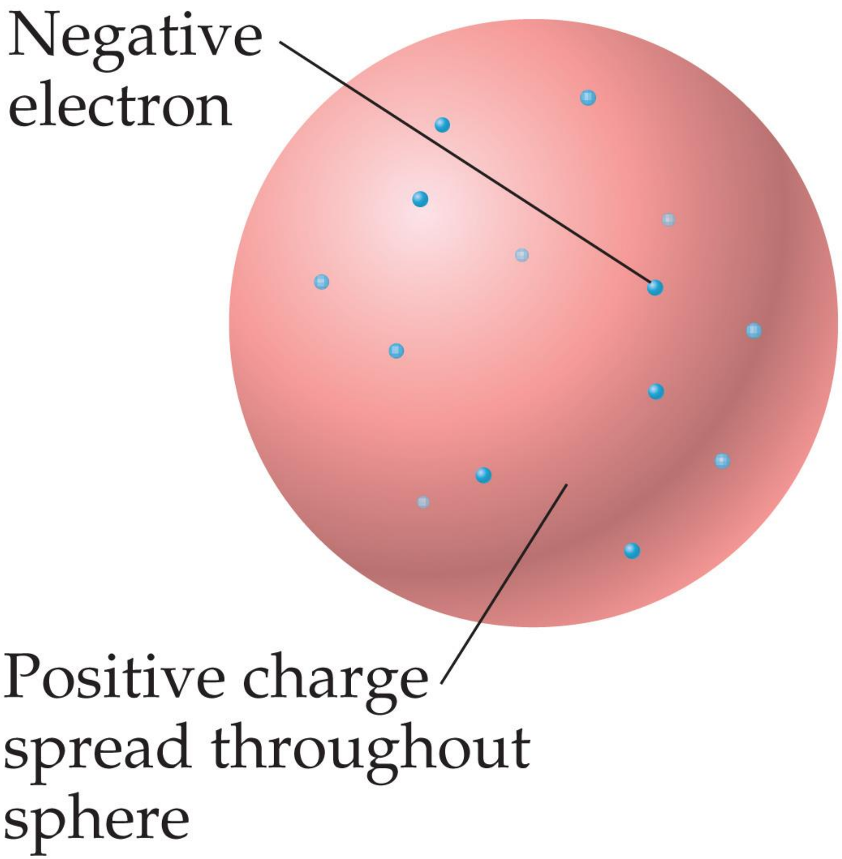
Thomson measured the charge/mass ratio of the electron to be 1.76×10^8 coulombs/gram (C/g).

Radioactivity

- **Radioactivity** is the spontaneous emission of high-energy radiation by an atom. Alpha (+) particles, Beta (-) particles and gamma rays
- 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.



