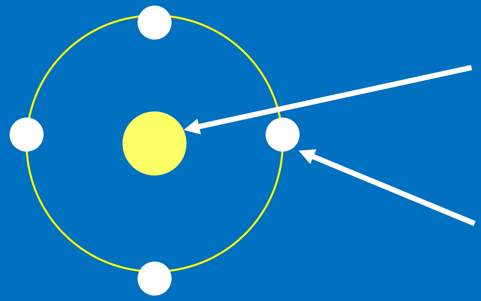
The Components of Matter

- 2.LEARNING and UNDERSTANDING CHEMISTRY and ENGINEERING TERMINILOGY
- Elements, Compounds, and Mixtures: An Atomic Overview
- The Observations That Led to an Atomic View of Matter
- Dalton’s Atomic Theory
- The Observations That Led to the Nuclear Atom Model
- The Atomic Theory Today
- Elements: A First Look at the Periodic Table
- Compounds: Introduction to Bonding
- Compounds: Formulas, Names, and Masses
- Mixtures: Classification and Separation

The Atom

- Atomic Structure - the atom contains charged particles

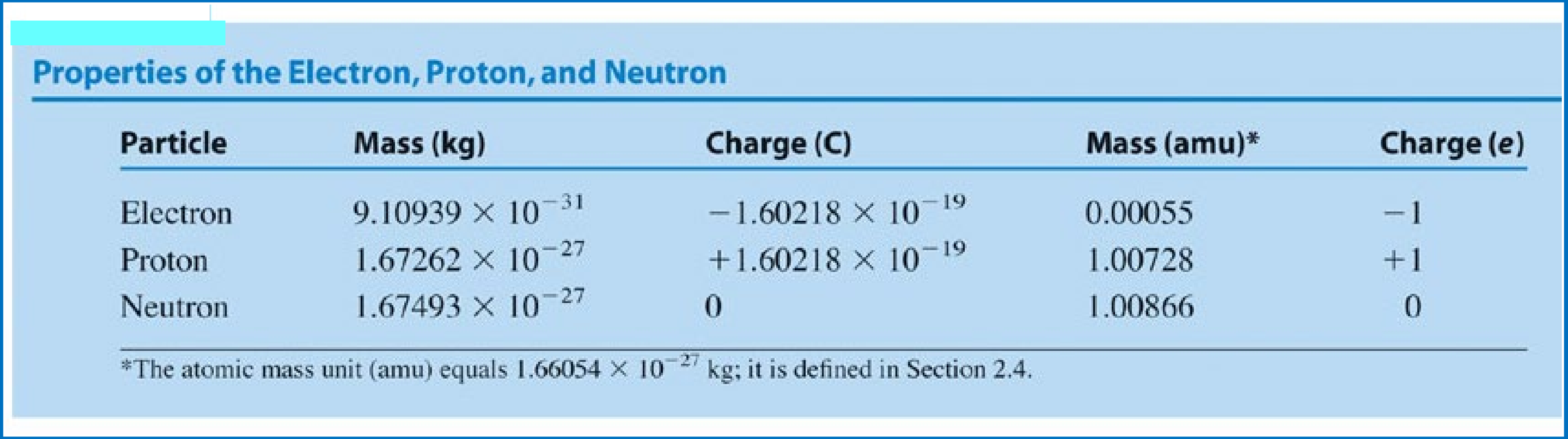


Nucleus (positively charged protons & neutral neutrons)

Electrons (negatively charged)

- The atom has a central core, the nucleus, which contains most of the atom’s mass (neutrally charged neutrons & positively charged protons)
- Electrons are very light particles that “encircle” the nucleus as a negatively charged cloud at very high speeds

Physical Properties of the Atom



Properties of the Electron, Proton, and Neutron

Particle	Mass (kg)	Charge (C)	Mass (amu)*	Charge (*e*)
Electron	9.10939×10^{-31}	-1.60218×10^{-19}	0.00055	-1
Proton	1.67262×10^{-27}	$+1.60218 \times 10^{-19}$	1.00728	$+1$
Neutron	1.67493×10^{-27}	0	1.00866	0

*The atomic mass unit (amu) equals 1.66054×10^{-27} kg; it is defined in Section 2.4.

Atomic Symbols - First Glance

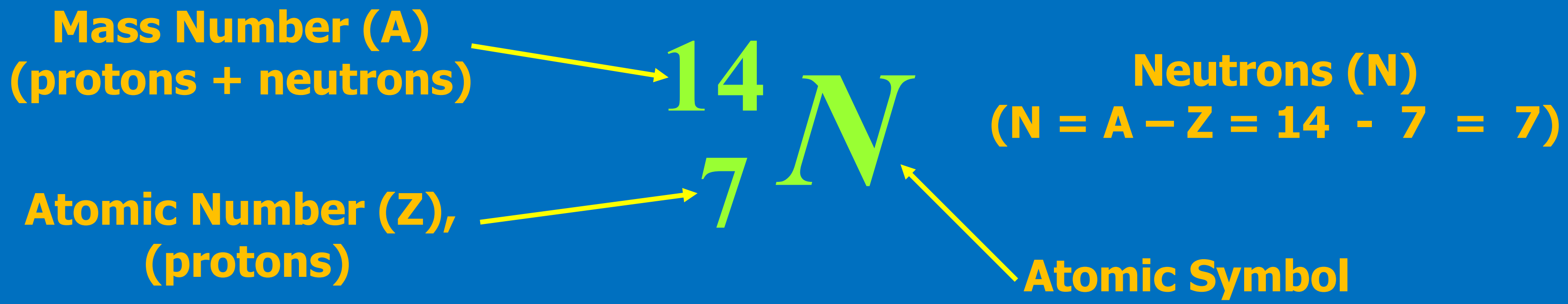
- **Atomic symbols** represent a shorthand way of expressing atoms of different elements
- Common examples (1 or 2 letter notation):

H	Hydrogen
C	Carbon
O	Oxygen
N	Nitrogen
Fe	Iron
Mn	Manganese
Hg	Mercury
Na	Sodium
Al	Aluminum
Cl	Chlorine

The names of many elements have Latin roots

Nuclear Structure

- The nucleus is composed of two different types of particles
  - Protons - nuclear particle having a positive charge and mass 1800 times an electron
  - Neutrons - nuclear particle having a mass almost identical to a proton but no electric charge
  - Nuclide symbol - notation representing the nuclear composition of each element



Mass Number (A)
(protons + neutrons)

$$^{14}_{7}N$$

Neutrons (N)
(N = A – Z = 14 - 7 = 7)

Atomic Number (Z),
(protons)

