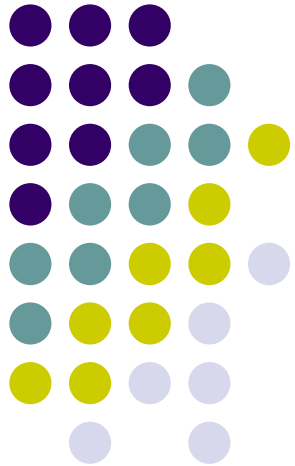
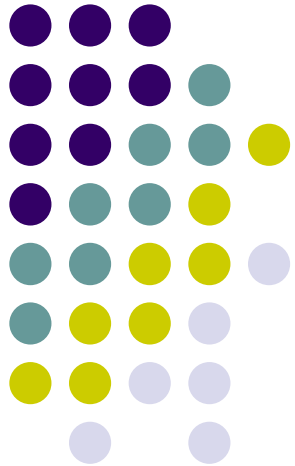
Chapter 2
Atoms, Molecules & Ions

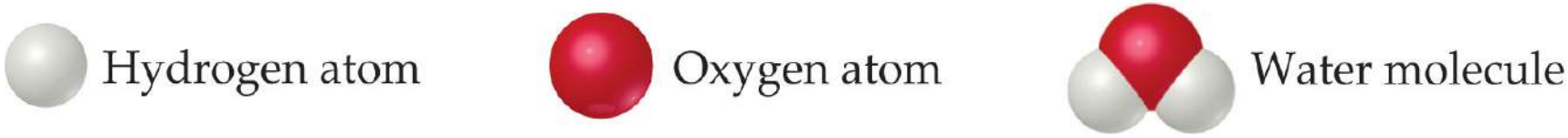


2.1 The Atomic Theory of Matter



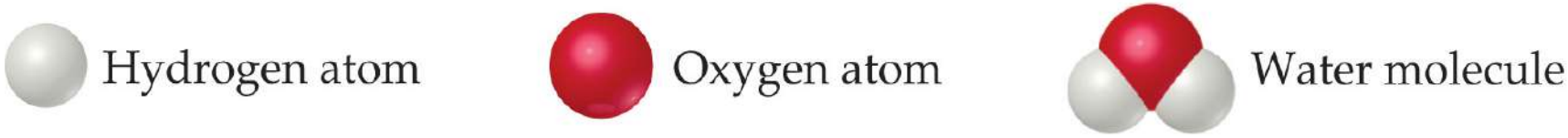
Atomic Theory of Matter

The theory that atoms are the fundamental building blocks of matter reemerged in the early 19th century, championed by John Dalton.



Dalton's Postulates

Each element is composed of extremely small particles called atoms.



Dalton's Postulates

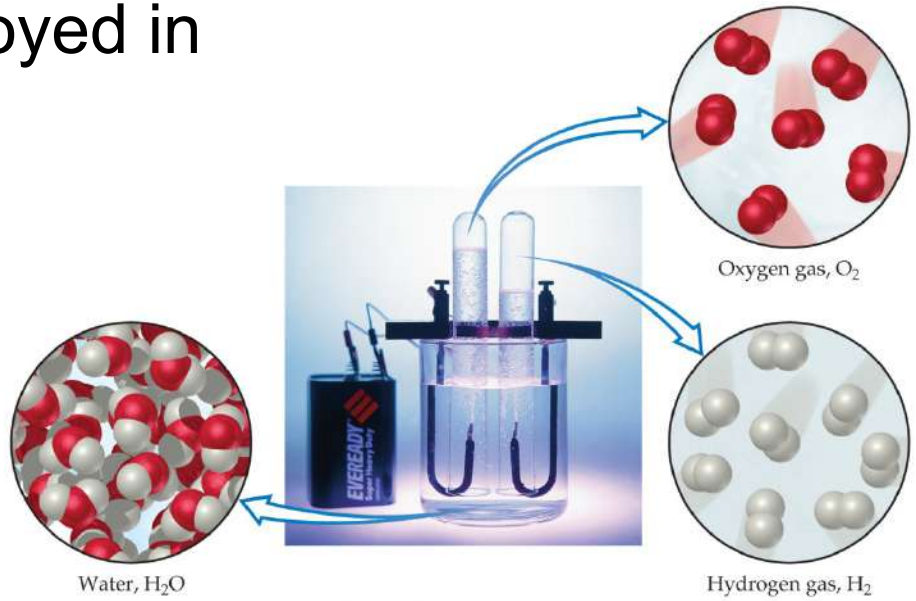
All atoms of a given element are identical to one another in mass and other properties, but the atoms of one element are different from the atoms of all other elements.

Oxygen molecule  (written O_2)

Hydrogen molecule  (written H_2)

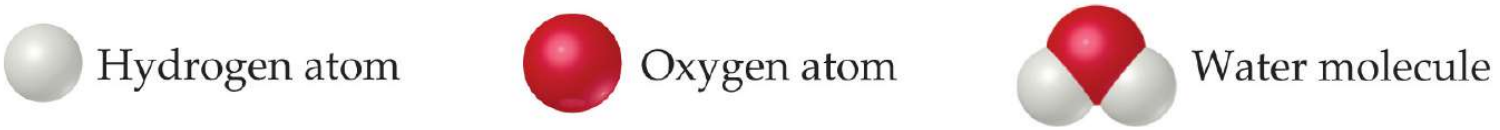
Dalton's Postulates

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.



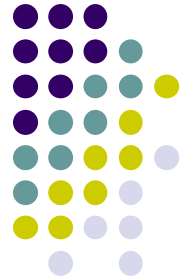
Dalton's Postulates

Compounds are formed when atoms of more than one element combine; a given compound always has the same relative number and kind of atoms.



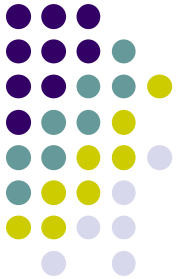
Law of Constant Composition

***Joseph Proust* (1754–1826)**



- This is also known as the law of definite proportions.
- It states that the elemental composition of a pure substance never varies.

Law of Conservation of Mass

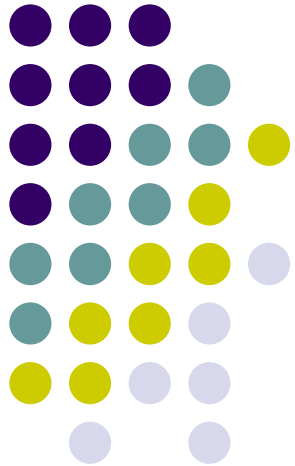


The total mass of substances present at the end of a chemical process is the same as the mass of substances present before the process took place.

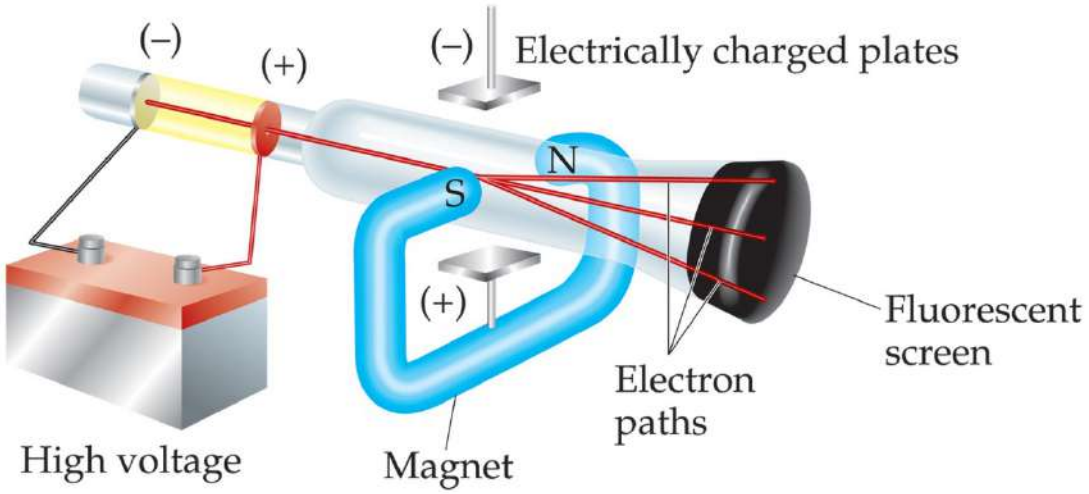
p.39 GIST

- One compound of carbon and oxygen contains 1.333 g of oxygen per gram of carbon, whereas a second compound contains 2.666 g of oxygen per gram of carbon.
  - A) What chemical law do these data illustrate?
  - B) If the first compound has an equal number of oxygen and carbon atoms, what can we conclude about the composition of the second compound?

2.2 The Discovery of Atomic Structure

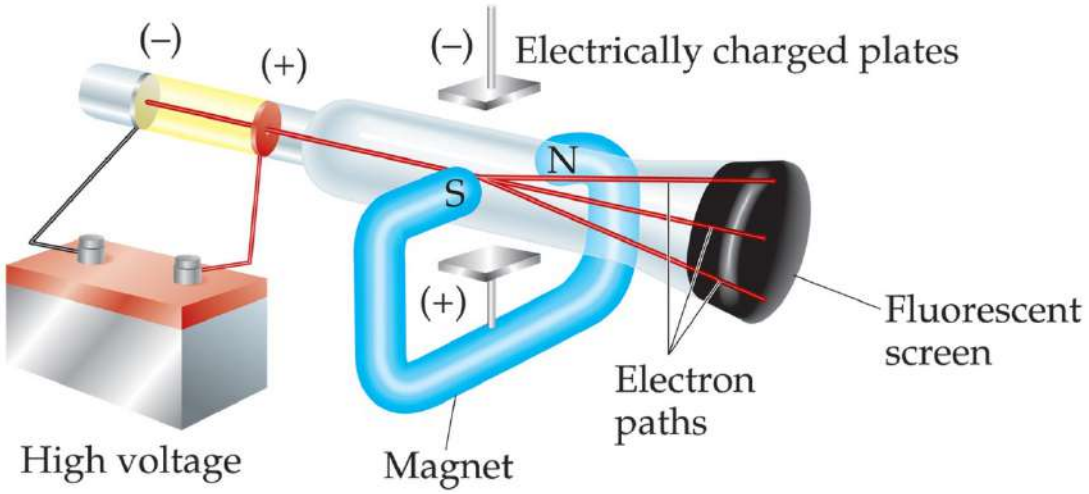


The Electron



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

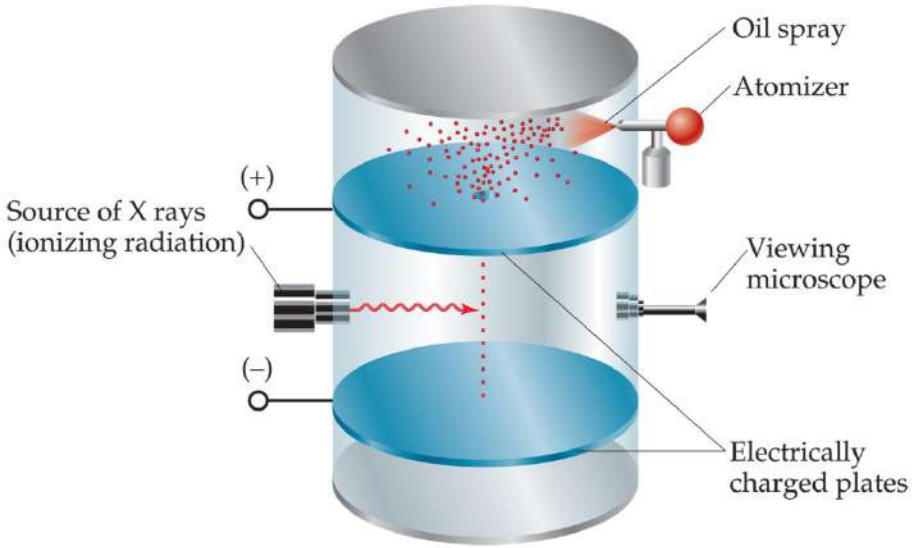
The Electron



Thompson measured the charge/mass ratio of the electron to be 1.76×10^8 coulombs/g.