The Atom, circa 1900

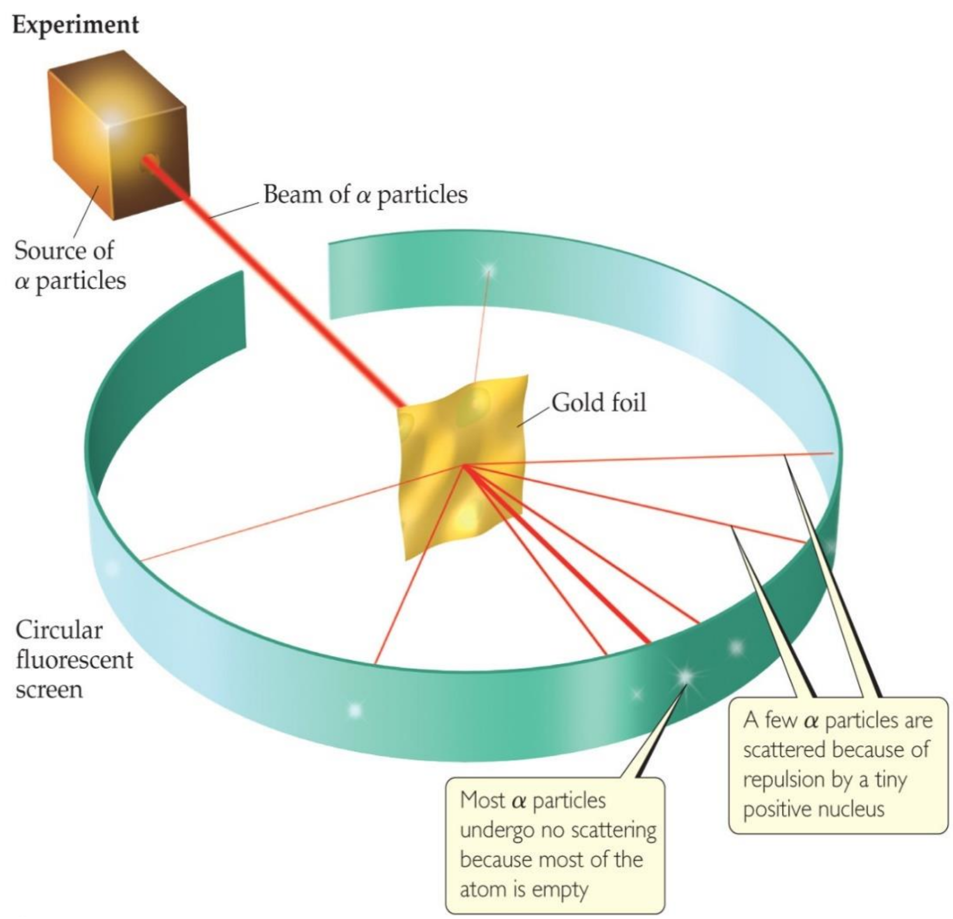


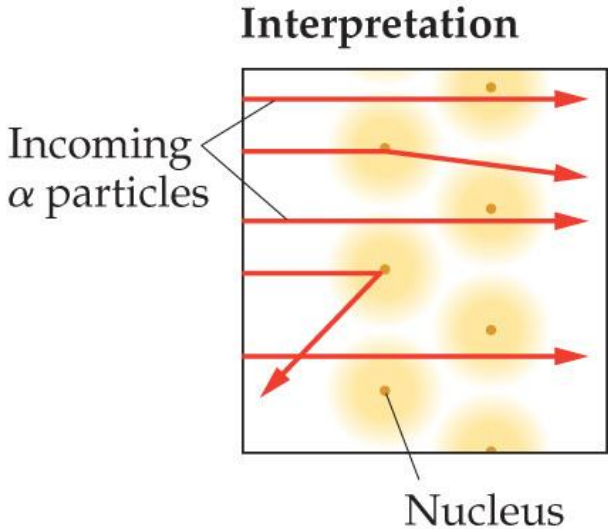
- The prevailing theory was that of the “plum pudding” model, put forward by Thomson.
- It featured a positive sphere of matter with negative electrons embedded in it.

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.

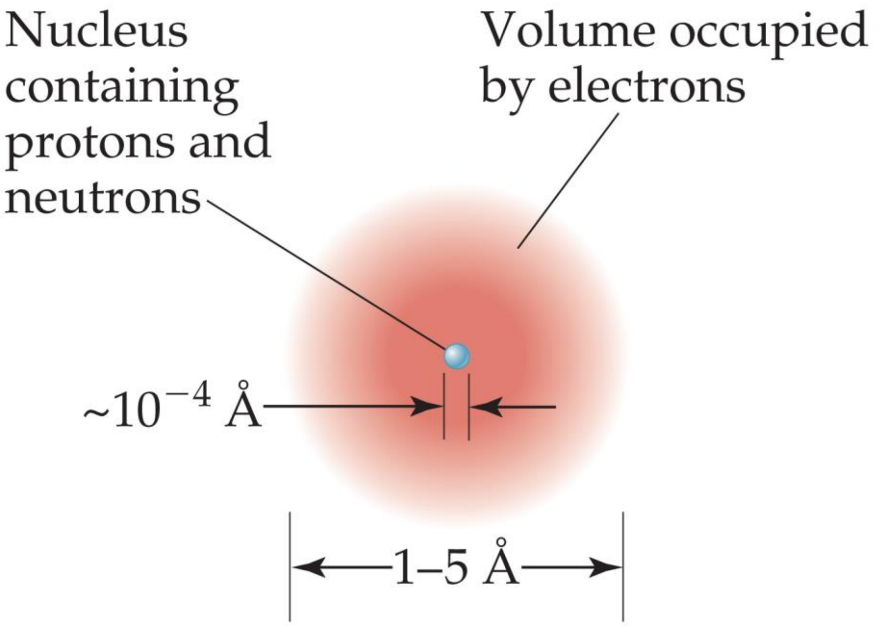
Since some particles were deflected at large angles, Thomson's model could not be correct.





