CHEMISTRY

The Molecular Nature of Matter and Change

Third Edition

Chapter 2

Lecture Outlines*

*See PowerPoint Image Slides for all figures and tables pre-inserted into PowerPoint without notes.

Chapter 2

The Components of Matter

Chapter 2: The Components of Matter

Definitions for Components of Matter

Element - the simplest type of substance with unique physical and chemical properties. *An element consists of only one type of atom.* It cannot be broken down into any simpler substances by physical or chemical means.

A Atoms of an element

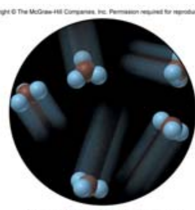
Molecule - a structure that consists of two or more atoms which are chemically bound together and thus behaves as an independent unit.

B Molecules of an element

Figure 2.1

Definitions for Components of Matter

Compound - a substance composed of two or more elements which are chemically combined.



C Molecules of a compound

Figure 2.1

D Mixture of two elements and a compound

Mixture - a group of two or more elements and/or compounds that are physically intermingled.

Table 2.1 Some Properties of Sodium, Chlorine, and Sodium Chloride

Property	Sodium +	Chlorine →	Sodium Chloride
			
Melting point	97.8°C	–101°C	801°C
Boiling point	881.4°C	–34°C	1413°C
Color	Silvery	Yellow-green	Colorless (white)
Density	0.97 g/cm^3	0.0032 g/cm^3	2.16 g/cm^3
Behavior in water	Reacts	Dissolves slightly	Dissolves freely

Law of Conservation of Mass:

The total mass of substances does not change during a chemical reaction.

reactant 1 + reactant 2 → product

total mass = *total mass*

calcium oxide + carbon dioxide → calcium carbonate

CaO + CO_2 → $CaCO_3$

56.08g + 44.00g → 100.08g

Calculating the Mass of an Element in a Compound
Ammonium Nitrate

How much nitrogen(N) is in 455kg of ammonium nitrate?

ammonium nitrate = NH_4NO_3

The Formula Mass of Cpd is:

4 x H = 4 x 1.008 = 4.032 g
2 x N = 2 X 14.01 = 28.02 g
3 x O = 3 x 16.00 = 48.00 g

80.052 g

Therefore g nitrogen/g cpd

$$\frac{28.02\text{g N}}{80.052\text{g cpd}} = 0.3500\text{gN/g cpd}$$

455kg x 1000g/kg = 455,000g NH_4NO_3

455,000g cpd x 0.3500g N/g cpd = 1.59×10^5g nitrogen

or: $$455 \text{ kg } NH_4NO_3 \times \frac{28.02 \text{ kg nitrogen}}{80.052 \text{ kg } NH_4NO_4} = 159 \text{ kg Nitrogen}$$

Sample Problem 2.1 **Calculating the Mass of an Element in a Compound**

PROBLEM: Pitchblende is the most commercially important compound of uranium Analysis shows that 84.2g of pitchblende contains 71.4g of uranium, with oxygen as the only other element. How many grams of uranium can be obtained from 102kg of pitchblende?

PLAN: The mass ratio of uranium/pitchblende is the same no matter the source. We can the ratio to find the answer.

mass(kg) of pitchblende → mass(g) of pitchblende → mass(g) of uranium

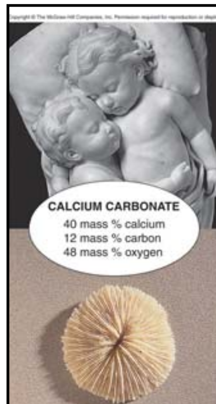
SOLUTION:

mass (kg) of uranium =

$$\text{mass(kg) pitchblende} \times \frac{\text{mass(kg) uranium in pitchblende}}{\text{mass(kg) pitchblende}}$$

$$= 102\text{kg pitchblende} \times \frac{71.4\text{kg uranium}}{84.2\text{kg pitchblende}} = 86.5 \text{ g uranium}$$

$$86.5 \text{ g uranium} \times \frac{1000\text{g}}{\text{kg}} = 8.65 \times 10^4\text{g uranium}$$



Law of Definite (or Constant) Composition:

No matter what its source, a particular chemical compound is composed of the same elements in the same parts (fractions) by mass.