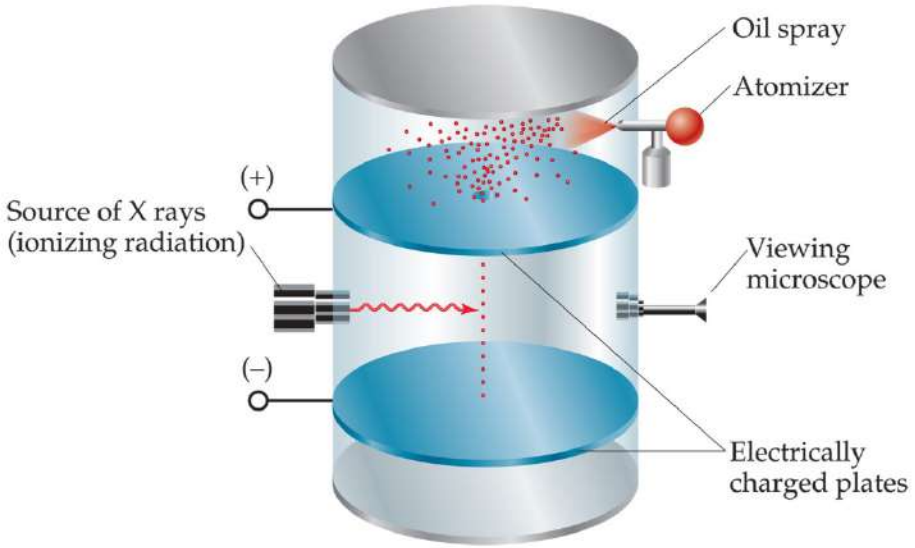
Millikan Oil Drop Experiment

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.

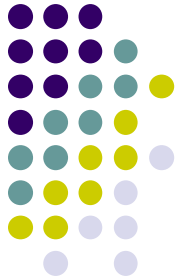


Millikan Oil Drop Experiment

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



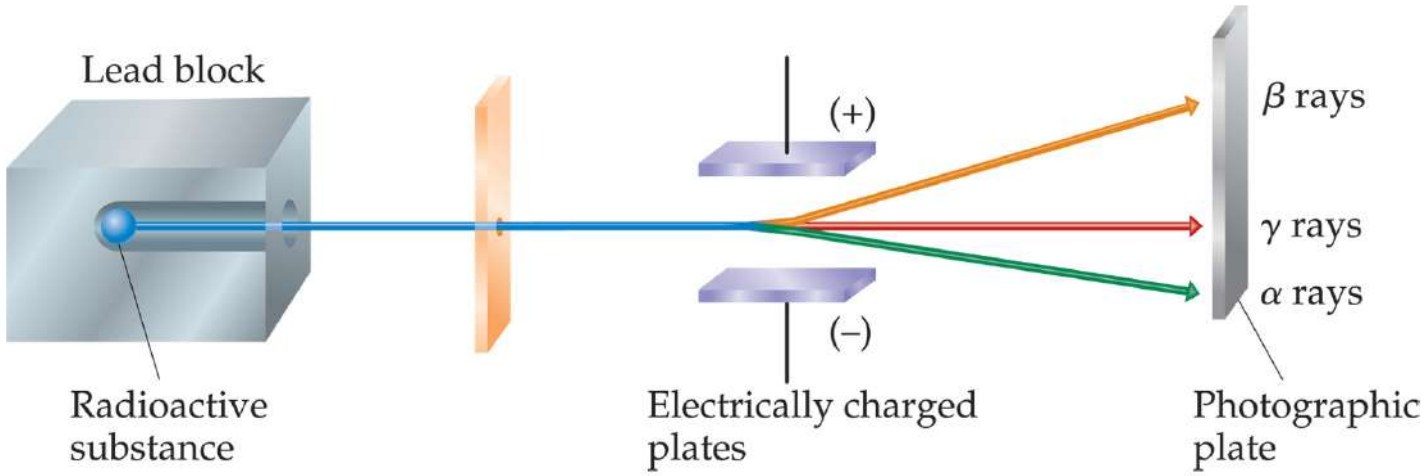
Radioactivity



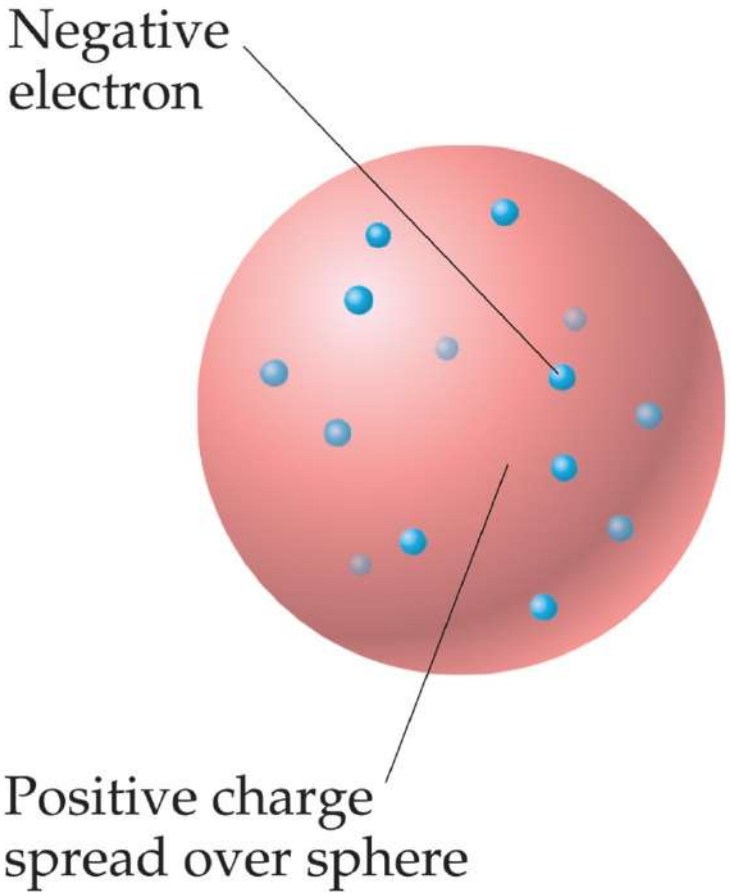
- Radioactivity is the spontaneous emission of radiation by an atom.
- It was first observed by Henri Becquerel.
- Marie and Pierre Curie also studied it.