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.



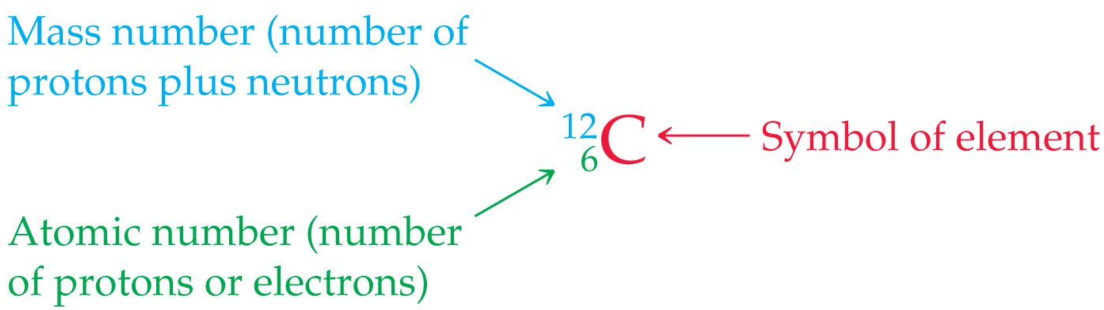
Subatomic Particles

- 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}

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.

Determining the Number of Subatomic Particles in Atoms (answers on next slide)

1. How many protons, neutrons, and electrons are in an atom of **(a)** ^{197}Au, **(b)** strontium-90?

2. Magnesium has three isotopes with mass numbers 24, 25, and 26. **(a)** Write the complete chemical symbol (superscript and subscript) for each. **(b)** How many neutrons are in an atom of each isotope?

Solution

(a)The superscript 197 is the mass number 1protons + neutrons2. According to the list of elements given on the front inside cover, gold has atomic number 79. Consequently, an atom of ^{197}Au has 79 protons, 79 electrons, and 197 – 79 = 118 neutrons.

(b) The atomic number of strontium is 38. Thus, all atoms of this element have 38 protons and 38 electrons. The strontium-90 isotope has 90 – 38 = 52 neutrons.

Solution

(a) Magnesium has atomic number 12, so all atoms of magnesium contain 12 protons and 12 electrons. The three isotopes are therefore represented by $^{24}_{12}Mg$, $^{25}_{12}Mg$, and $^{26}_{12}Mg$. **(b)** The number of neutrons in each isotope is the mass number minus the number of protons. The numbers of neutrons in an atom of each isotope are therefore 12, 13, and 14, respectively.

Isotopes

- **Isotopes** are atoms of the same element with different masses. They 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.

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.

Calculating the Atomic Weight of an Element from Isotopic Abundances

Naturally occurring chlorine is 75.78% ^{35}Cl (atomic mass 34.969 amu) and 24.22% ^{37}Cl (atomic mass 36.966 amu). Calculate the atomic weight of chlorine.

Solution

We can calculate the atomic weight by multiplying the abundance of each isotope by its atomic mass and summing these products. Because 75.78% = 0.7578 and 24.22% = 0.2422, we have

Atomic weight = (0.7578) (34.969 amu) + (0.2422)(36.966 amu)