Atomic Symbol

Isotopes

- Isotopes
  - Atoms whose nuclei have the same number of protons (atomic number, Z) but different numbers of neutrons (N), thus different mass numbers (A)
- Naturally occurring isotopes of phosphorus

$$^{31}_{15}P$$

Phosphorus-31

Mass No. (A) - 31
Atomic No. (Z) - 15
No. Neutrons (N) - 16

$$^{32}_{15}P$$

Phosphorus-32

Mass No. (A) - 32
Atomic No. (Z) - 15
No. Neutrons (N) - 17

Practice Problem

How many neutrons are in carbon-14?

$$^{14}_{6}\mathrm{C}$$

a. 5 b. 6 c. 7 d. 8 e. 9

Ans: d (8)

The Mass Number (A) for C-14 is 14

The Atomic Number (Z) is 6 (6 protons)

The No. of Neutrons (N) is A – Z = 14 - 6 = 8

Practice Problem

How many electrons are in one atom of fluorine-19?

$${}^{19}_{9}F$$

a. 2 b. 8 c. 9 d. 10 e. 19

Ans: c (9)

The Mass Number (A) is 19

The Atomic Number (Z) is 9 (9 protons)

∴ For a neutral atom with 9 protons,
there must be 9 electrons

Practice Problem

How many electrons are in the lead (IV) (Pb^{+4}) ion?

$$^{207}_{82}\mathrm{Pb} \rightarrow {}^{207}_{82}\mathrm{Pb}^{+4} + 4e^{-}$$

a. 82 b. 85 c. 80 d. 78 e. none of the above

Ans: d (78)

Neutral Atom – 82 protons & 82 electrons

Cation (+4) has four less electrons than neutral atom

(82 – 4 = 78)

Practice Problem

Do both members of the following pairs have the same number of Protons? Neutrons? Electrons?

a. ${}^{3}_{1}H$ and ${}^{3}_{2}H$ b. ${}^{14}_{6}C$ and ${}^{15}_{7}N$ c. ${}^{19}_{9}F$ and ${}^{18}_{9}F$

a) These have different numbers of protons, neutrons, and electrons, but have the same atomic mass number A=3

b) These have the same number of neutrons,

$A – Z = N \quad (14 - 6 = 8) \quad (15 – 7 = 8)$

but different number of protons and electrons

6 p 6 e^- & 7p 7 e^-

a) These have the same number of protons (Z = 9) and electrons (9), but different number of neutrons

19 – 9 = 10 & 18 – 9 = 9

Postulates of Atomic Theory

- Dalton's Atomic Theory
  - All matter consists of atoms
  - Atoms of one element *cannot* be converted into atoms of another element
  - Atoms of a given element are *identical in mass* and other properties and are different from atoms of any other element
  - Compounds result from the chemical combination of a *specific ratio of atoms* of different elements

Postulates of Atomic Theory

- Theory vs Mass Laws
  - Mass Conservation
    - Atoms cannot be created or destroyed
    - Each atom has a fixed mass that does not change during a chemical reaction

Laws of Matter
Law of Mass Conservation

- Mass Conservation
  - The total masses of the substances involved in a chemical reaction does not change
  - The number of substances can change and their properties can change

180 g glucose + 192 g oxygen → 264 g CO_2 + 108 g H_2O

372 g before reaction → 372 g after reaction

Laws of Matter

Law of Definite Composition (Multiple Proportions)

- Multiple Proportions or Constant Composition

  A pure compound, whatever its source, always contains definite or constant proportions of the elements by mass

$CaCO_3$ (Calcium Carbonate)

Analysis by Mass (grams/20.0 g)	Mass Fraction (parts/1.00 part)	Percent by Mass (parts/100 parts)
8.0 g calcium	8.0/20.0 = 0.40 calcium	40% calcium
2.4 g carbon	2.4/20.0 = 0.12 carbon	12% carbon
9.6 g oxygen	9.6/20.0 = 0.48 oxygen	48% oxygen
20.0 g	1.00 part by mass	100% by mass

Postulates of Atomic Theory

- Multiple Proportions
  - Atoms of an element have the same mass and are indivisible
  - The masses of element B that combine with a fixed mass of element A give a small whole number ratio because different numbers of B combine with different numbers of A in different compounds

Law of Multiple Proportions (Dalton)

- If elements A & B react to form more than one compound, different masses of "B" that combine with a fixed mass of "A" can be expressed as a ratio of SMALL WHOLE NUMBERS

Ex. Assume two compounds containing just Carbon and Oxygen with the following relative compositions

Carbon Oxide (I): 57.1 % Oxygen and 42.9 % Carbon

Carbon Oxide (II): 72.7 % Oxygen and 27.3 % Carbon

Mass Ratios: Oxide (I) = 57.1 O / 42.9 C = 1.33 g O / g C

Oxide (II) = 72.7 O / 27.3 C = 2.66 g O / g C

Ratio Oxide (II) / Oxide (I) = 2.66 / 1.33 = 2 / 1

∴ For a given amount of C, Oxide II contains twice the Oxygen of Oxide I

The ratio of Oxygen atoms to Carbon atoms in Oxide I is 1:1 (CO)

The ratio of Oxygen atoms to Carbon atoms in Oxide II is 2:1 (CO_2)