Radioactivity

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

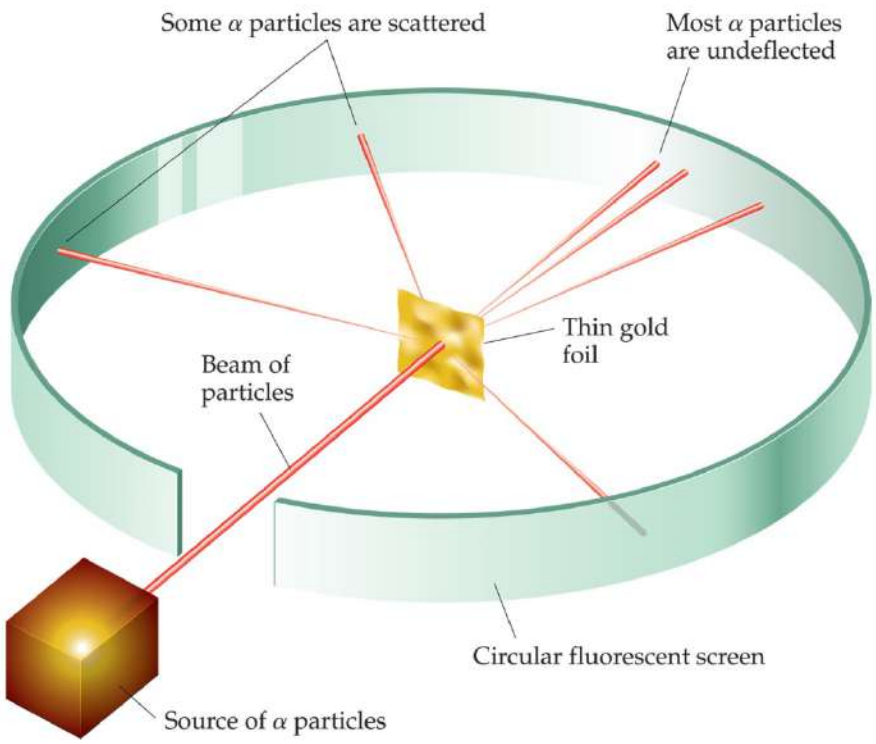


The Atom, circa 1900



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

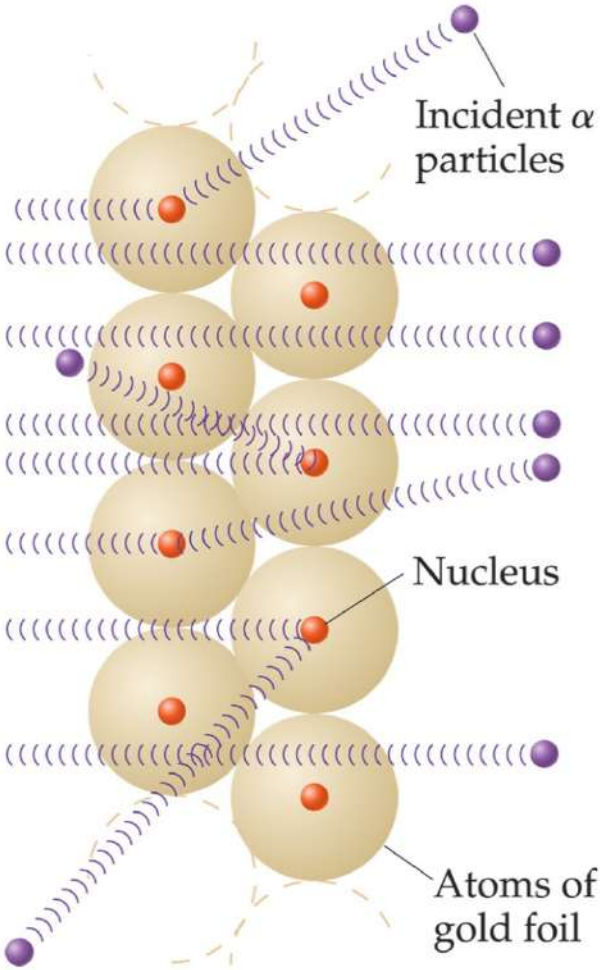
Discovery of the Nucleus



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

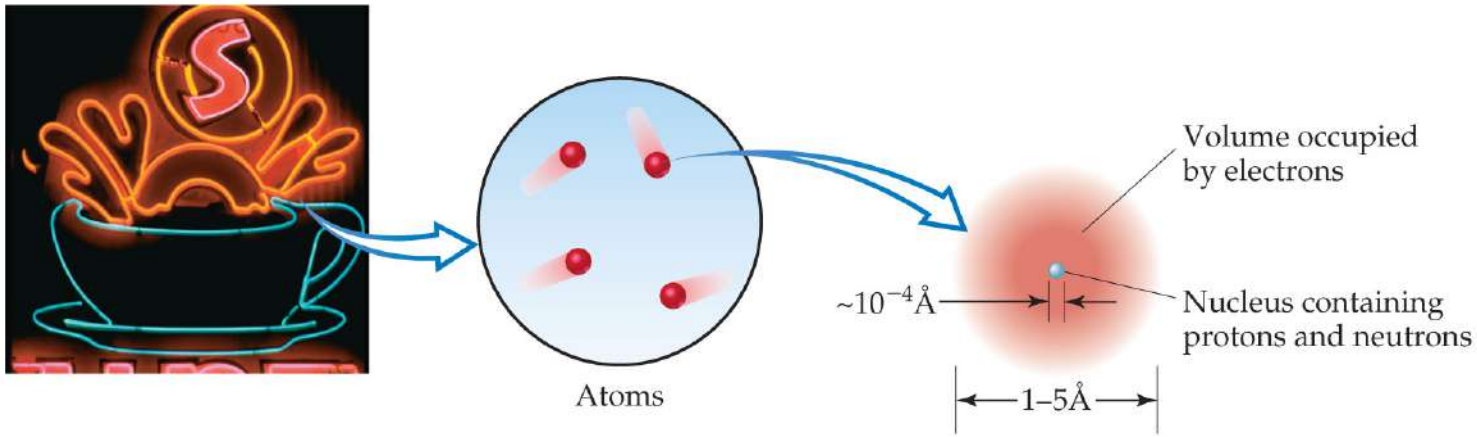
The Nuclear Atom

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

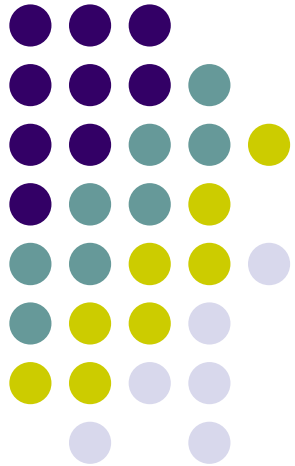


The Nuclear Atom

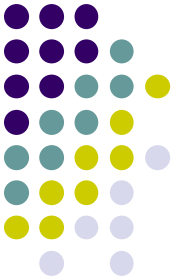
- Rutherford postulated a very small, dense nucleus with the electrons around the outside of the atom.
- Most of the volume of the atom is empty space.



2.3 The Modern View of Atomic Structure



Other Subatomic Particles



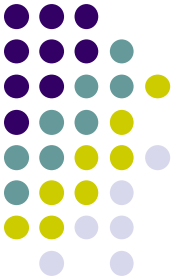
- Protons were discovered by Rutherford in 1919.
- Neutrons were discovered by James Chadwick in 1932.

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.

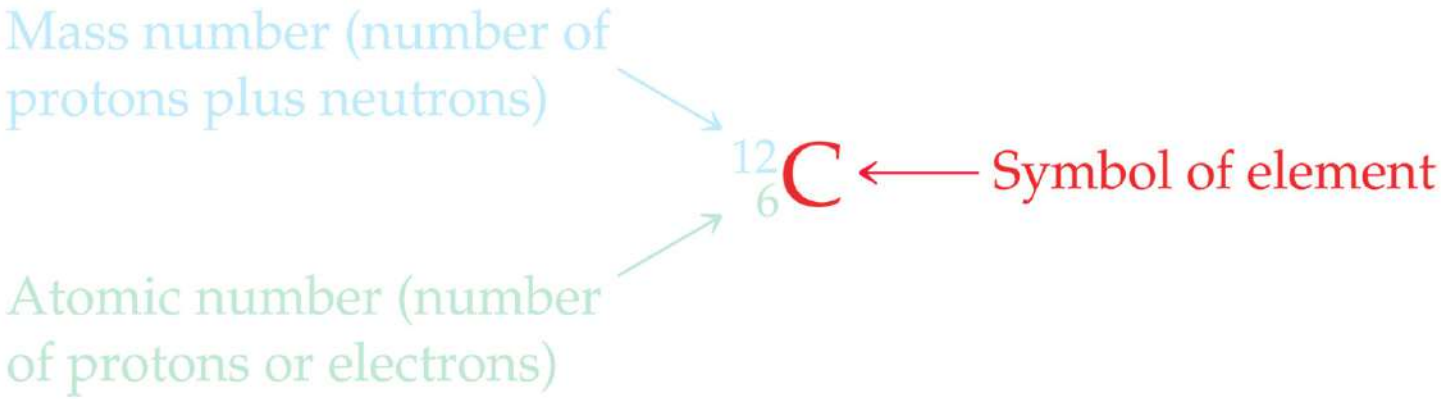
Particle	Charge	Mass (amu)
Proton	Positive (1+)	1.0073
Neutron	None (neutral)	1.0087
Electron	Negative (1−)	5.486×10^{-4}

Sample Exercise 2.1



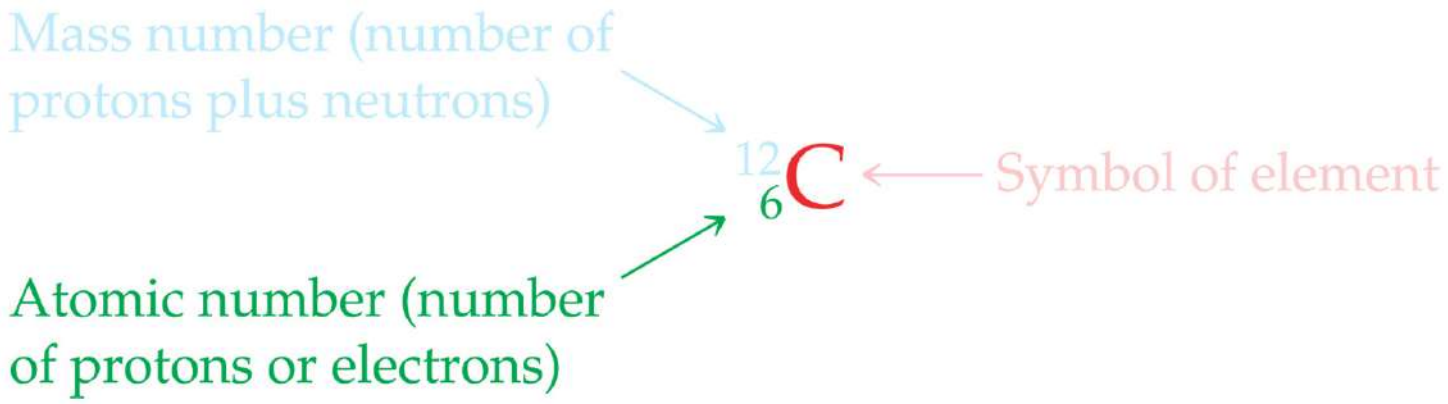
- The diameter of a US penny is 19 mm. The diameter of a silver atom, by comparison, is only 2.88 Å. How many silver atoms could be arranged side by side in a straight line across the diameter of a penny?
- The diameter of a carbon atom is 1.54 Å. Express this diameter in picometers. How many carbon atoms could be aligned side by side in a straight line across the width of a pencil line that is 0.20 mm wide?

Symbols of Elements



Elements are symbolized by one or two letters.

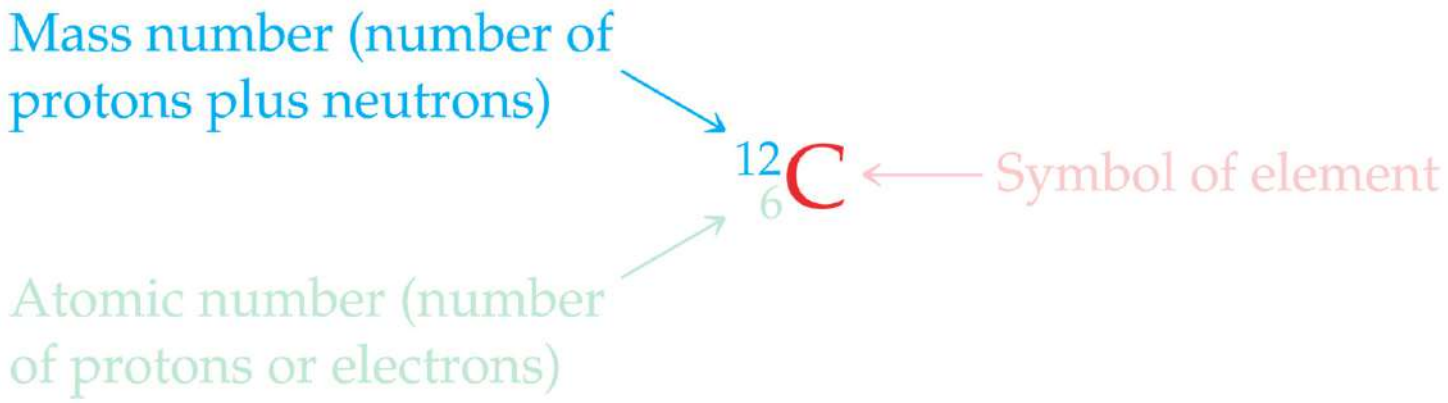
Atomic Number



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

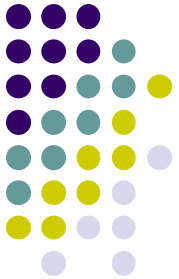
- Isotopes are atoms of the same element with different masses.
- Isotopes have different numbers of neutrons.

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

Sample Exercise 2.2

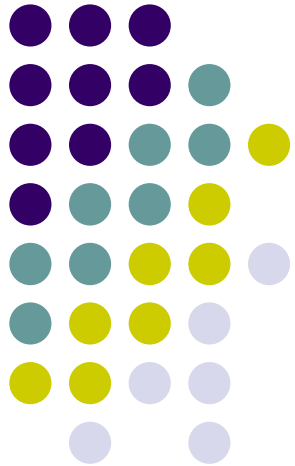
- How many protons, neutrons, and electrons are in:
  - A) an atom of ^{197}Au?
  - B) an atom of strontium-90?
  - C) a ^{138}Ba atom?
  - D) an atom of phosphorus-31?