= 26.50 amu + 8.953 amu

= 35.45 amu

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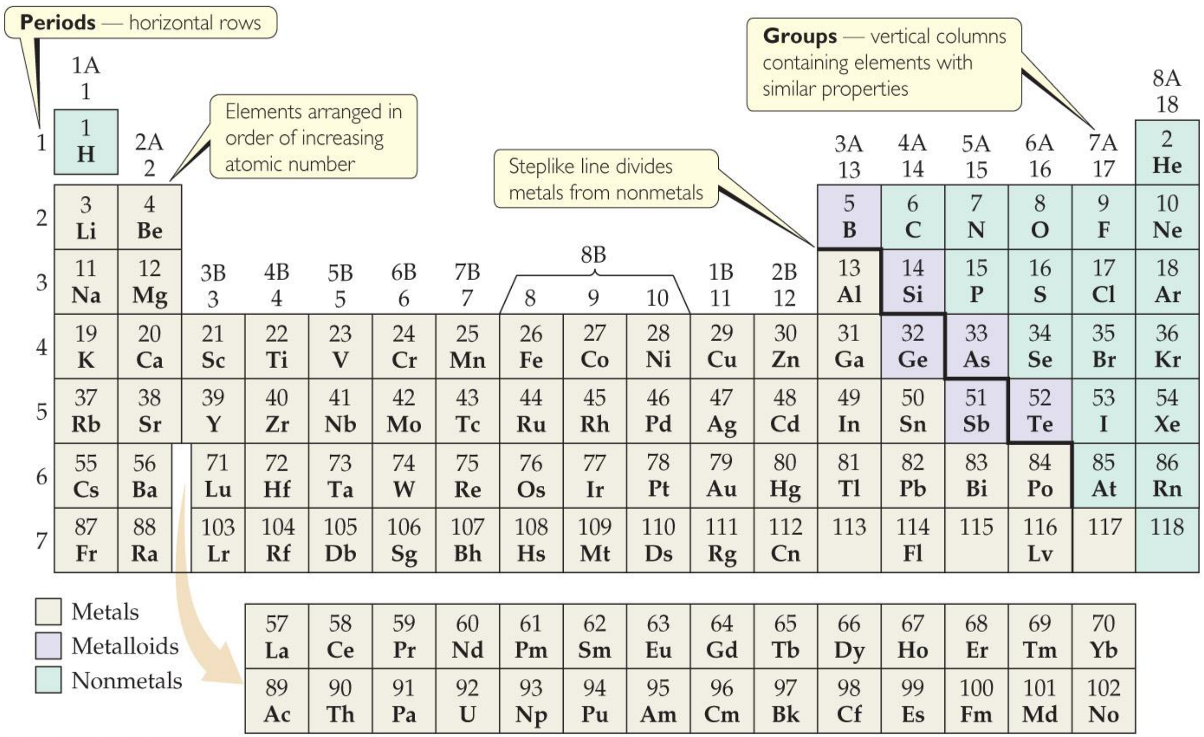
Periodic Table



The **periodic table** is a systematic organization of the elements.

Elements are arranged in order of atomic number.

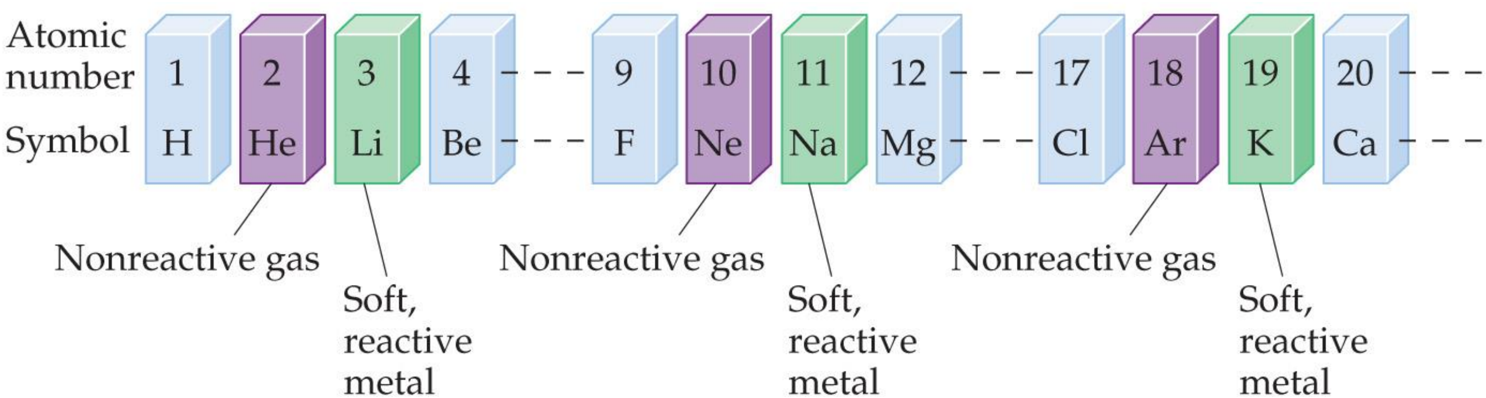
The rows on the periodic table are called **periods**.
Columns are called **groups**.
Elements in the same group have similar chemical properties.