Ratios, Masses, Molecules, Moles, Formulas

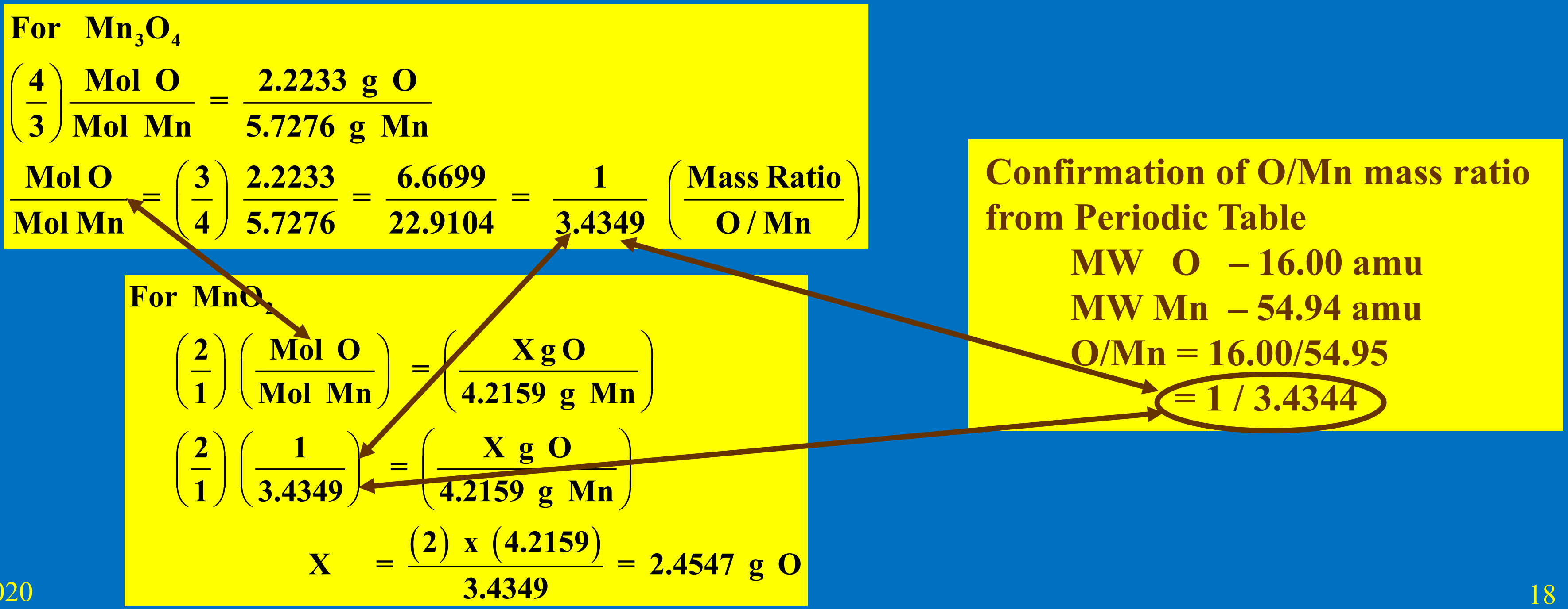
- Early theories and relatively precise measurements of reactants and products in chemical reactions suggested that *Elements* combine in *fixed ratios* by mass to form compounds
- The fixed ratio theory of elemental combination has been confirmed by direct measurements of the masses of protons & neutrons (atomic weights), the evolution of the modern atomic theory, and the development of the *Periodic Table*, which lists the *Molecular Weights* of the elements
- The ratios of the Molecular Weights of elements are the same as the ratios of the weighed masses of elements and compounds in early experiments

Ratios, Masses, Molecules, Moles, Formulas

Example:

The relationship between the fixed mass ratios of elements in compounds and the molecular weights of compounds represented in the Periodic Table can be demonstrated in the following example

A sample of Mn_3O_4 is composed of 5.7276 g Manganese (Mn) and 2.2233 g Oxygen (O). Not using the Periodic Table, compute the grams of Oxygen in a sample of MnO_2 that contained 4.2159 g of Manganese



For Mn_3O_4

$$\left(\frac{4}{3}\right)\frac{\text{Mol O}}{\text{Mol Mn}} = \frac{2.2233\ \text{g O}}{5.7276\ \text{g Mn}}$$

$$\frac{\text{Mol O}}{\text{Mol Mn}} = \left(\frac{3}{4}\right)\frac{2.2233}{5.7276} = \frac{6.6699}{22.9104} = \frac{1}{3.4349}\left(\frac{\text{Mass Ratio}}{\text{O / Mn}}\right)$$

For MnO_2

$$\left(\frac{2}{1}\right)\left(\frac{\text{Mol O}}{\text{Mol Mn}}\right) = \left(\frac{\text{X g O}}{4.2159\ \text{g Mn}}\right)$$

$$\left(\frac{2}{1}\right)\left(\frac{1}{3.4349}\right) = \left(\frac{\text{X g O}}{4.2159\ \text{g Mn}}\right)$$

$$X = \frac{(2)\ \text{x}\ (4.2159)}{3.4349} = 2.4547\ \text{g O}$$

Confirmation of O/Mn mass ratio from Periodic Table

MW O – 16.00 amu

MW Mn – 54.94 amu

O/Mn = 16.00/54.95

= 1 / 3.4344

Atomic Weight
(Physical Property of Atoms)

- Atomic mass units (amu) - mass standard relative to Carbon-12
  - By definition C-12 is assigned 12 amu
  - 1 amu = 1/12 mass of a Carbon-12 atom
  - 1 amu = 1.66054 x 10^{-24} g
  - C-12 = 12 x 1.66054 x 10^{-24} = 1.99265 x 10^{-23}g
  - The atomic mass of one atom expressed in atomic mass units (amu) is numerically the same as the mass of 1 mole of the element expressed in grams (Chapter 3)

C-12 = 12 amu = 12 g/mole

- Atomic (mass) weight of a naturally occurring element takes into account the atomic masses of all naturally occurring isotopes of the element

  The composite atomic weight of naturally occurring Carbon as reported in the periodic table is 12.0107 amu =12.0107 g/mol

Calculating Average Atomic Weights

- Average atomic weights for each element are determined using accurate *atomic masses* (amu) and *fractional abundances* (FA) for each isotope

- Procedure

mass(g) of isotope

multiply by fractional abundance of isotope

Repeat for each isotope

add isotopic portions

atomic mass

Calculating Average Atomic Weights

Example: Chlorine

Chlorine occurs naturally as Cl-35 and Cl-37

Isotope	Atomic Mass (amu)	Abundance
Cl-35	34.96885	0.75771
Cl-37	36.96590	0.24229

Avg Mass = (34.96885 x 0.75771) + (36.96590 x 0.24229)

= 35.453 amu (Value listed in Periodic Table)

NOTE: In computing average atomic weight of an element with more than one isotope, the atomic mass of each isotope is multiplied by the fractional abundance of that isotope

Practice Problem

The naturally occurring isotopes of Silver (Z = 47) are

^{107}Ag and ^{109}Ag

Calculate the atomic mass of Ag from the Mass data below:

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

PLAN: Find the weighted average of the isotopic masses

SOLUTION:

- mass portion from ^{107}Ag = 106.90509 amu x 0.5184
  = 55.42 amu
- mass portion from ^{109}Ag = 108.90476 amu x 0.4816
  = 52.45 amu
- Atomic mass of Ag = 55.42 amu + 52.45amu = 107.87 amu
- Atomic mass (MW) of Ag in Periodic Table = 107.8

Practice Problem

Copper has two naturally occurring isotopes

^{63}Cu (isotopic mass – 62.9396 amu)

^{65}Cu (isotopic mass – 64.9278 amu)

If the atomic mass (Molecular Weight) of Copper is 63.546 amu, what is the % abundance of each isotope?