$CaCO_3$

1 atom of Ca	**40.08 amu**
1 atom of C	**12.00 amu**
3 atoms of O	**3 x 16.00 amu**
	100.08 amu

$$\frac{40.08 \text{ amu}}{100.08 \text{ amu}} = 0.401 \text{ parts Ca}$$

$$\frac{12.00 \text{ amu}}{100.08 \text{ amu}} = 0.120 \text{ parts C}$$

$$\frac{48.00 \text{ amu}}{100.08 \text{ amu}} = 0.480 \text{ parts O}$$

Law of Multiple Proportions

If elements A and B react to form two compounds, the different masses of B that combine with a fixed mass of A can be expressed as a ratio of small whole numbers:

Example: Nitrogen Oxides I & II

Nitrogen Oxide I : 46.68% Nitrogen and 53.32% Oxygen
Nitrogen Oxide II : 30.45% Nitrogen and 69.55% Oxygen

Assume that you have 100g of each compound.
In 100 g of each compound: g O = 53.32g for oxide I & 69.55g for oxide II
g N = 46.68g for oxide I & 30.45g for oxide II

$$\frac{gO}{gN} = \frac{53.32}{46.68} = 1.142 \qquad \frac{gO}{gN} = \frac{69.55}{30.45} = 2.284$$

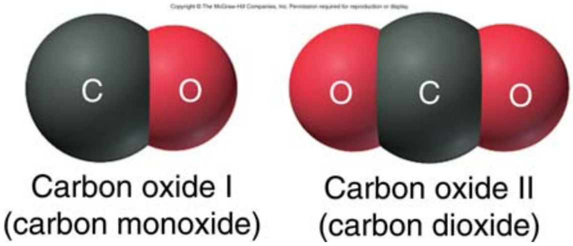
$$\frac{2.284}{1.142} = 2$$

Dalton's Atomic Theory

1. All matter consists of **atoms.**
2. Atoms of one element *cannot* be converted into atoms of another element.
3. Atoms of an element are identical in mass **(not true!)** and other properties and are different from atoms of any other element.
4. Compounds result from the chemical combination of a specific ratio of atoms of different elements.