Groups

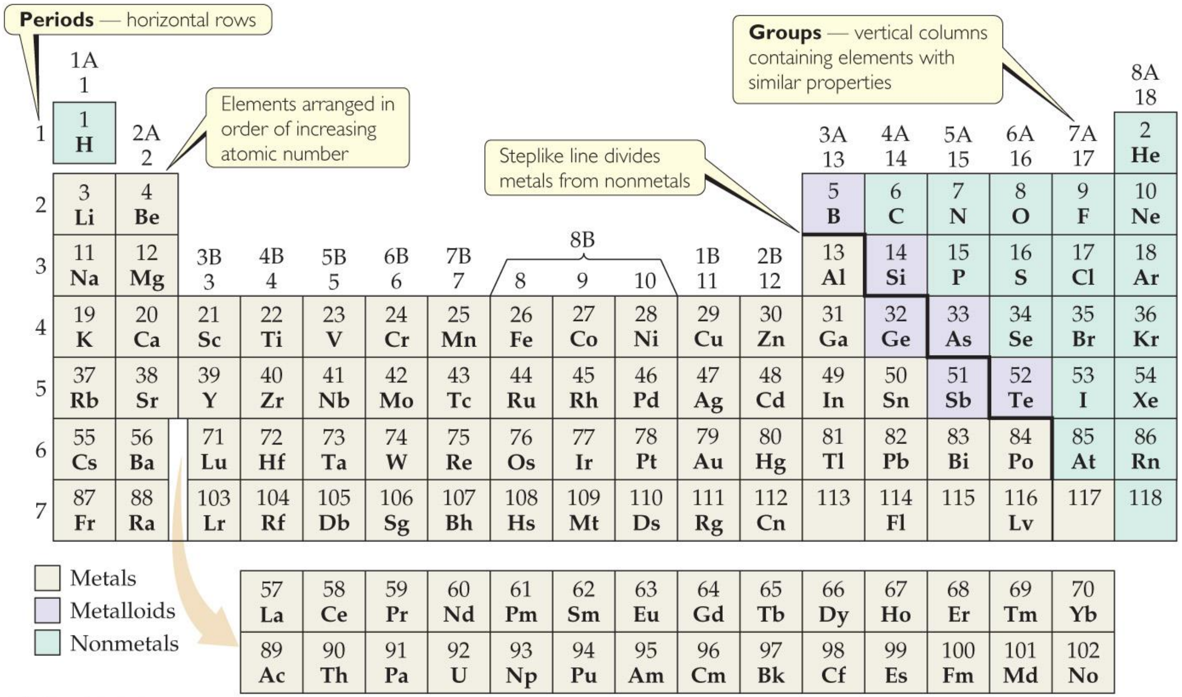
Table 2.3 Names of Some Groups in the Periodic Table

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

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



Periodic Table



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

Elements on the step like line are metalloids (except Al, Po, and At).

Metals are on the left side of the periodic table.

Some properties of metals include

- shiny luster.
- conducting heat and electricity.
- solidity (except mercury).

Which two of these elements would you expect to show the greatest similarity in chemical and physical properties: B, Ca, F, He, Mg, P?

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Solution

Elements in the same group of the periodic table are most likely to exhibit similar properties. We therefore expect Ca and Mg to be most alike because they are in the same group (2A, the alkaline earth metals).