Let: x equal the fractional abundance of ^{63}Cu and

(1 – x) equal the fractional abundance of ^{65}Cu

$\therefore$ 63.546 = 62.9396 (x) + 64.9278 (1 – x)

63.546 = 62.9396 (x) + 64.9278 – 64.9278(x)

63.546 = 64.9278 – 1.9882(x)

1.9882(x) = 1.3818

x = 0.69500

1 – x = 1 - 0.69500 = 0.30500

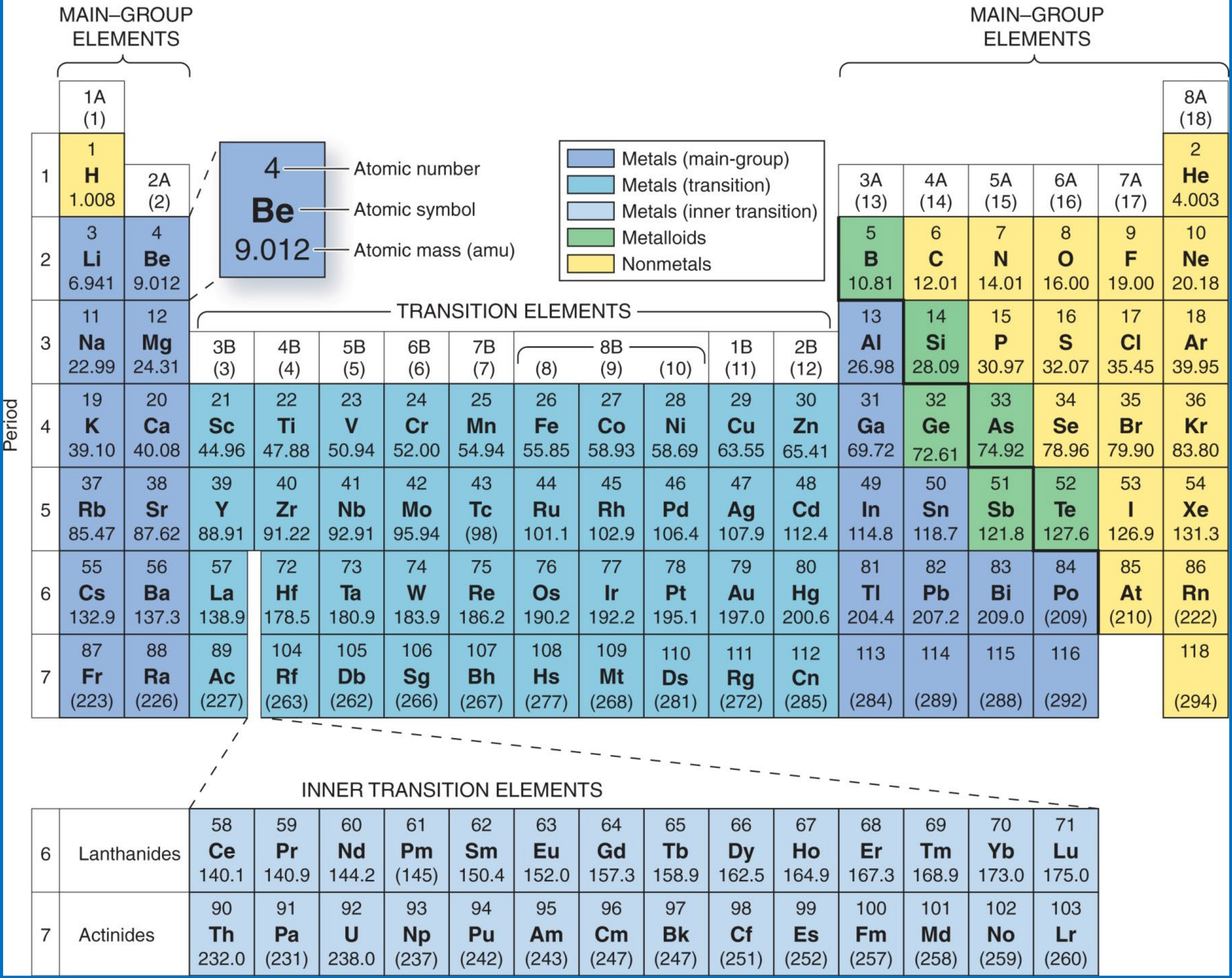
% abundance ^{63}Cu = 69.50%

% abundance ^{65}Cu = 30.50%

The Periodic Table of Elements

- In 1869 Dmitri Mendeleev and J. Meyer proposed the periodic table of elements
- Periodic Table – arrangement of elements in rows and columns featuring the commonality of properties
  - Period – Horizontal Row (1 - 7)
  - Group (Family) – Column; each given a Roman Numeral (IA, 2A, IB - VIIIB, .. IIIA - VIIIA)
- Element Group Classification
  - A (main group elements)
  - B (transition elements and inner-transition elements)
    - Lanthanides
    - Actinides

A Modern Form of the Periodic Table



MAIN–GROUP ELEMENTS

MAIN–GROUP ELEMENTS

TRANSITION ELEMENTS

4 — Atomic number
Be — Atomic symbol
9.012 — Atomic mass (amu)

🟦 Metals (main-group)
🟦 Metals (transition)
⬜ Metals (inner transition)
🟩 Metals (inner transition)
🟩 Metalloids
🟨 Nonmetals

Period

	1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	(9)	(10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.41	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
6	55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (263)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (267)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (281)	111 **Rg** (272)	112 **Cn** (285)	113 (284)	114 (289)	115 (288)	116 (292)		118 (294)

INNER TRANSITION ELEMENTS

6	Lanthanides	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
7	Actinides	90 **Th** 232.0	91 **Pa** (231)	92 **U** 238.0	93 **Np** (237)	94 **Pu** (242)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

Features of Periodic Table

- Most elements are metals (blue boxes)
  - **Metal** – substance having luster and a good conductor of electricity
- Nonmetals (tan)
  - **Nonmetal** – substance that does not have features of a metal
- A few are metalloids (green)
  - **Metalloid** – substances having both metal and nonmetal properties