Sample Exercise 2.3

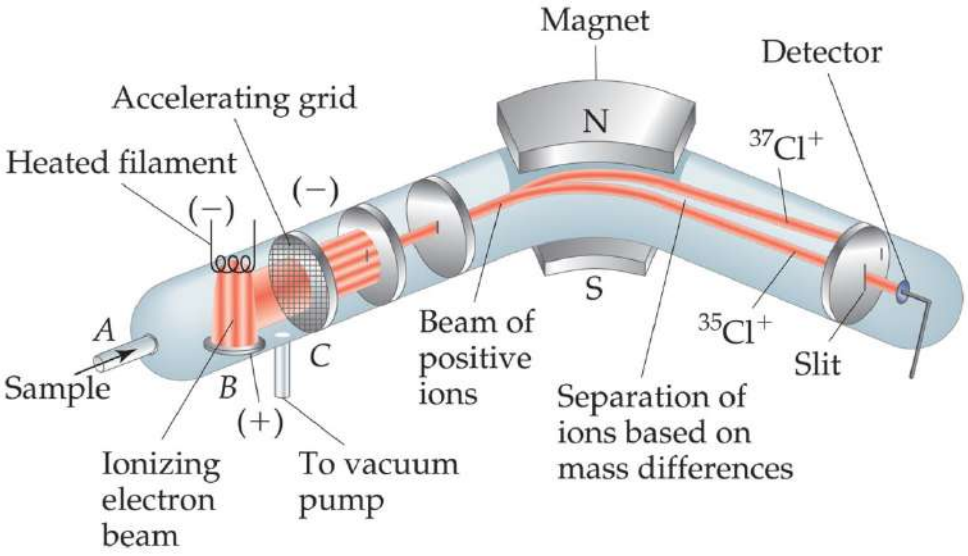


- Magnesium has three isotopes, with mass numbers 24, 25, and 26. Write the complete chemical symbol for each of them. How many neutrons are in an atom of each isotope?
- Give the complete chemical symbol for the atom that contains 82 protons, 82 electrons and 126 neutrons.

2.4 Atomic Weights

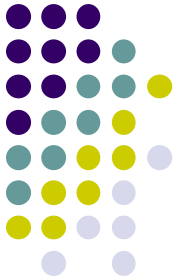


Atomic Mass



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

Average Mass



- 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.

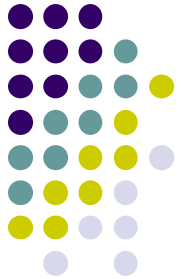
p.47 GIST

- A particular atom of chromium has a mass of 52.94 amu, whereas the atomic weight of chromium is 51.99 amu. Explain the difference in the two masses.

Sample Exercise 2.4

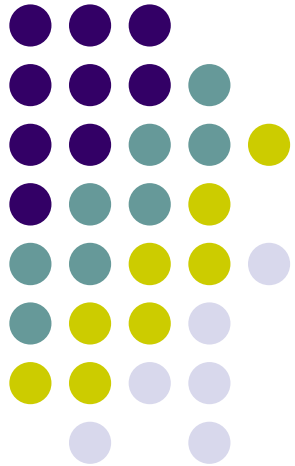
- Naturally occuring chlorine is 75.78% ^{35}Cl, which has an atomic mass of 34.969 amu, and 24.22% ^{37}Cl, which has an atomic mass of 36.966 amu. Calculate the average atomic mass of chlorine.

Average Atomic Mass Practice

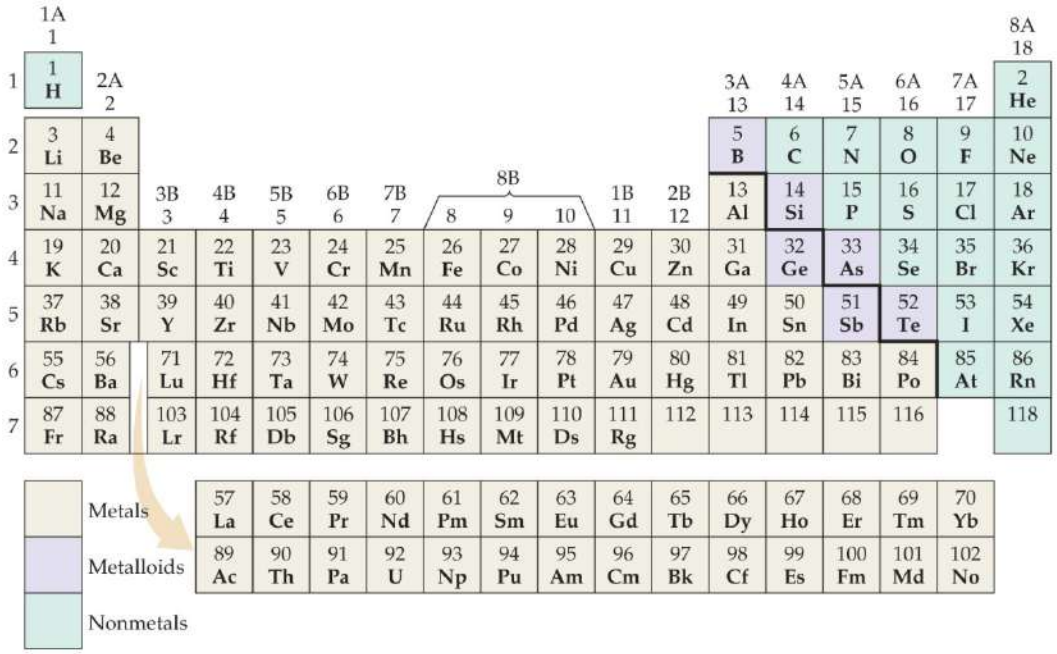


- Three isotopes of silicon occur in nature: ^{28}Si (92.23%), which has an atomic mass of 27.97693 amu; ^{29}Si (4.68%), which has an atomic mass of 28.97649 amu; and ^{30}Si (3.09%) which has an atomic mass of 29.97377 amu. Calculate the atomic weight of silicon.

2.5 The Periodic Table

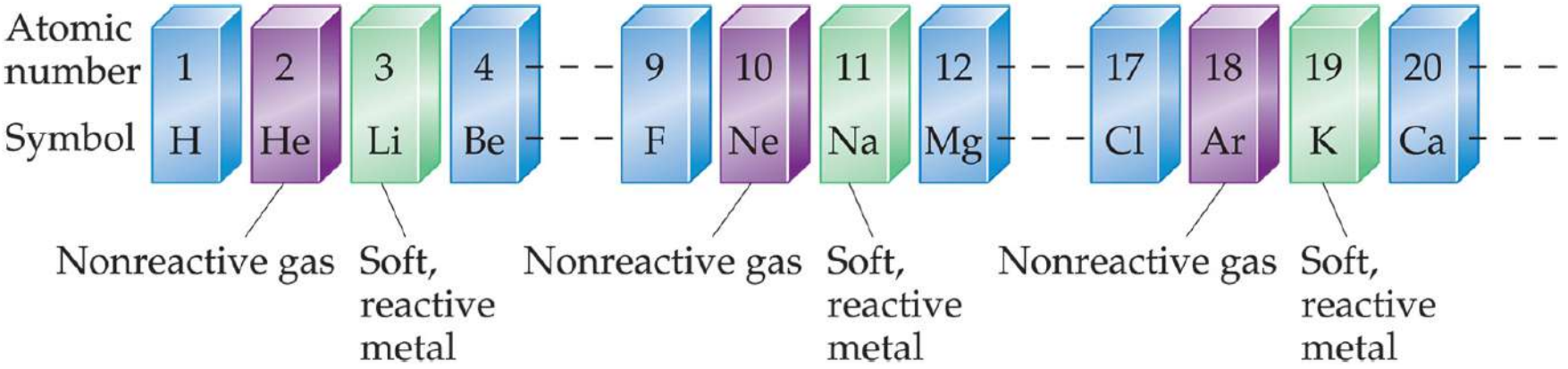


Periodic Table



- It is a systematic catalog of the elements.
- Elements are arranged in order of atomic number.

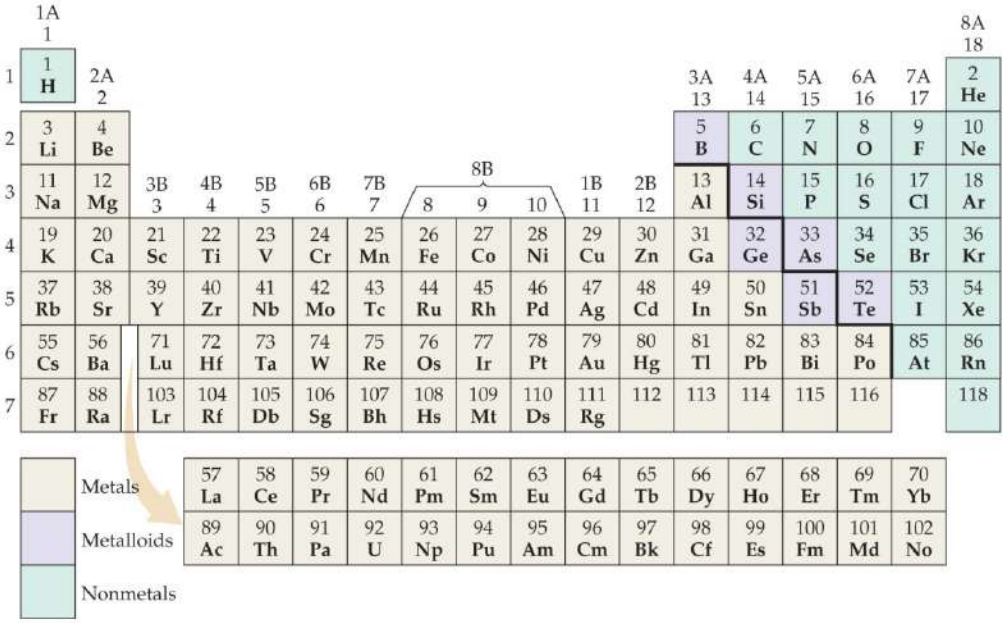
Periodicity



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.