Diatomic Molecules

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

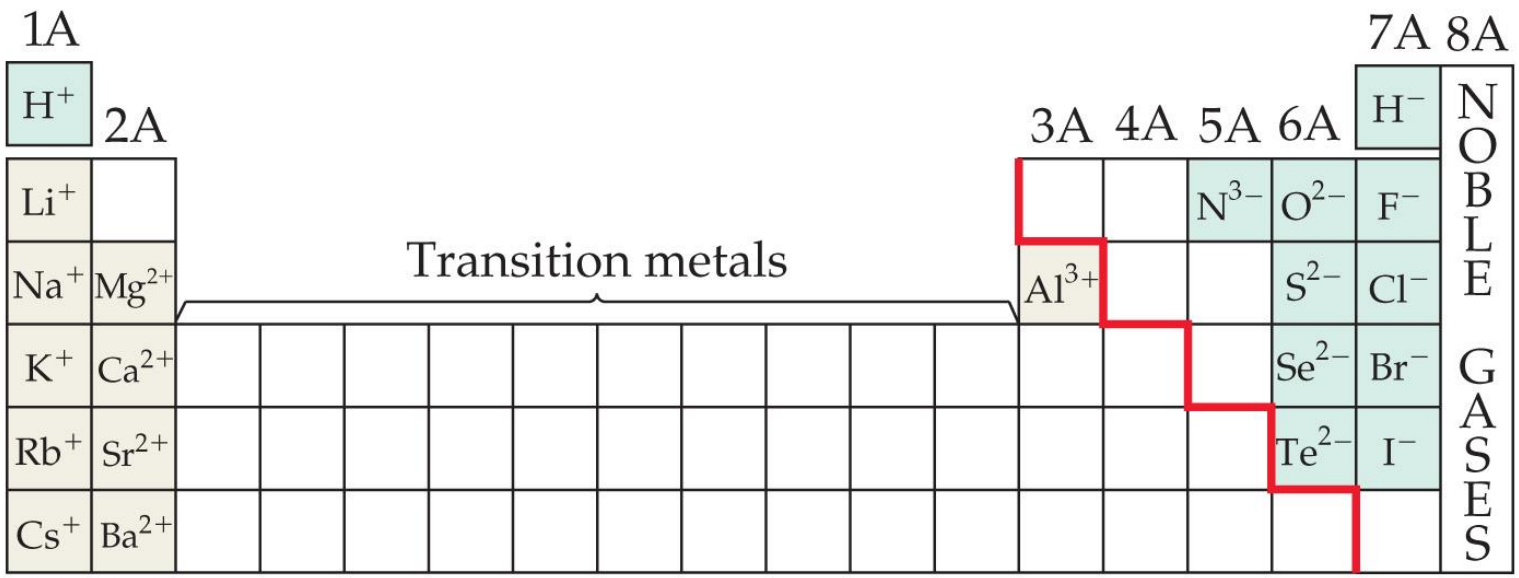
REMEMBER HONClBrIF

Types of Formulas

- **Empirical formulas** give the lowest whole-number ratio of atoms of each element in a compound. It is a mole/mole ratio
- **Molecular formulas** give the exact number of atoms of each element in a compound. It is the empirical formula multiplied by whole number
- Ex. CH_2O is the empirical formula

  $C_6H_{12}O$ is the molecular formula

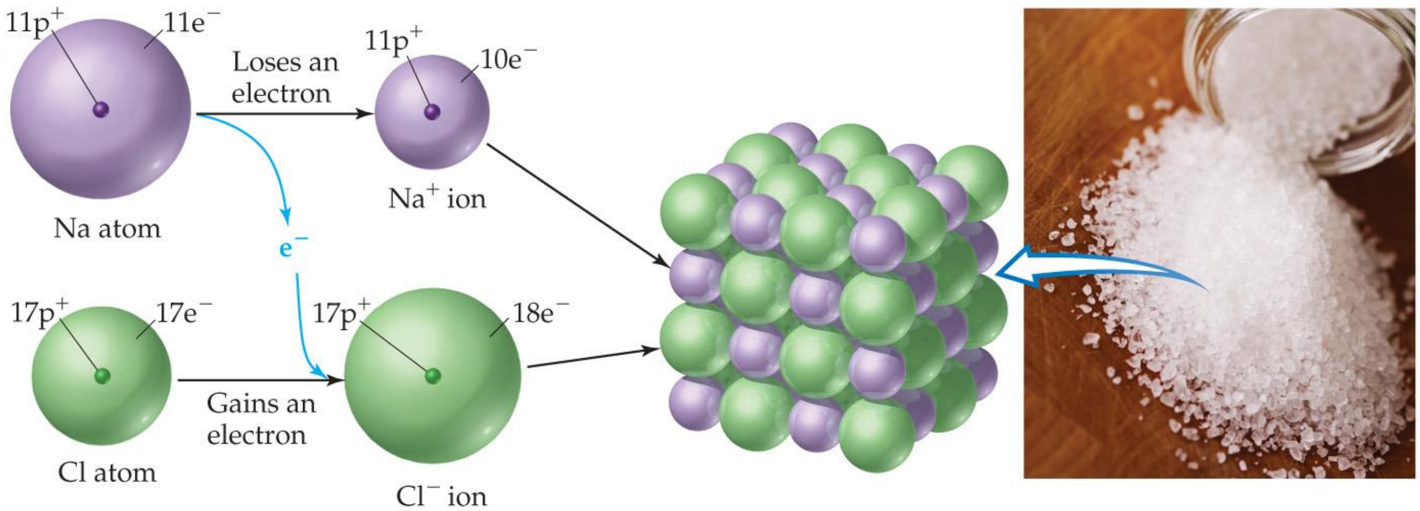
Ions



- 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.