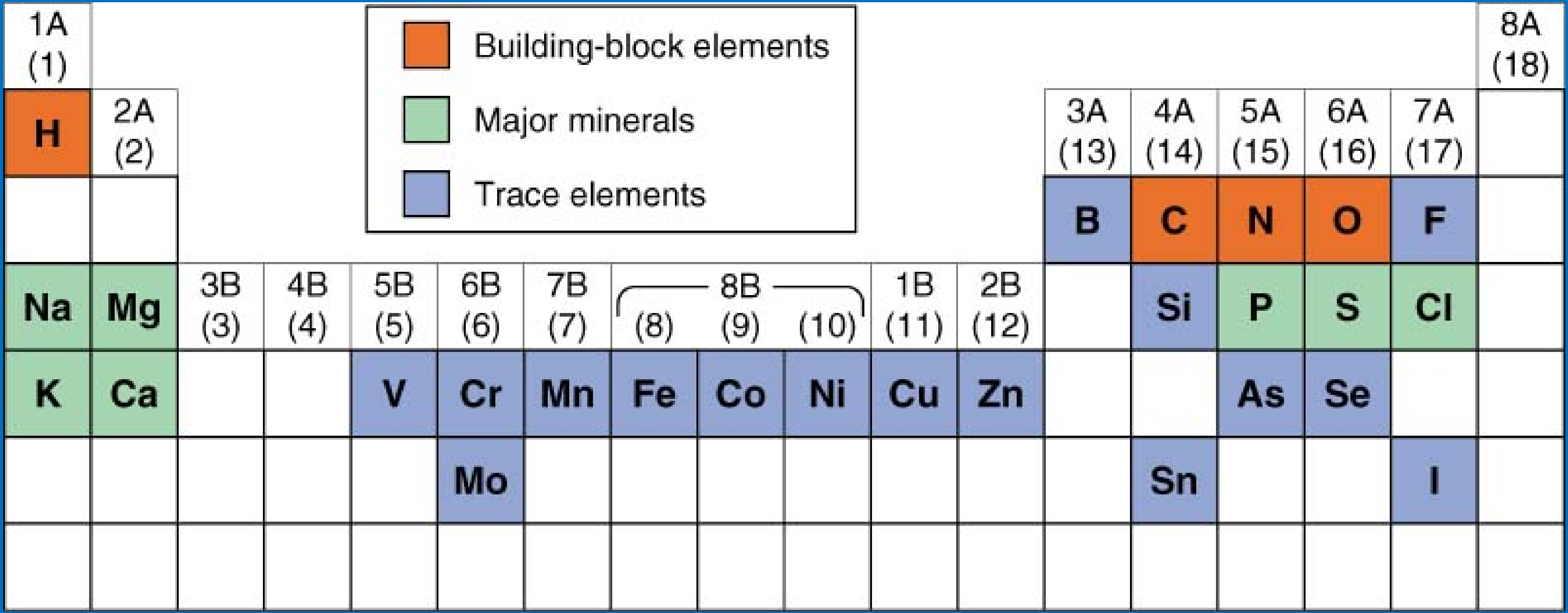
Inorganic Compounds

- Inorganic Chemistry focuses on all elements and compounds except organic (carbon based) compounds
  - Catalysts
  - Electronic Materials
  - Metals and Metal Alloys
  - Mineral Salts
- With the explosion in biomedical and materials research, the dividing line between Organic and Inorganic branches is greatly diminished

Organic Compounds

- Organic Chemistry is the study of compounds of Carbon, specifically those containing Hydrogen, Oxygen, Nitrogen, Halides, Sulfur, Phosphorus
- Organic compounds number in the millions and represent an extremely diverse group of products used in our society
  - Plastics
  - Dyes
  - Polymers
  - Fuels (gasoline, diesel, propane, Alcohol)
  - Herbicides, Pesticides
  - Pharmaceuticals (drugs)
  - Bio-molecules (DNA, proteins, fats, sugars, etc.)

A Biological Periodic Table



🟧 Building-block elements

🟩 Major minerals

🟦 Trace elements

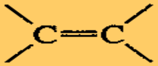
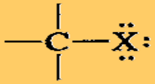
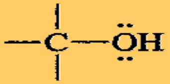
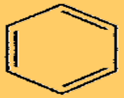
1A (1)																	8A (18)
H	2A (2)											3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	
												B	C	N	O	F	
Na	Mg	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	(8)	8B (9)	(10)	1B (11)	2B (12)		Si	P	S	Cl	
K	Ca			V	Cr	Mn	Fe	Co	Ni	Cu	Zn			As	Se		
					Mo								Sn			I	

Building Block Elements: Elements that make up the major portion of Biological compounds (99% of atoms, 96% mass of body weight) in organisms

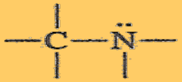
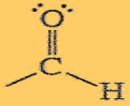
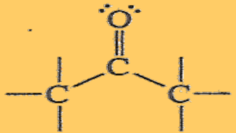
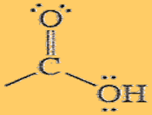
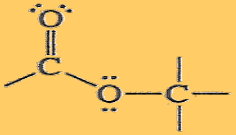
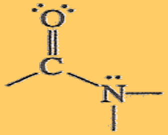
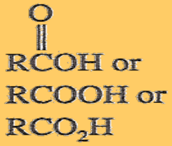
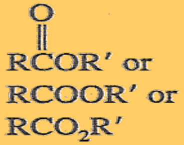
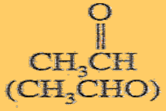
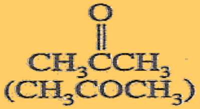
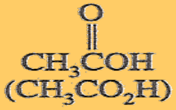
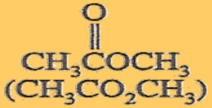
Major Minerals (macronutrients): 2% of Mass in organisms

Trace Elements (micronutrients): <<<1%; (Iron(Fe) 0.005%

Principal Families of Organic Compounds

	Alkane	Alkene	Alkyne	Aromatic	Halo alkane	Alcohol	Ether
Functional Group	**C—H and C—C bonds**		$-C\equiv C-$	**Aromatic Ring**	 $-\overset{\mid}{\underset{\mid}{C}}-\ddot{\underset{..}{X}}:$	 $-\overset{\mid}{\underset{\mid}{C}}-\ddot{\underset{..}{O}}H$	 $-\overset{\mid}{\underset{\mid}{C}}-\ddot{\underset{..}{O}}-\overset{\mid}{\underset{\mid}{C}}-$
General Formula	RH	$RCH{=}CH_2$ $RCH{=}CHR$ $R_2C{=}CHR$ $R_2C{=}CR_2$	$RC\equiv CH$ $RC\equiv CR'$	ArH	RX	ROH	ROR'
Specific Example	CH_3CH_3	$H_2C{=}CH_2$	$HC\equiv CH$		CH_3CH_2Cl	CH_3CH_2OH	CH_3OCH_3
IUPAC Name	**Ethane**	**Ethene**	**Ethyne**	**Benzene**	**Chloro-ethane**	**Ethanol**	**Methoxy-methane**
Common Name	**Ethane**	**Ethylene**	**Acetylene**	**Benzene**	**Ethyl chloride**	**Ethyl alcohol**	**Dimethyl ether**