The Atomic Basis of the Law of Multiple Proportions

Figure 2.4



Experiments to Determine the Properties of Cathode Rays

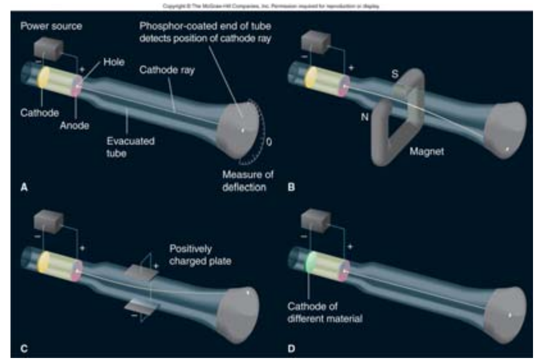


Figure 2.5

Millikan's Oil-Drop Experiment for Measuring an Electron's Charge

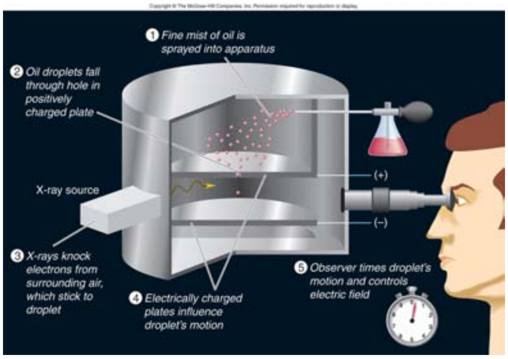


Figure 2.7

Rutherford's α-Scattering Experiment and Discovery of the Atomic Nucleus

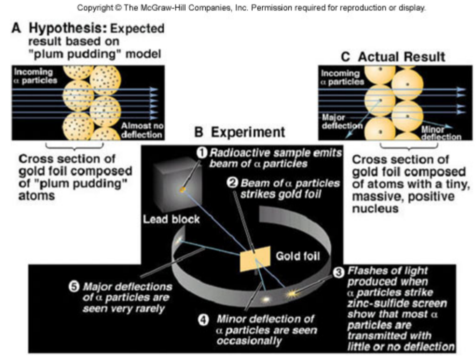


Figure 2.8

General Features of the Atom

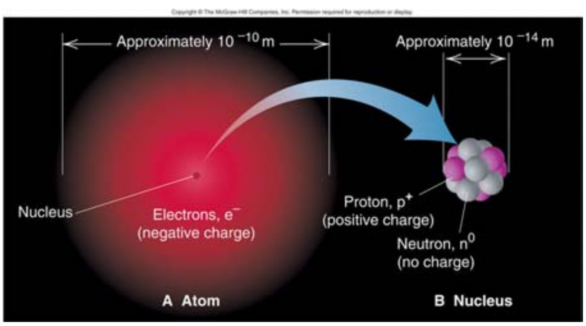


Figure 2.9

The Modern Reassessment of the Atomic Theory

1. *All matter is composed of atoms.* The atom is the smallest body that *retains the unique identity* of the element.
2. *Atoms of one element cannot be converted into atoms of another element in a chemical reaction.* Elements can only be converted into other elements in nuclear reactions.
3. *All atoms of an element have the same number of protons and electrons, which determines the chemical behavior of the element.* Isotopes of an element differ in the number of neutrons, and thus in mass number. A sample of the element is treated as though its atoms have an *average* mass.
4. *Compounds are formed by the chemical combination of two or more elements in specific ratios.*

Properties of the Three Key Subatomic Particles

Name(Symbol)	Charge: Relative	Charge: Absolute(C)*	Mass: Relative(amu)†	Mass: Absolute(g)	Location in the Atom
Proton (p^+)	1+	$+1.60218\times10^{-19}$	1.00727	1.67262×10^{-24}	Nucleus
Neutron (n^0)	0	0	1.00866	1.67493×10^{-24}	Nucleus
Electron (e^-)	1-	-1.60218×10^{-19}	0.00054858	9.10939×10^{-28}	Outside Nucleus

Table 2.2

Atomic Symbols, Isotopes, Numbers

$^A_Z J$ —The Symbol of the Atom or Isotope

J = Atomic symbol of the element

A = mass number; A = Z + N

Z = atomic number
(the number of protons in the nucleus)

N = number of neutrons in the nucleus

Isotope = atoms of an element with the same number of protons, but a different number of neutrons

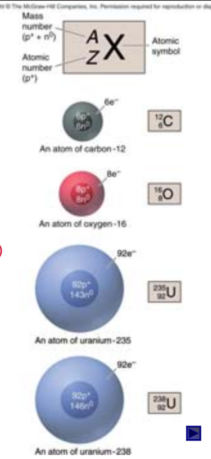


Figure 2.10

Tools

Sample Problem 2.2 **Determining the Number of Subatomic Particles in the Isotopes of an Element**

PROBLEM: Silicon(Si) is essential to the computer industry as a major component of semiconductor chips. It has three naturally occurring isoltopes: ^{28}Si, ^{29}Si, and ^{30}Si. Determine the number of protons, neutrons, and electrons in each silicon isotope.

PLAN: We have to use the atomic number and atomic masses.

SOLUTION: The atomic number of silicon is 14. Therefore

^{28}Si has $14p^+$, $14e^-$ and $14n^0$ (28-14)

^{29}Si has $14p^+$, $14e^-$ and $15n^0$ (29-14)

^{30}Si has $14p^+$, $14e^-$ and $16n^0$ (30-14)

Sample Problem 2.3 **Calculating the Atomic Mass of an Element**

PROBLEM: Silver(Ag: Z = 47) has 46 known isotopes, but only two occur naturally, ^{107}Ag and ^{109}Ag. Given the following mass spectrometric data, calculate the atomic mass of Ag:

Isotope	Mass(amu)	Abundance(%)
^{107}Ag	106.90509	51.84
^{109}Ag	108.90476	48.16

PLAN: We have to find the weighted average of the isotopic masses, so we multiply each isotopic mass by its fractional abundance and then sum those isotopic portions.

SOLUTION: mass(g) of each isotope → multiply by fractional abundance of each isotope → atomic mass portion of each isotope → add isotopic portions → atomic mass

mass portion from ^{107}Ag = 106.90509amu x 0.5184 = 55.42amu

mass portion from ^{109}Ag = 108.90476amu x 0.4816 = 52.45amu

atomic mass of Ag = 55.42amu + 52.45amu = 107.87amu

Sample Problem 2.4 **Predicting the Ion an Element Forms**

PROBLEM: What monatomic ions do the following elements form?