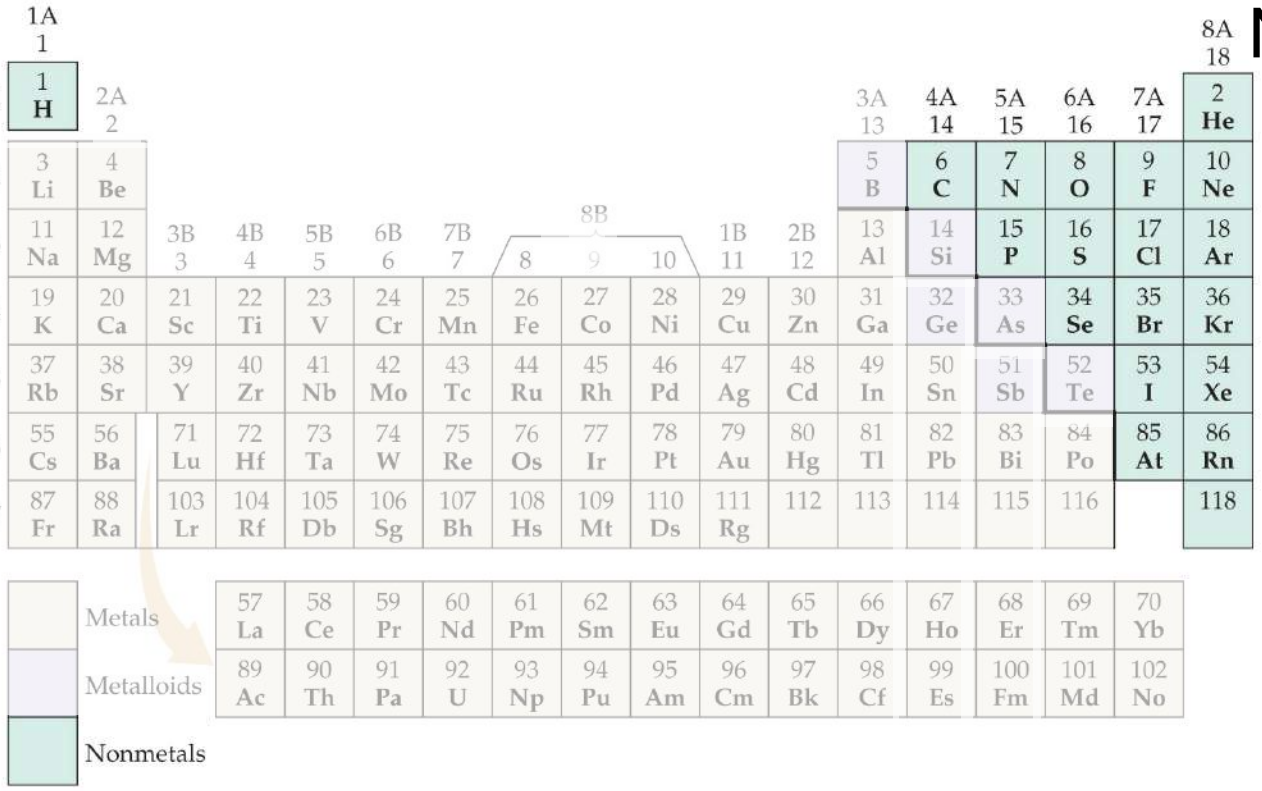


Groups

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

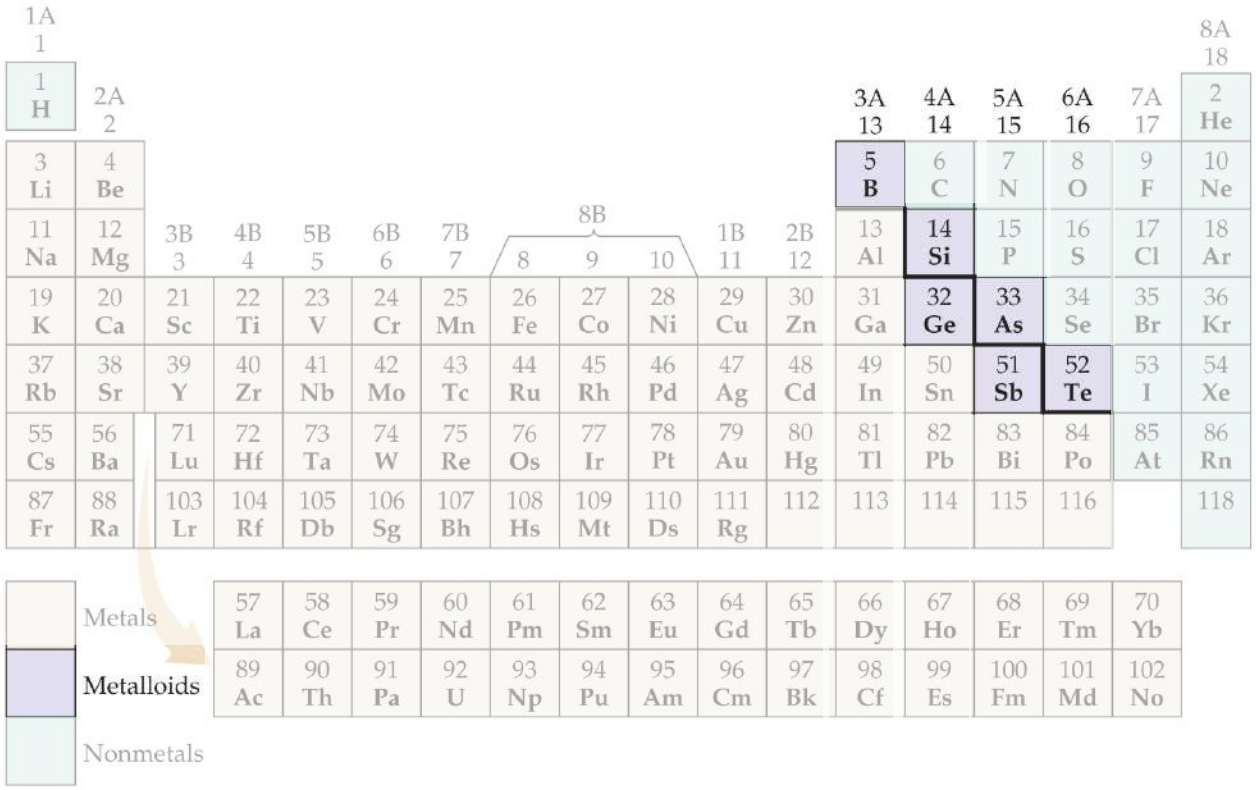
These five groups are known by their names.

Periodic Table



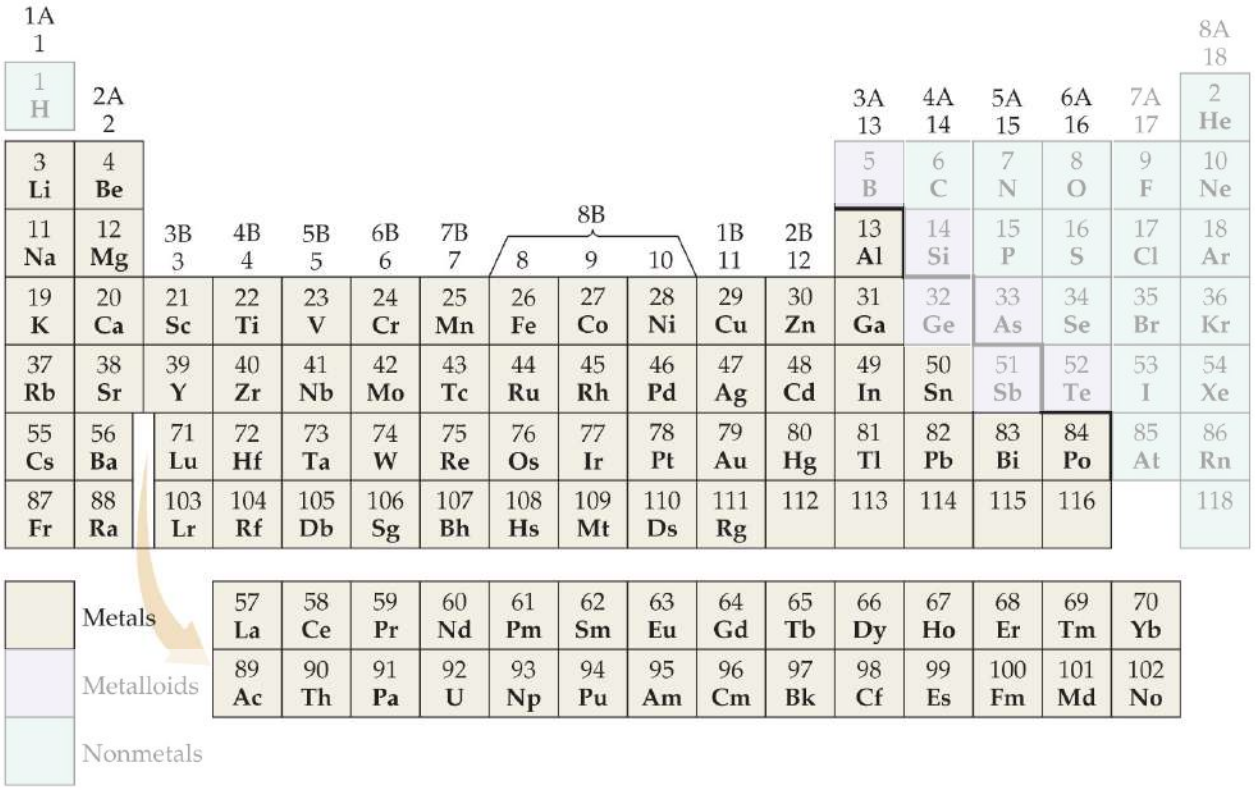
Nonmetals are on the right side of the periodic table (with the exception of H).

Periodic Table



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

Periodic Table

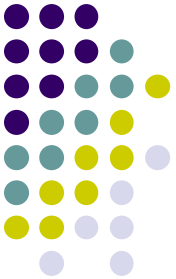


Metals are on the left side of the chart.

p.51 GIST

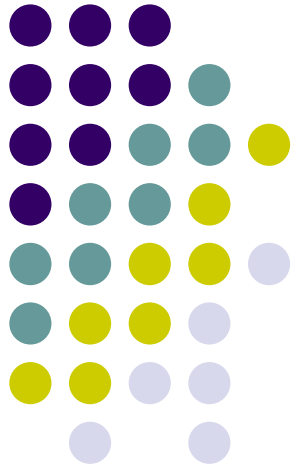
- Chlorine is a halogen. Locate this element on the periodic table.
  - A) What is its symbol?
  - B) In what period and in what group is the element located?
  - C) What is its atomic number?
  - D) Is it a metal, nonmetal or metalloid?

Sample Exercise 2.5

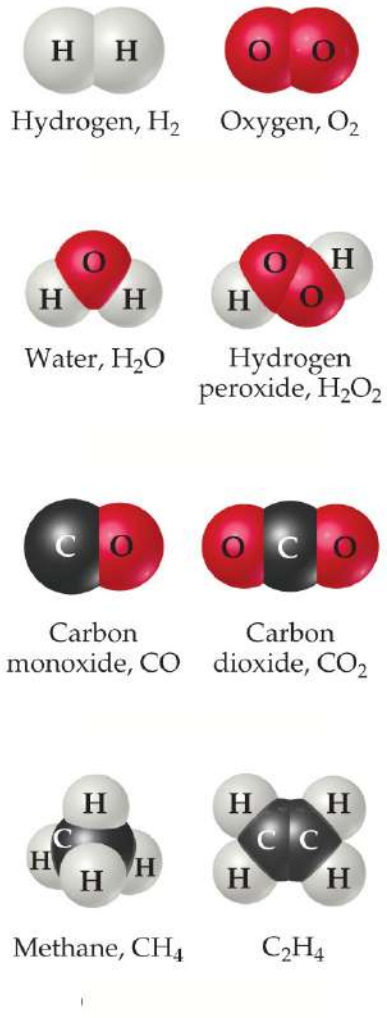


- Which of the following elements would you expect to show the greatest similarity in chemical and physical properties: B, Ca, F, He, Mg, P?
- Locate Na and Br on the periodic table. Give the atomic number of each, and label each as a metal, metalloid, or nonmetal.