Principle Families of Organic Compounds

	Amine	Aldehyde	Ketone	Carboxylic Acid	Ester	Amide	Nitrile
Functional Group							$-C\equiv N:$
General Formula	RNH_2 R_2NH R_3N	 $R\overset{O}{\overset{\|}{C}}H$ or $RCHO$	 $R\overset{O}{\overset{\|}{C}}R'$ or $RCOR'$	 $R\overset{O}{\overset{\|}{C}}OH$ or $RCOOH$ or RCO_2H	 $R\overset{O}{\overset{\|}{C}}OR'$ or $RCOOR'$ or RCO_2R'	 $R\overset{O}{\overset{\|}{C}}NH_2$ $R\overset{O}{\overset{\|}{C}}NHR'$ $R\overset{O}{\overset{\|}{C}}NR'R''$	RCN
Specific Example	CH_3NH_2	 $CH_3\overset{O}{\overset{\|}{C}}H$ (CH_3CHO)	 $CH_3\overset{O}{\overset{\|}{C}}CH_3$ (CH_3COCH_3)	 $CH_3\overset{O}{\overset{\|}{C}}OH$ (CH_3CO_2H)	 $CH_3\overset{O}{\overset{\|}{C}}OCH_3$ $(CH_3CO_2CH_3)$	 $CH_3\overset{O}{\overset{\|}{C}}NH_2$ (CH_3CONH_2)	$CH_3C\equiv N$
IUPAC Name	Methanamine	Ethanal	Propanone	Ethanoic Acid	Methyl ethanoate	Ethanamide	Ethanenitrile
Common Name	Methylamine	Acetaldehyde	Acetone	Acetic Acid	Methyl acetate	Acetamide	Acetonitrile

Elements, Compounds and Atomic Symbols

- *Elements* are unique combinations of protons, neutrons, electrons that exist in nature as populations of atoms

- A *Molecule* is an independent structure consisting of two or more atoms of the same or different elements chemically bound together

- A *compound* is a type of matter composed of two or more different elements that are chemically bound together

- Recall, a mixture is a group of two or more substances (compounds) physically intermingled, but not chemically combined

Compounds – Chemical Bonding

- In nature an overwhelming majority of elements occur in *chemical combination* with other elements – compounds

- Relatively few elements occur in nature in free form:

Noble Gases: He, Ne, Ar, Kr, Xe, Rn

Non-metals: O_2, N_2, S_2, C

Metals: Cu, Ag, Au, Pt

- *Compounds* are substances composed of two or more elements in *fixed* proportions

- *Compounds* are formed by the *interaction (bonding)* of the *valence* electrons between atoms

Chemical & Molecular Formulas

- *Chemical Formulas* – atomic symbols with subscripts to display the relative number and type of each atom in a molecule (compound)
- The *Elements* in a compound are present in a fixed mass ratio as denoted by numerical subscripts
- Examples:

H_2S	Hydrogen Sulfide (swamp gas)
$NaHCO_3$	Sodium Bicarbonate (antacid)
$C_7H_5N_3O_6$	Trinitrotoluene (TNT) (explosive)
NH_3	Ammonia
H_2SO_4	Sulfuric Acid
$NaCl$	Sodium Chloride (Common Salt)
C_2H_6	Ethane
CO	Carbon monoxide
CO_2	Carbon dioxide
H_2O	Water (Dihydrogen Oxide)

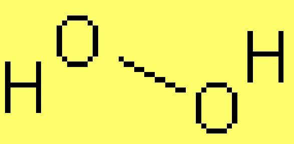
Chemical & Molecular Formulas

- Molecule – one or more atoms chemically bonded together in one *formula unit*
- Empirical Formula – Shows the smallest whole number ratio of numbers of atoms in a molecule
- Molecular formula – Shows actual No. atoms in molecule
- Structural formula – chemical formula showing how the atoms are bonded together in a molecule

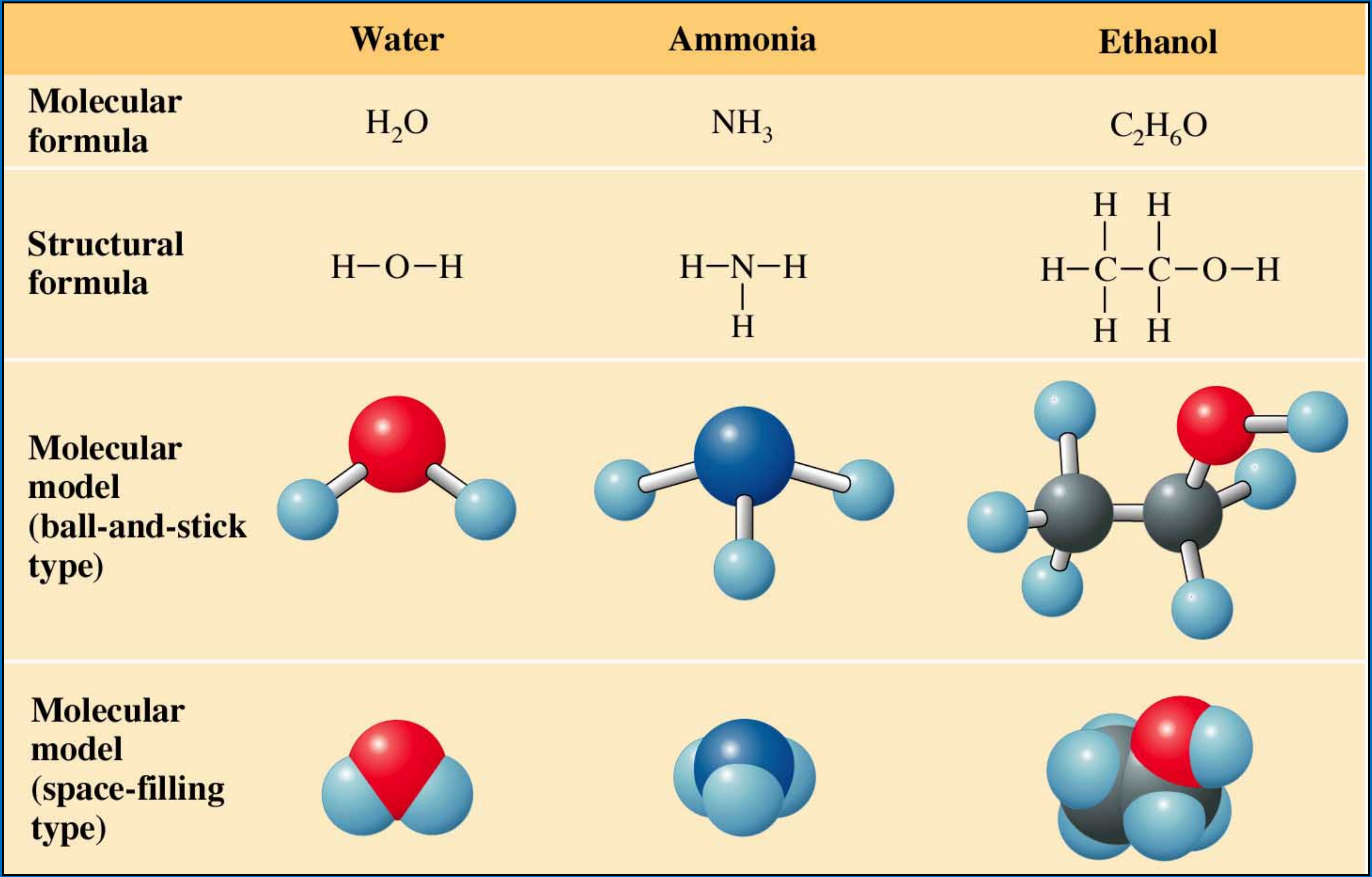
Ex. Hydrogen Peroxide (H_2O_2)