(a) Iodine (Z = 53) **(b)** Calcium (Z = 20) **(c)** Aluminum (Z = 13)

PLAN: Use Z to find the element. Find it's relationship to the nearest noble gas. Elements occurring before the noble gas gain electrons and elements following lose electrons.

SOLUTION: I^- Iodine is a nonmetal in Group 7A(17). It gains one electron to have the same number of electrons as $_{54}$Xe.

Ca^{2+} Calcium is a metal in Group 2A(2). It loses two electrons to have the same number of electrons as $_{18}$Ar.

Al^{3+} Aluminum is a metal in Group 3A(13). It loses three electrons to have the same number of electrons as $_{10}$Ne.

The Modern Periodic Table

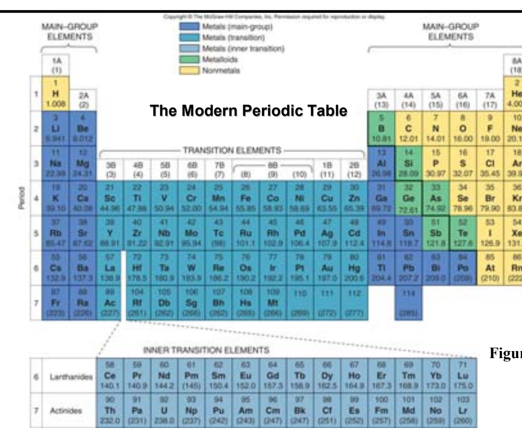


Figure 2.11

Metals, Metalloids, and Nonmetals

Figure 2.12

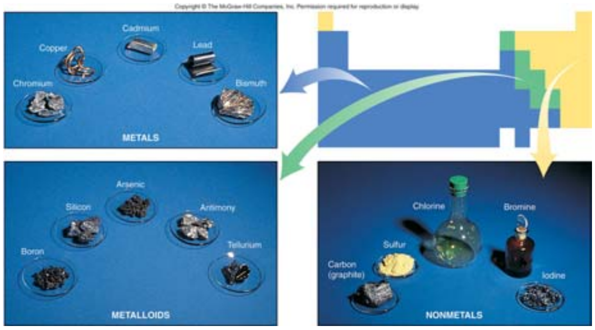


Figure 2.13

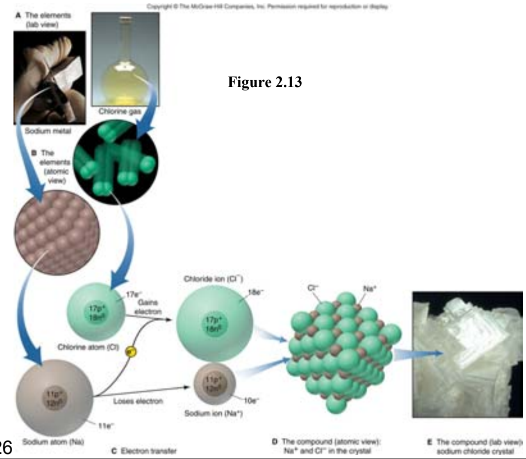
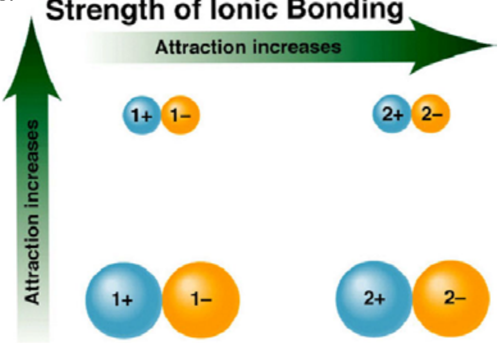