2.6 Molecules and Molecular Compounds

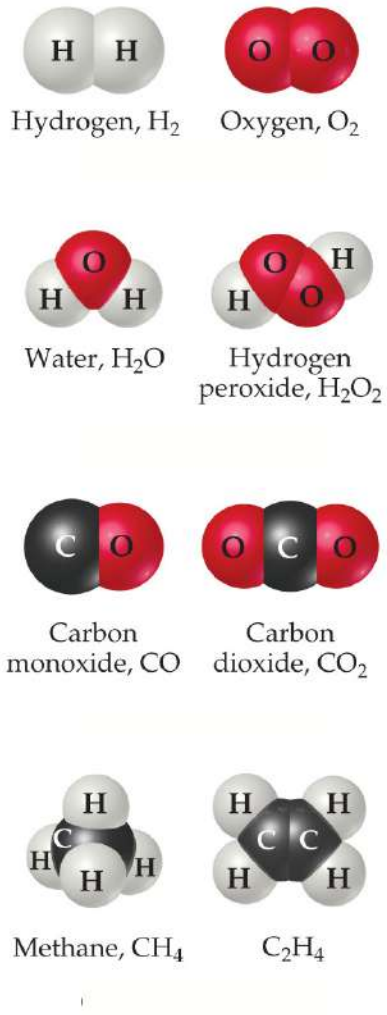


Chemical Formulas



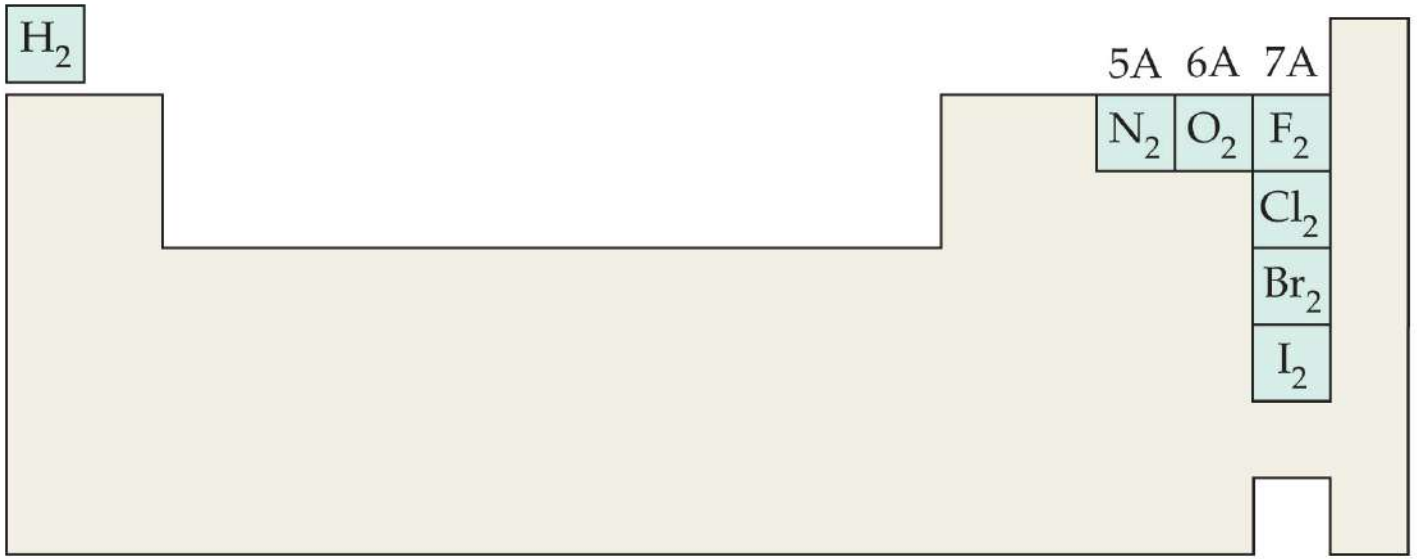
The subscript to the right of the symbol of an element tells the number of atoms of that element in one molecule of the compound.

Chemical Formulas



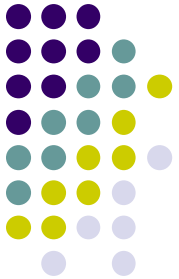
Molecular compounds are composed of molecules and almost always contain only nonmetals.

Diatomic Molecules



These seven elements occur naturally as molecules containing two atoms.

Types of Formulas

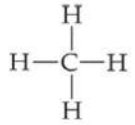


- Empirical formulas give the lowest whole-number ratio of atoms of each element in a compound.
- Molecular formulas give the exact number of atoms of each element in a compound.

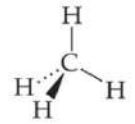
Empirical and Molecular Formula Practice

- Write the empirical formula for:
  - A) glucose ($C_6H_{12}O_6$)
  - B) nitrous oxide (laughing gas, N_2O)
  - C) diborane (B_2H_6)

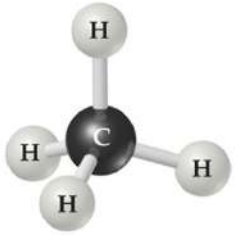
Types of Formulas



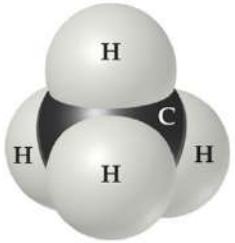
Structural formula



Perspective drawing



Ball-and-stick model

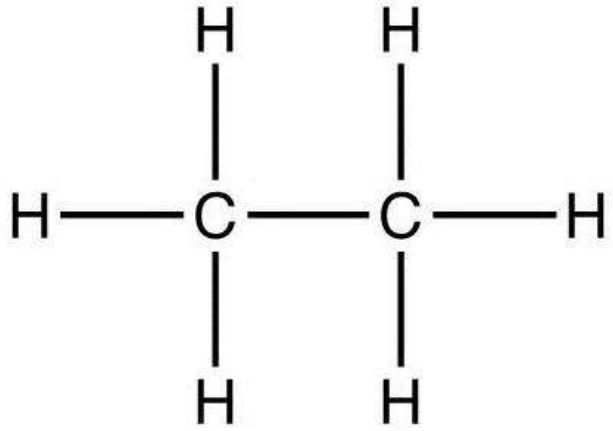


Space-filling model

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

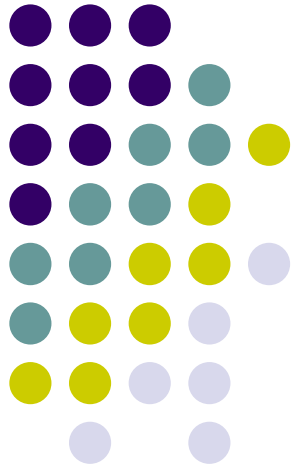
p.54 GIST

- The structural formula for ethane is shown here:

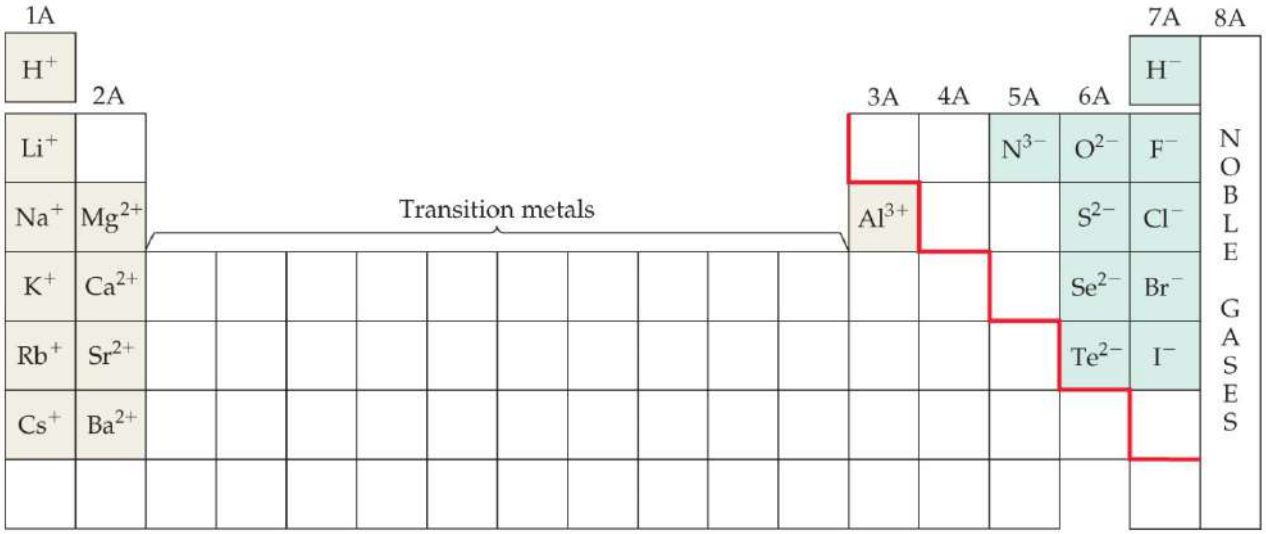


- A) What is the molecular formula for ethane?
- B) What is its empirical formula?
- C) What kind of molecular model would most clearly show the angles between atoms?

2.7 Ions and Ionic Compounds

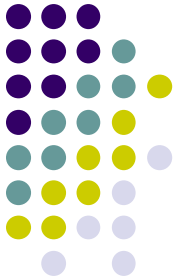


Ions



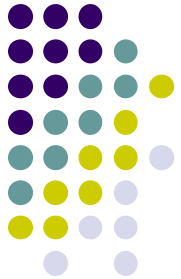
- When atoms lose or gain electrons, they become ions.
  - Cations are positive and are formed by elements on the left side of the periodic chart.
  - Anions are negative and are formed by elements on the right side of the periodic chart.

Ion Symbols Practice



- Give the chemical symbol for:
  - A) Ion with 22 protons, 26 neutrons, and 19 electrons
  - B) Ion of sulfur that has 16 neutrons and 18 electrons
- How many protons, neutrons and electrons does the $^{79}Se^{2-}$ ion have?