Empirical Formula: HO; Molecular Formula: H_2O_2

Structural:



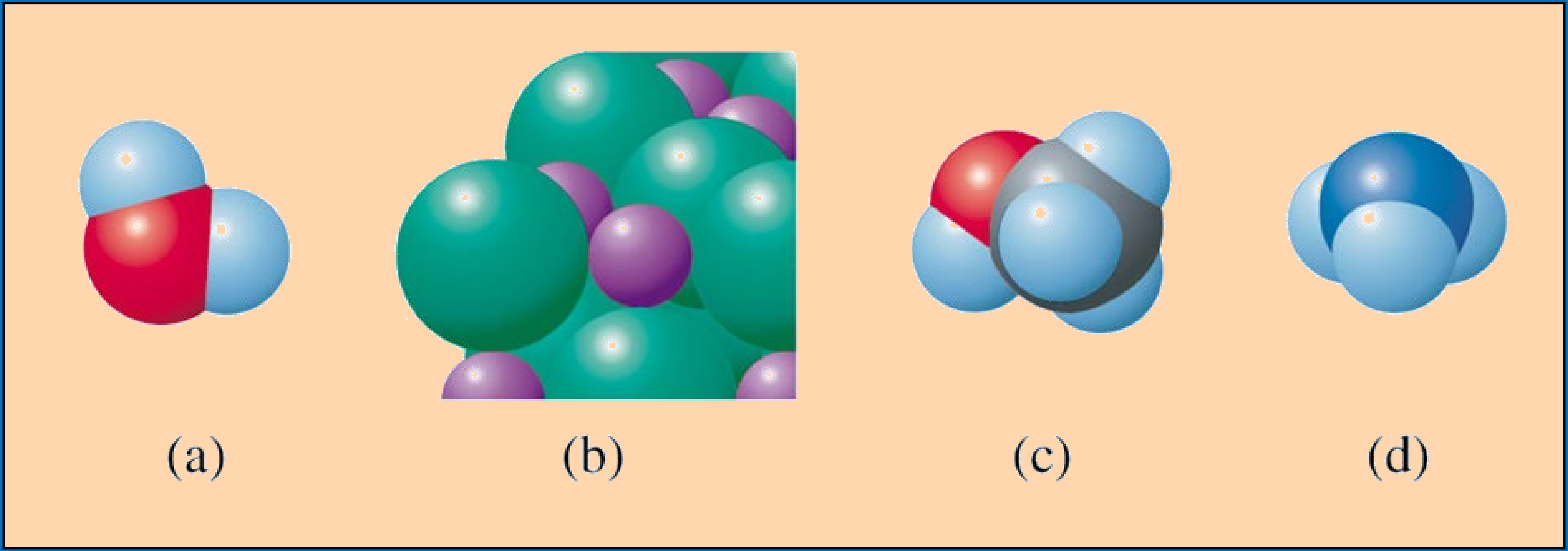
Molecular and Structural Formulas and Molecular Models



	Water	**Ammonia**	**Ethanol**
Molecular formula	H_2O	NH_3	C_2H_6O
Structural formula	$H-O-H$	$\begin{array}{ccccc} H & - & N & - & H \\ & & \vert & & \\ & & H & & \end{array}$	$\begin{array}{ccccccccc} & & H & & H & & & & \\ & & \vert & & \vert & & & & \\ H & - & C & - & C & - & O & - & H \\ & & \vert & & \vert & & & & \\ & & H & & H & & & & \end{array}$
Molecular model (ball-and-stick type)			
Molecular model (space-filling type)			

Practice Problem

- Match the molecular model with the correct chemical formula: CH_3OH, NH_3, KCl, H_2O



(a) – H_2O (b) – KCl (c) – CH_3OH (d) – NH_3

Practice Problem

The total number of atoms in one formula unit of $(C_2H_5)_4NClO_4$ (Tetraethylammonium Perchlorate) is:

a. 5 b. 13 c. 14 d. 34 e. 36

Ans: d

$$[(2+5) * 4] + 1 + 1 + 4 = 28 + 6 = 34$$

Molecular Masses & Chemical Formulas

- The Molecular Mass(MM or FM), also referred to as Molecular Weight (MW), of a compound is the sum of the atomic masses (weights) of all atoms in one formula unit of the compound
- The term "Molecular Mass(MM)" is often associated with compounds held together by "Covalent" bonds
- The term "Formula Mass(FM)" also refers to the molecular weight of a compound, but its formal definition refers to the sum of the atomic weights of the atoms in a formula unit of an ionic bonded compound
- The computation of Molecular or Formula masses is mathematically the same

Practice Problem

Determine the Molecular Mass of Water (H_2O)