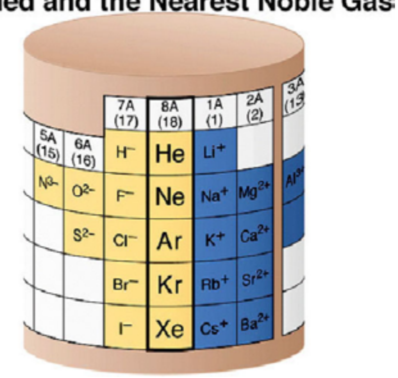
Figure 2.14

Factors that Influence the Strength of Ionic Bonding



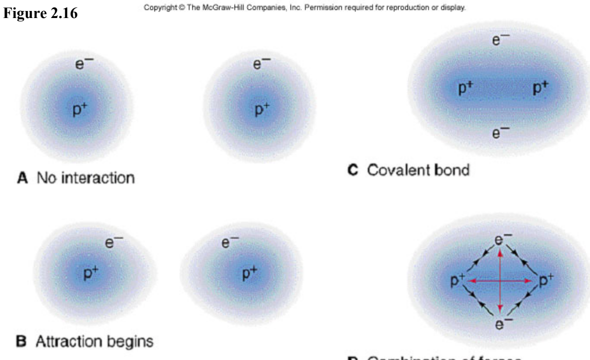
The Relationship Between Ions Formed and the Nearest Noble Gas

Figure 2.15

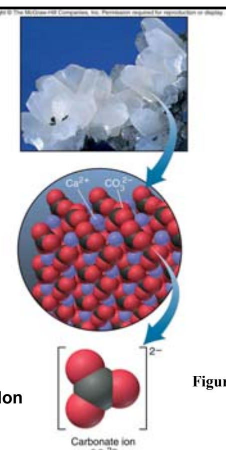


Formation of a Covalent Bond between Two H Atoms

Figure 2.16



Elements That Are Polyatomic



A Polyatomic Ion

Figure 2.18

Table 2.3 **Common Monoatomic Ions**

Cations Charge	Formula	Name	Anions Charge	Formula	Name
+1	H^+	hydrogen	-1	H^-	hydride
	Li^+	lithium		F^-	fluoride
	Na^+	sodium		Cl^-	chloride
	K^+	potassium		Br^-	bromide
	Cs^+	cesium		I^-	iodide
	Ag^+	silver			
+2	Mg^{2+}	magnesium	-2	O^{2-}	oxide
	Ca^{2+}	calcium		S^{2-}	sulfide
	Sr^{2+}	strontium			
	Ba^{2+}	barium			
	Zn^{2+}	zinc			
	Cd^{2+}	cadmium			
+3	Al^{3+}	aluminum	-3	N^{3-}	nitride

Common ions are in blue.

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Metals With Several Oxidation States

Table 2.4 (partial)

Element	Ion Formula	Systematic Name	Common Name
Copper	Cu^{+1}	copper(I)	cuprous
	Cu^{+2}	copper(II)	cupric
Cobalt	Co^{+2}	cobalt(II)	
	Co^{+3}	cobalt (III)	
Iron	Fe^{+2}	iron(II)	ferrous
	Fe^{+3}	iron(III)	ferric
Manganese	Mn^{+2}	manganese(II)	
	Mn^{+3}	manganese(III)	
Tin	Sn^{+2}	tin(II)	stannous
	Sn^{+4}	tin(IV)	stannic

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Sample Problem 2.5 **Naming Binary Ionic Compounds**

PROBLEM: Name the ionic compound formed from the following pairs of elements:

(a) magnesium and nitrogen **(b)** iodine and cadmium

(c) strontium and fluorine **(d)** sulfur and cesium

PLAN: Use the periodic table to decide which element is the metal and which the nonmetal. The metal (cation) is named first and we use the *-ide* suffix on the nonmetal name root.

SOLUTION:

(a) magnesium nitride

(b) cadmium iodide

(c) strontium fluoride

(d) cesium sulfide

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Sample Problem 2.6 **Determining Formulas of Binary Ionic Compounds**

PROBLEM: Write empirical formulas for the compounds named in Sample Problem 2.5.

PLAN: Compounds are neutral. We find the smallest number of each ion which will produce a neutral formula. Use *subscripts* to the *right* of the element symbol.

SOLUTION:

(a) Mg^{2+} and N^{3-}; three Mg^{2+}(6+) and two N^{3-}(6-); Mg_3N_2

(b) Cd^{2+} and I^-; one Cd^{2+}(2+) and two I^-(2-); CdI_2

(c) Sr^{2+} and F^-; one Sr^{2+}(2+) and two F^-(2-); SrF_2

(d) Cs^+ and S^{2-}; two Cs^+(2+) and one S^{2-} (2-); Cs_2S

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Sample Problem 2.7 **Determining Names and Formulas of Ionic Compounds of Elements That Form More Than One Ion**

PROBLEM: Give the systematic names or the formulas for the names of the following compounds:

(a) tin(II) fluoride **(b)** CrI_3

(c) ferric oxide **(d)** CoS

PLAN: Compounds are neutral. We find the smallest number of each ion which will produce a neutral formula. Use *subscripts* to the *right* of the element symbol.