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.



Atoms, Molecules, and Ions

Give the chemical symbol, including superscript indicating mass number, for **(a)** the ion with 22 protons, 26 neutrons, and 19 electrons; and **(b)** the ion of sulfur that has 16 neutrons and 18 electrons.

Which of these compounds would you expect to be ionic: N_2O, Na_2O, CaC_{l2}, SF_4

Solution

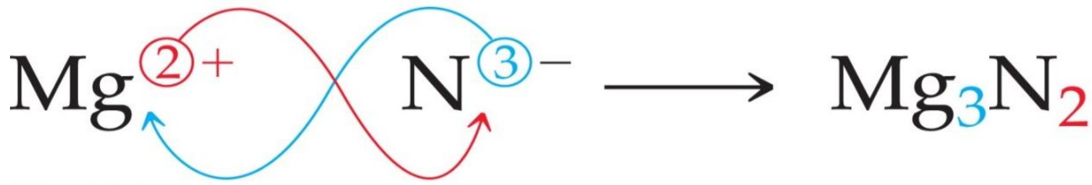
1.(a) The number of protons is the atomic number of the element. A periodic table or list of elements tells us that the element with atomic number 22 is titanium (Ti). The mass number (protons plus neutrons) of this isotope of titanium is 22 + 26 = 48. Because the ion has three more protons than electrons, it has a net charge of 3+ and is designated $^{48}Ti^{3+}$.

(b) The periodic table tells us that sulfur (S) has an atomic number of 16. Thus, each atom or ion of sulfur contains 16 protons. We are told that the ion also has 16 neutrons, meaning the mass number is 16 + 16 = 32. Because the ion has 16 protons and 18 electrons, its net charge is 2– and the ion symbol is $^{32}S^{2-}$.

Solution

We predict that Na_2O and CaC_{l2} are ionic compounds because they are composed of a metal combined with a nonmetal. We predict (correctly) that N_2O and SF_4 are molecular compounds because they are composed entirely of 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, reduce

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. (transition metals and some others like Sn and Pb)
- 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.
- When there are two oxyanions involving the same element
  - the one with more oxygens ends in ***-ate.***
  - the one with less oxygens ends in ***-ite.***
    - ClO_3^{1-} : chlorate; ClO_2^{1-} : chlorite
- The one with 2 less oxygens has the prefix ***hypo-*** and ends in ***-ite:*** ClO^{-} is hypochlorite.
- The one with one more oxygen has the prefix ***per-*** and ends in ***-ate:*** ClO_4^{-} is perchlorate.

Acid Nomenclature

Anion		Acid
________ide (chloride, Cl^-)	add H^+ ions →	hydro______ic acid (hydrochloric acid, HCl)
________ate (chlorate, ClO_3^-) (perchlorate, ClO_4^-)	add H^+ ions →	________ic acid (chloric acid, $HClO_3$) (perchloric acid, $HClO_4$)
________ite (chlorite, ClO_2^-) (hypochlorite, ClO^-)	add H^+ ions →	________ous acid (chlorous acid, $HClO_2$) (hypochlorous acid, HClO)

- 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).

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

Name the ionic compounds **(a)** K_2SO_4, **(b)** $Ba(OH)_2$, **(c)** $FeCl_3$.

Name the acids **(a)** HCN, **(b)** HNO_3, **(c)** H_2SO^4, **(d)** H_2SO_3

Name the compounds **(a)** SO_2, **(b)** PCl_5, **(c)** Cl_2O_3

1.(a) The cation is K^+, the potassium ion, and the anion is SO_4^{2-}, the sulfate ion, making the name potassium sulfate.
(If you thought the compound contained S^{2-} and O^{2-} ions, you failed to recognize the polyatomic sulfate ion.)

(b) The cation is Ba^{2+}, the barium ion, and the anion is OH^-, the hydroxide ion: barium hydroxide.

(c) You must determine the charge of Fe in this compound because an iron atom can form more than one cation. Because the compound contains three chloride ions, Cl^-, the cation must be Fe^{3+}, the iron(III), or ferric, ion. Thus, the compound is iron(III) chloride or ferric chloride.