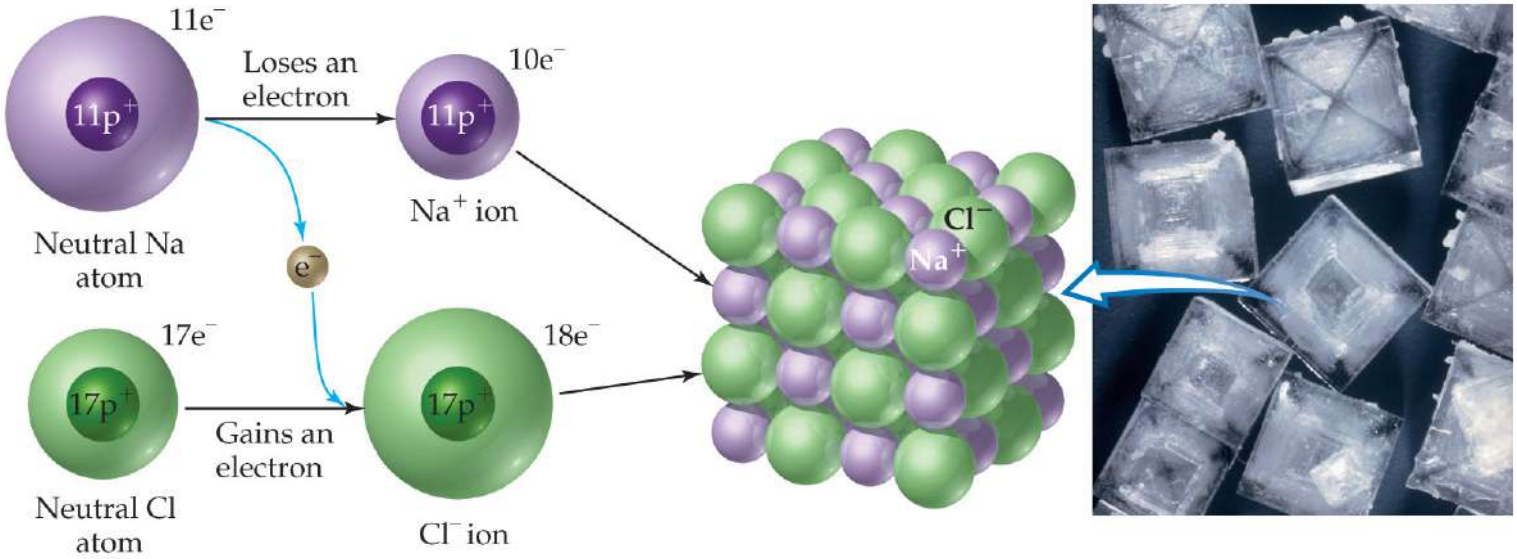
Sample Exercise 2.8



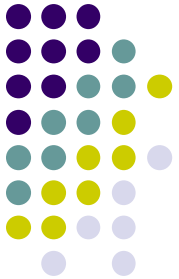
- Predict the charge for the most stable ion of barium and for the most stable ion of oxygen.
- Predict the charge for the most stable ion of aluminum and of fluorine.

Ionic Bonds

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

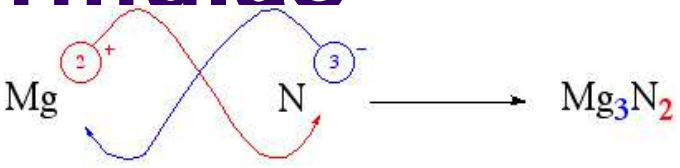


Ionic or molecular compounds?



- CBr_4
- FeS
- P_4O_6
- PbF_2
- N_2O
- Na_2O
- $CaCl_2$
- SF_4

Writing Formulas

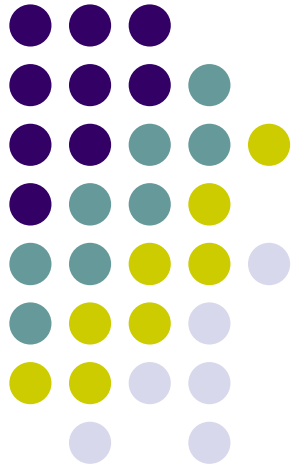


- Because compounds are electrically neutral, one can determine the formula of a compound this way:
  - The charge on the cation becomes the subscript on the anion.
  - The charge on the anion becomes the subscript on the cation.
  - If these subscripts are not in the lowest whole-number ratio, divide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

Ionic Formulas Practice

- Write formulas for the following ions:
  - Na^{+} and PO_4^{3-}
  - Zn^{2+} and SO_4^{2-}
  - Fe^{3+} and CO_3^{2-}
  - Al^{3+} and Cl^{-}
  - Al^{3+} and O^{2-}
  - Mg^{2+} and NO_3^{-}

2.8 Naming Inorganic Compounds



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	**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**

* The most common ions are in boldface.

Inorganic Nomenclature

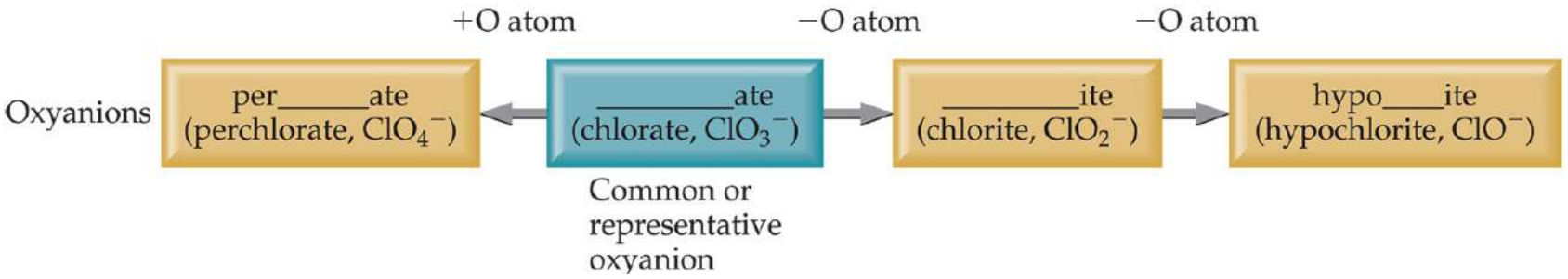
- Write the name of the cation.
- If the anion is an element, change its ending to -*ide*; if the anion is a polyatomic ion, simply write the name of the polyatomic ion.
- If the cation can have more than one possible charge, write the charge as a Roman numeral in parentheses.

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

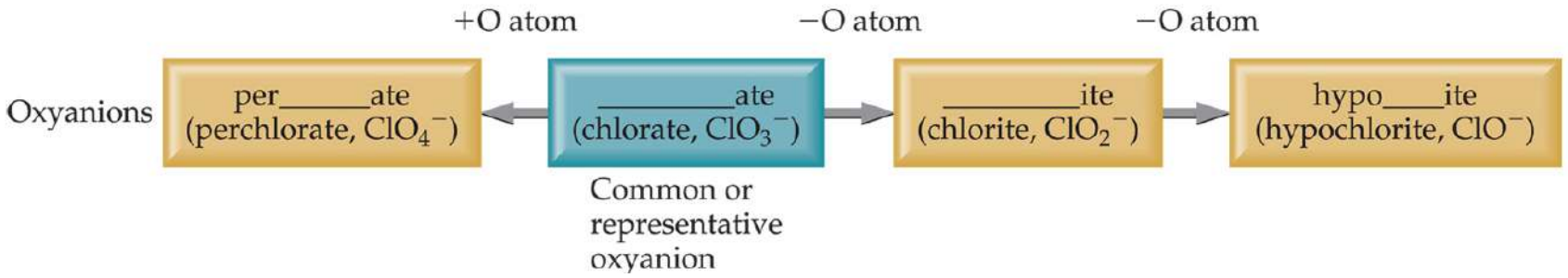
Patterns in Oxyanion Nomenclature

- 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



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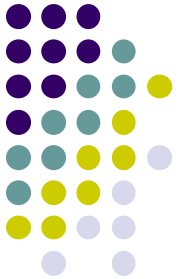
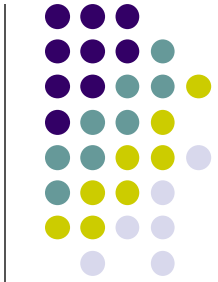
- GIST: Predict the formulas for the borate ion and silicate ion.
- SE 2.11: Based on the formula for the sulfate ion, predict the formula for the selenate ion and the selenite ion.
- PE: The formula for the bromate ion is analogous to that for the chlorate ion. Write the formula for the hypobromite and perbromate ions.

Sample Exercises 2.12 & 2.13



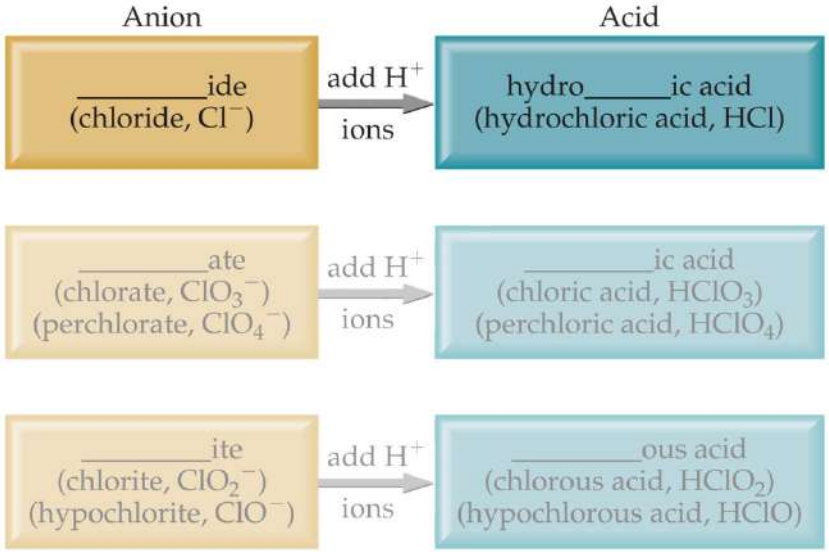
- Name the following compounds:
  - A) K_2SO_4
  - B) $Ba(OH)_2$
  - C) $FeCl_3$
- Write the chemical formulas for the following compounds:
  - A) potassium sulfide
  - B) calcium hydrogen carbonate
  - C) nickel (II) perchlorate

Ionic Names and Formulas Practice



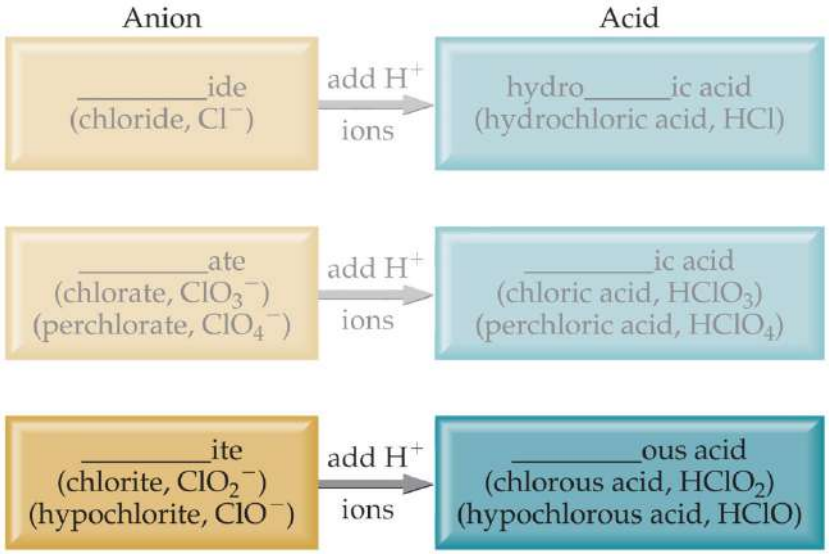
- Name the following:
  - NH_4Br
  - Cr_2O_3
  - $Co(NO_3)_2$
- Write formulas for:
  - Magnesium sulfate
  - Silver sulfide
  - Lead (II) nitrate