SOLUTION: **(a)** Tin (II) is Sn^{2+}; fluoride is F^-; so the formula is SnF_2.

(b) The anion I is iodide(I^-); $3I^-$ means that Cr(chromium) is +3. CrI_3 is chromium(III) iodide

(c) Ferric is a common name for Fe^{3+}; oxide is O^{2-}, therefore the formula is Fe_2O_3.

(d) Co is cobalt; the anion S is sulfide(2-); the compound is cobalt (II) sulfide.

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Some Common Polyatomic Ions

Formula	Name	Formula	Name
Cations			
NH_4^+	ammonium	H_3O^+	hydronium
Common Anions			
CH_3COO^-	acetate	CO_3^{-2}	carbonate
CN^-	cyanide	CrO_4^{-2}	chromate
OH^-	hydroxide	$Cr_2O_7^{-2}$	dichromate
ClO_3^-	chlorate	O_2^{-2}	oxide
NO_2^-	nitrite	SO_4^{-2}	sulfate
NO_3^-	nitrate	PO_4^{-3}	phosphate
MnO_4^-	permanganate		

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Naming oxoanions

Figure 2.20

No. of O atoms (arrow pointing up)

Prefixes	Root	Suffixes	Examples	
per	*root*	ate	ClO_4^-	perchlorate
	root	ate	ClO_3^-	chlorate
	root	ite	ClO_2^-	chlorite
hypo	*root*	ite	ClO^-	hypochlorite

Numerical Prefixes for Hydrates and Binary Covalent Compounds

Table 2.6

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

Sample Problem 2.8 **Determining Names and Formulas of Ionic Compounds Containing Polyatomic Ions**

PROBLEM: Give the systematic names or the formula or the formulas for the names of the following compounds:

(a) $Fe(ClO_4)_2$ **(b)** sodium sulfite **(c)** $Ba(OH)_2 \bullet 8H_2O$

PLAN: Note that polyatomic ions have an overall charge so when writing a formula with more than one polyatomic unit, place the ion in a set of parentheses.

SOLUTION: **(a)** ClO_4^- is perchlorate; iron must have a 2+ charge. This is iron(II) perchlorate.

(b) The anion sulfite is SO_3^{2-} therefore you need 2 sodiums per sulfite. The formula is Na_2SO_3.

(c) Hydroxide is OH^- and barium is a 2+ ion. When water is included in the formula, we use the term "hydrate" and a prefix which indicates the number of waters. So it is barium hydroxide octahydrate.

Sample Problem 2.9 **Recognizing Incorrect Names and Fromulas of Ionic Compounds**

PROBLEM: Something is wrong with the second part of each statement. Provide the correct name or formula.

(a) $Ba(C_2H_3O_2)_2$ is called barium diacetate.

(b) Sodium sulfide has the formula $(Na)_2SO_3$.

(c) Iron(II) sulfate has the formula $Fe_2(SO_4)_3$.

(d) Cesium carbonate has the formula $Cs_2(CO_3)$.

SOLUTION: **(a)** Barium is always a +2 ion and acetate is -1. The "di-" is unnecessary.

(b) An ion of a single element does not need parentheses. Sulfide is S^{2-}, not SO_3^{2-}. The correct formula is Na_2S.

(c) Since sulfate has a 2- charge, only 1 Fe^{2+} is needed. The formula should be $FeSO_4$.

(d) The parentheses are unnecessary. The correct formula is Cs_2CO_3.

Sample Problem 2.11 **Determining Names and Formulas of Binary Covalent Compounds**

PROBLEM: **(a)** What is the formula of carbon disulfide?

(b) What is the name of PCl_5?

(c) Give the name and formula of the compound whose molecules each consist of two N atoms and four O atoms.

SOLUTION: **(a)** Carbon is C, sulfide is sulfur S and di-means 2 - CS_2.