Solution

2. (a) The anion from which this acid is derived is CN^-, the cyanide ion. Because this ion has an *-ide* ending, the acid is given a *hydro-* prefix and an *-ic* ending: hydrocyanic acid.

(b) Because NO_3^- is the nitrate ion, HNO_3 is called nitric acid (the *-ate* ending of the anion is replaced with an *-ic* ending in naming the acid).

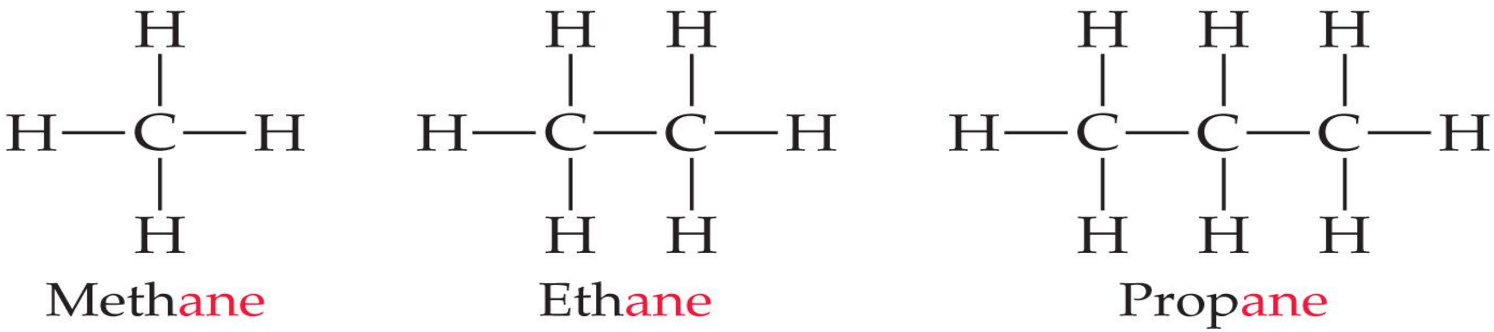
(c) Because SO_4^{2-} is the sulfate ion, H_2SO_4 is called sulfuric acid.

(d) Because SO_3^{2-} is the sulfite ion, H_2SO_3 is sulfurous acid (the *-ite* ending of the anion is replaced with an *-ous* ending).

Solution

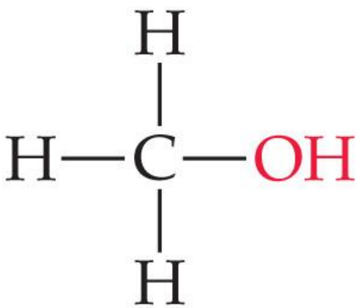
The compounds consist entirely of nonmetals, so they are molecular rather than ionic. Using the prefixes in Table 2.6, we have **(a)** sulfur dioxide, **(b)** phosphorus pentachloride, **(c)** dichlorine trioxide.

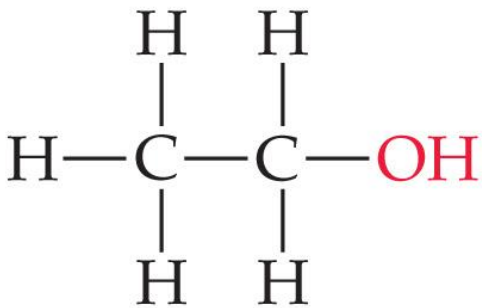
Nomenclature of Organic Compounds

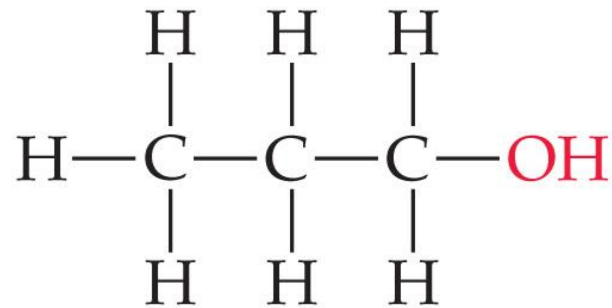


- **Organic chemistry** is the study of carbon.
- Organic chemistry has its own system of nomenclature.
- The simplest hydrocarbons (compounds containing only carbon and hydrogen) are **alkanes**. They have only single bonds.
- The first part of the names just listed correspond to the number of carbons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

Nomenclature of Organic Compounds


Methanol


Ethanol


1-Propanol

- 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*.