Acid Nomenclature



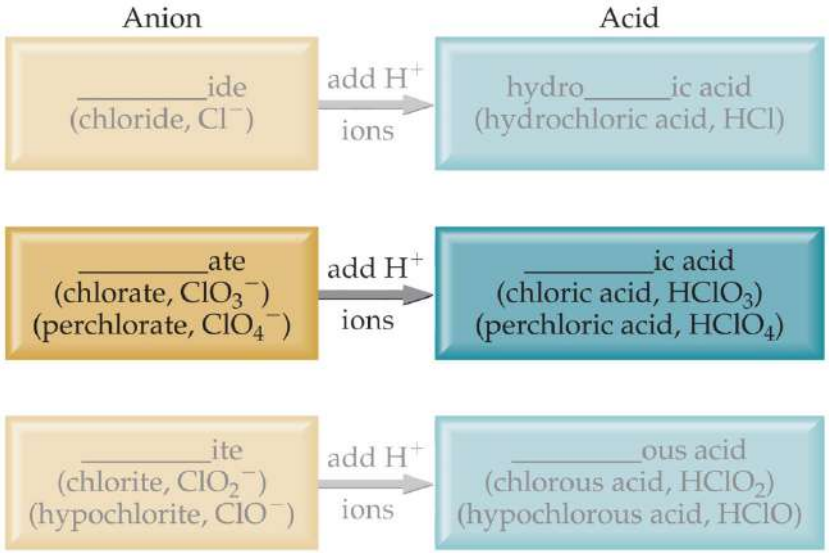
- If the anion in the acid ends in -*ide*, change the ending to -*ic acid* and add the prefix *hydro*- .
  - HCl: hydrochloric acid
  - HBr: hydrobromic acid
  - HI: hydroiodic acid

Acid Nomenclature



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

- Name the following acids:
  - HCN
  - HNO_3
  - H_2SO_4
  - H_2SO_3
- Write formulas for the following acids:
  - Hydrobromic acid
  - Carbonic 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*
Tetra-	*4*
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

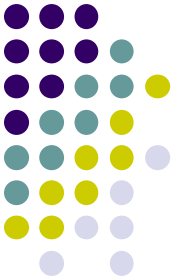
Nomenclature of Binary Compounds

Prefix	Meaning
Mono-	*1*
Di-	*2*
Tri-	*3*
Tetra-	*4*
Penta-	*5*
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.

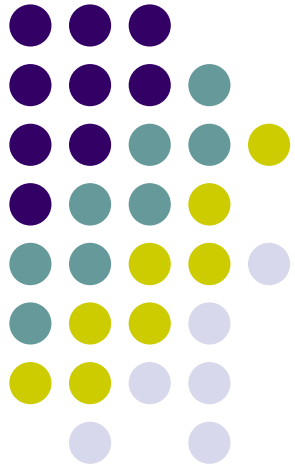
N_2O_5: dinitrogen pentoxide

Molecular Compound Nomenclature Practice

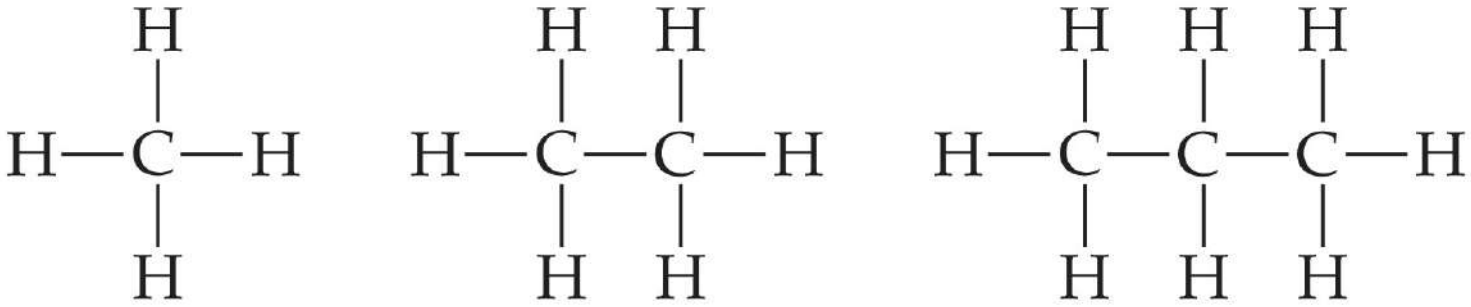


- Name the following compounds
  - SO_2
  - PCl_5
  - N_2O_3
- Write the chemical formula for:
  - Silicon tetrabromide
  - Disulfur dichloride

2.9 Some Simple Organic Compounds

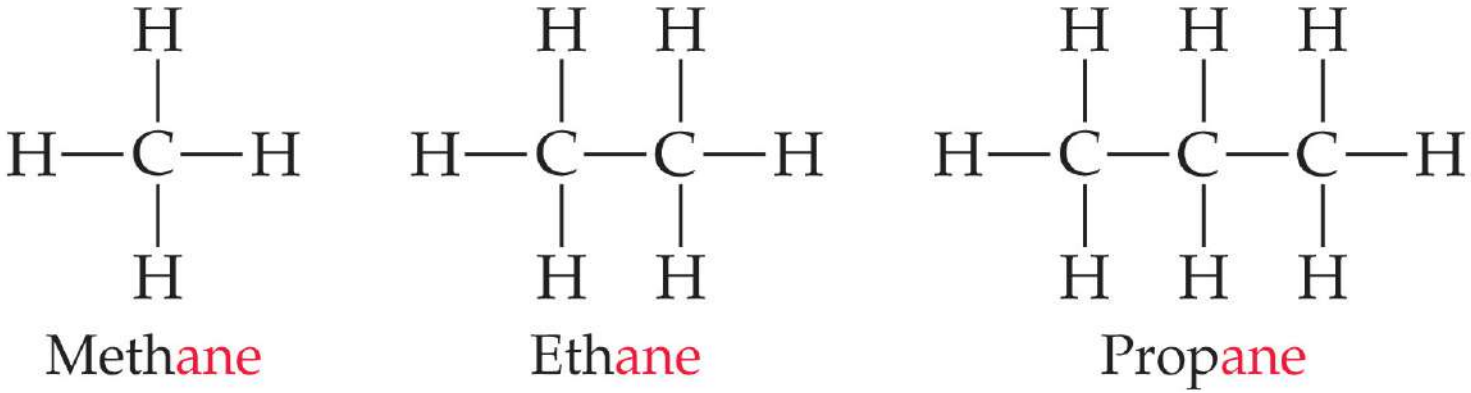


Nomenclature of Organic Compounds



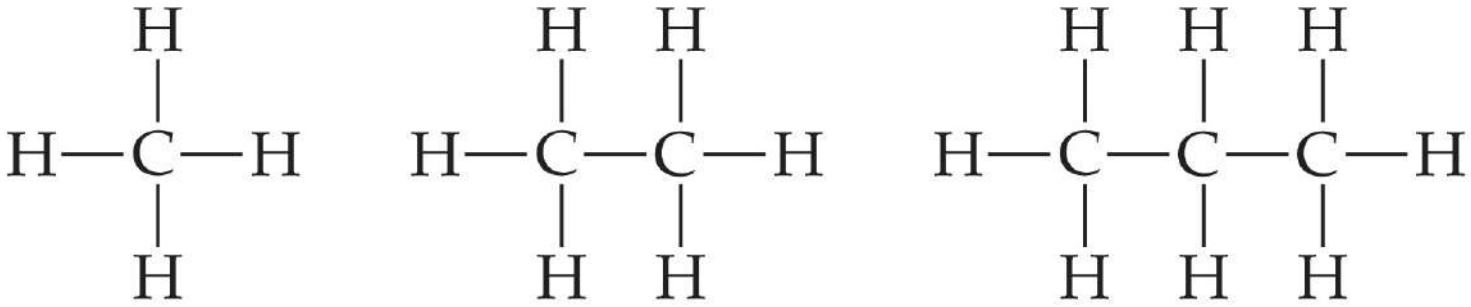
- Organic chemistry is the study of carbon.
- Organic chemistry has its own system of nomenclature.

Nomenclature of Organic Compounds



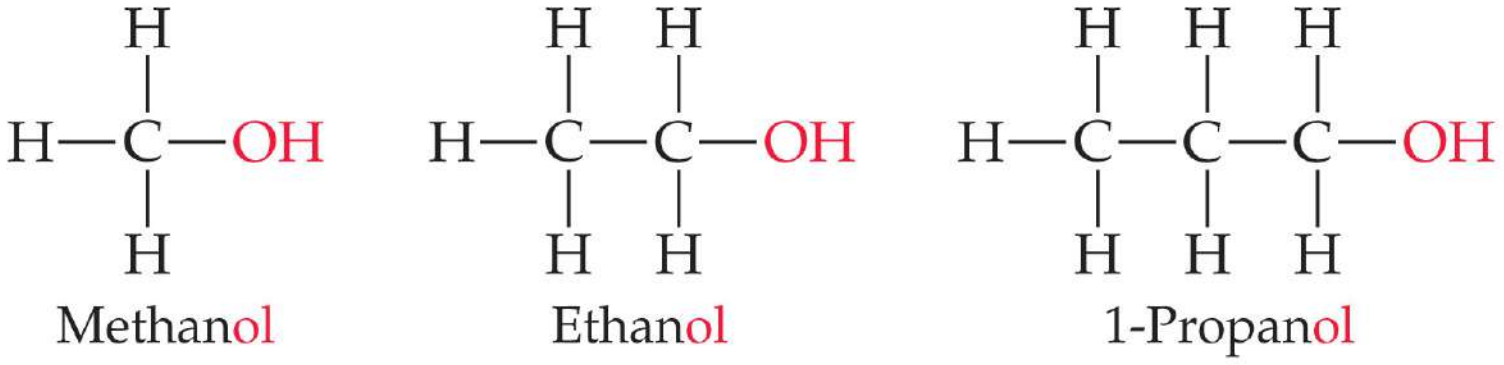
The simplest hydrocarbons (compounds containing only carbon and hydrogen) are alkanes.

Nomenclature of Organic Compounds



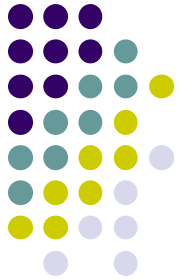
The first part of the names above correspond to the number of carbons (*meth*- = 1, *eth*- = 2, *prop*- = 3, etc.).

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*.

Organic Nomenclature Practice



- What is the structural formula for pentane? What is its molecular formula?
- Write a structural formula for hexane. What is its molecular formula?
- What is the molecular formula for butane? What is the name and molecular formula of an alcohol derived from butane?