(b) P is phosphorous, Cl is chloride, the prefix for 5 is penta-. Phosphorous pentachloride.

(c) N is nitrogen and is in a lower group number than O (oxygen). Therefore the formula is N_2O_4 - dinitrogen tetraoxide.

Sample Problem 2.12 **Recognizing Incorrect Names and Formulas of Binary Covalent Compounds**

PROBLEM: Explain what is wrong with the name of formula in the second part of each statement and correct it:

(a) SF_4 is monosulfur pentafluoride.

(b) Dichlorine heptaoxide is Cl_2O_6.

(c) N_2O_3 is dinitrotrioxide.

SOLUTION: **(a)** The prefix mono- is not needed for one atom; the prefix for four is tetra-. So the name is sulfur tetrafluoride.

(b) Hepta- means 7; the formula should be Cl_2O_7.

(c) The first element is given its elemental name so this is dinitrogen trioxide.

Sample Problem 2.13 **Calculating the Molecular Mass of a Compound**

PROBLEM: Using the data in the periodic table, calculate the molecular (or formula) mass of the following compounds:

(a) Tetraphosphorous trisulfide **(b)** Ammonium nitrate

PLAN: Write the formula and then multiply the number of atoms(in the subscript) by the respective atomic masses. Add the masses for the compound.

SOLUTION:

(a) P_4S_3

molecular mass = (4xatomic mass of P) + (3xatomic mass of S)

= (4x30.97amu) + (3x32.07amu)

= 220.09amu

(b) NH_4NO_3

molecular mass = (2xatomic mass of N) + (4xatomic mass of H) + (3xatomic mass of O)

= (4x14.01amu)+ (4x1.008amu) + (3x16.00amu)

= 80.05amu

Naming Acids

1) Binary acids solutions form when certain gaseous compounds dissolve in water.
For example, when gaseous hydrogen chloride(HCl) dissolves in water, it forms a solution called hydrochloric acid. Prefix *hydro-* + anion nonmetal *root* + suffix *-ic* + the word *acid* - *hydrochloric acid*

2) Oxoacid names are similar to those of the oxoanions, except for two suffix changes:
Anion "*-ate*" suffix becomes an "*-ic*" suffix in the acid. Anion "*-ite*" suffix becomes an "*-ous*" suffix in the acid.
The oxoanion prefixes "*hypo-*" and "*per-*" are retained. Thus, BrO_4^- is *perbromate*, and $HBrO_4$ is *perbromic* acid; IO_2^- is *iodite*, and HIO_2 is *iodous acid.*

Sample Problem 2.12 **Recognizing Incorrect Names and Fromulas of Ionic Compounds**

PROBLEM: Something is wrong with the second part of each statement. Provide the correct name or formula.

(a) $Ba(C_2H_3O_2)_2$ is called barium diacetate.

(b) Sodium sulfide has the formula $(Na)_2SO_3$.

(c) Iron(II) sulfate has the formula $Fe_2(SO_4)_3$.

(d) Cesium carbonate has the formula $Cs_2(CO_3)$.

SOLUTION: **(a)** Barium is always a +2 ion and acetate is -1. The "di-" is unnecessary.

(b) An ion of a single element does not need parentheses. Sulfide is S^{2-}, not SO_3^{2-}. The correct formula is Na_2S.

(c) Since sulfate has a 2- charge, only 1 Fe^{2+} is needed. The formula should be $FeSO_4$.

(d) The parentheses are unnecessary. The correct formula is Cs_2CO_3.

Chemical Formulas

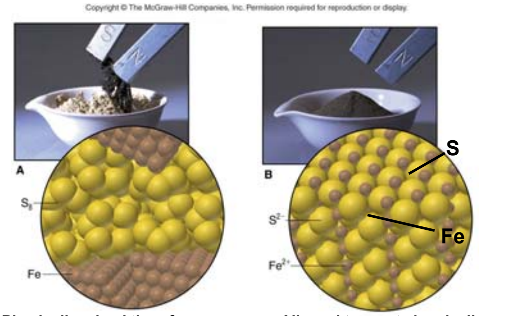
Empirical Formula - Shows the *relative* number of atoms of each element in the compound. It is the simplest formula, and is derived from masses of the elements.

Molecular Formula - Shows the *actual* number of atoms of each element in the molecule of the compound.

Structural Formula - Shows the actual number of atoms, and *the bonds between them* , that is, the arrangement of atoms in the molecule.

Mixtures and Compounds

Figure 2.21



Physically mixed therefore can be separated by physical means.

Allowed to react chemically therefore cannot be separated by physical means.

Mixtures

Heterogeneous mixtures : has one or more visible boundaries between the components.

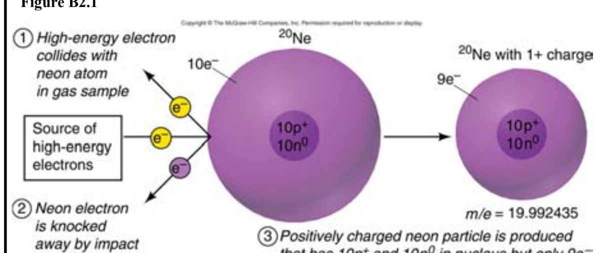
Homogeneous mixtures : has no visible boundaries because the components are mixed as individual atoms, ions, and molecules.

Solutions : A homogeneous mixture is also called a solution. Solutions in water are called ***aqueous solutions***, and are very important in chemistry. Although we normally think of solutions as liquids, they can exist in all three physical states.

Tools of the Laboratory

Formation of a Positively Charged Neon Particle in a Mass Spectrometer

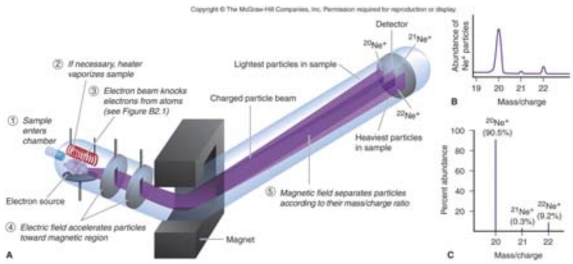
Figure B2.1



Tools

Figure B2.2

The Mass Spectrometer and Its Data



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Basic Separation Techniques

Filtration : Separates components of a mixture based upon *differences in particle size.* Normally separating a precipitate from a solution, or particles from an air stream.

Crystallization : Separation is based upon *differences in solubility* of components in a mixture.

Distillation : separation is based upon *differences in volatility*. Tools

Extraction : Separation is based upon *differences in solubility* in different solvents (major material). Tools

Chromatography : Separation is based upon *differences in solubility* in a solvent versus a stationary phase. Tools

Figure B2.5

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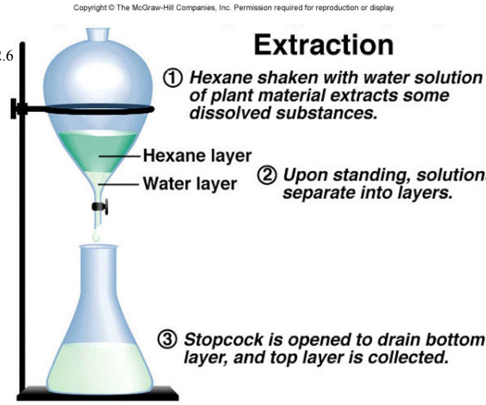
Figure B2.6



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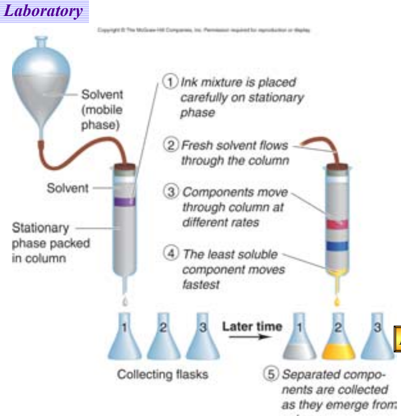
Procedure for Column Chromatography

Figure B2.7



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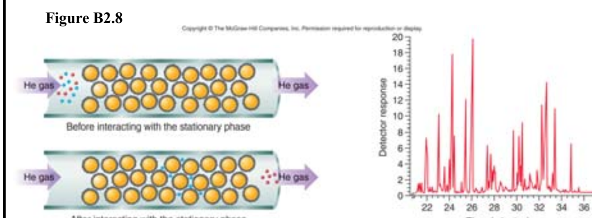
Separation by Gas - Liquid Chromatography

Figure B2.8



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