Molecular Mass (Molecular Weight) = sum of atomic masses

H_2O

[2 x atomic mass hydrogen (H)] = 2 x 1.00794 amu

[1 x atomic mass of oxygen (O)] = 1 x 15.9994 amu

2.01588 amu + 15.9994 amu = 18.0152 amu

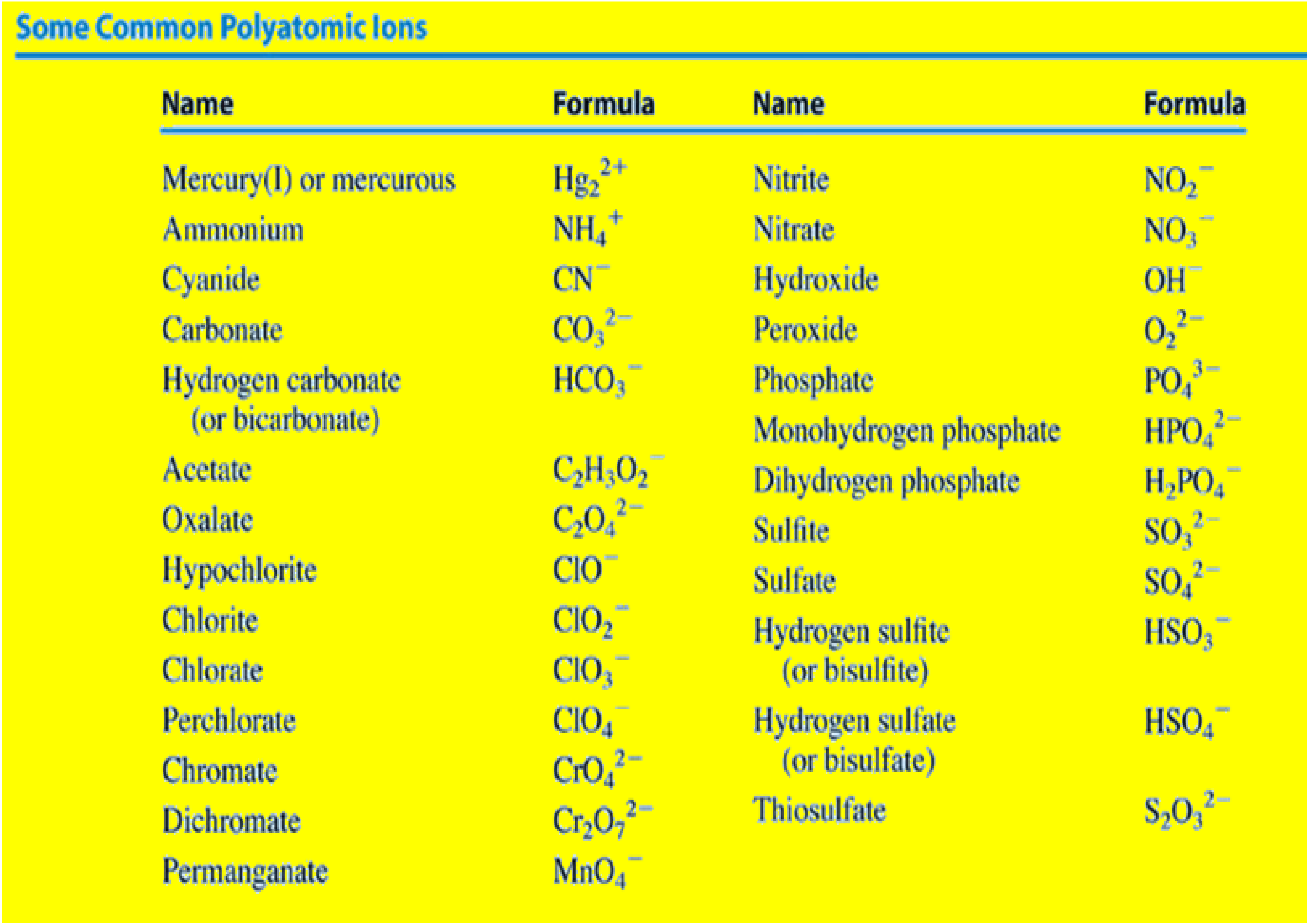
Compounds – Chemical Bonding (IONS)

- Ions are formed when atoms or groups of atoms gain or lose valence electrons
- An ion resulting from the gain or loss of valence electrons has the same number of electrons as the nearest "Noble" gas (Group VIIIA)
- Monatomic Ions – A single atom with an excess or deficient number of electrons
- Polyatomic ions – groups of atoms with an excess or deficient number of electrons
- Cations – positively charged ions
- Anions – negatively charged ions

Monatomic Cations & Anions

Common Cations			Transition Element Cations			Anions		
Charge	Formula	Name	Charge	Formula	Name	Charge	Formula	Name
+1	H^+	Hydrogen	+2	Cd^{2+}	Cadmium	-1	H^-	Hydride
+1	Li^+	Lithium	+2	Cr^{2+}	Chromium(II)	-1	F^-	Fluoride
+1	Na^+	Sodium	+3	Cr^{3+}	Chromium(III)	-1	Cl^-	Chloride
+1	K^+	Potassium	+2	Mn^{2+}	Manganese (II)	-1	Br^-	Bromide
+1	Cs+	Cesium	+2	Fe^{2+}	Iron(II)	-1	I^-	Iodide
+2	Mg^{2+}	Magnesium	+3	Fe^{3+}	Iron(III)	-2	O_2^-	Oxide
+2	Ca^{2+}	Calcium	+2	Co^{2+}	Cobalt(II)	-2	S_2^-	Sulfide
+2	Sr^{2+}	Strontium	+3	Co^{3+}	Cobalt(III)			
+2	Ba^{2+}	Barium	+2	Ni^{2+}	Nickel(II)			
+3	Al^{3+}	Aluminum	+1	Cu^+	Copper(I)			
			+2	Cu^{2+}	Copper(II)			
			+2	Zn^{2+}	Zinc			
			+1	Hg_2^{2+}	Mercury(I)			
			+2	Hg^{2+}	Mercury(II)			

Polyatomic Ions



Some Common Polyatomic Ions

Name	Formula	Name	Formula
Mercury(I) or mercurous	Hg_2^{2+}	Nitrite	NO_2^-
Ammonium	NH_4^+	Nitrate	NO_3^-
Cyanide	CN^-	Hydroxide	OH^-
Carbonate	CO_3^{2-}	Peroxide	O_2^{2-}
Hydrogen carbonate (or bicarbonate)	HCO_3^-	Phosphate	PO_4^{3-}
		Monohydrogen phosphate	HPO_4^{2-}
Acetate	$C_2H_3O_2^-$	Dihydrogen phosphate	$H_2PO_4^-$
Oxalate	$C_2O_4^{2-}$	Sulfite	SO_3^{2-}
Hypochlorite	ClO^-	Sulfate	SO_4^{2-}
Chlorite	ClO_2^-	Hydrogen sulfite (or bisulfite)	HSO_3^-
Chlorate	ClO_3^-		
Perchlorate	ClO_4^-	Hydrogen sulfate (or bisulfate)	HSO_4^-
Chromate	CrO_4^{2-}		
Dichromate	$Cr_2O_7^{2-}$	Thiosulfate	$S_2O_3^{2-}$
Permanganate	MnO_4^-		

Nomenclature
Charges & Ionic Compounds

- Nomenclature – systematic way of naming things
  - Rules for charges on monatomic ions
    - Elements in "A" groups I, II, III & IV have charges equal to group no; e.g., Na^+, Mg^{2+}, Al^{3+}; Pb^{4+}
    - Group IV elements also commonly have ions of charge +2; e.g., Pb^{2+}, Sn^{2+}
    - For nonmetals in groups V-VII, the charge is:
      ([V-VII] – 8): e.g., $N^{3-\,(5-8)}$, $O^{2-\,(6-8)}$, $Cl^{-\,(7-8)}$
    - Transition elements (B group), usually have a charge of 2+ but typically form more than one ion

Predicting the Ion and 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 (atomic number) to find the element

Find relationship of element to the nearest noble gas

Group I –IV elements lose electrons and assume the electron configuration of the noble gas of the "Period" just above

Group V-VII elements gain electrons and assume the configuration of the noble gas of the same period

Predicting the Ion and Element Forms

Exs:

a. Iodine is a nonmetal in Group 7A(17)

It gains 1 electron to have the same number of electrons as $_{54}$Xe (I^-),
i.e., Iodine is in same row as Xe

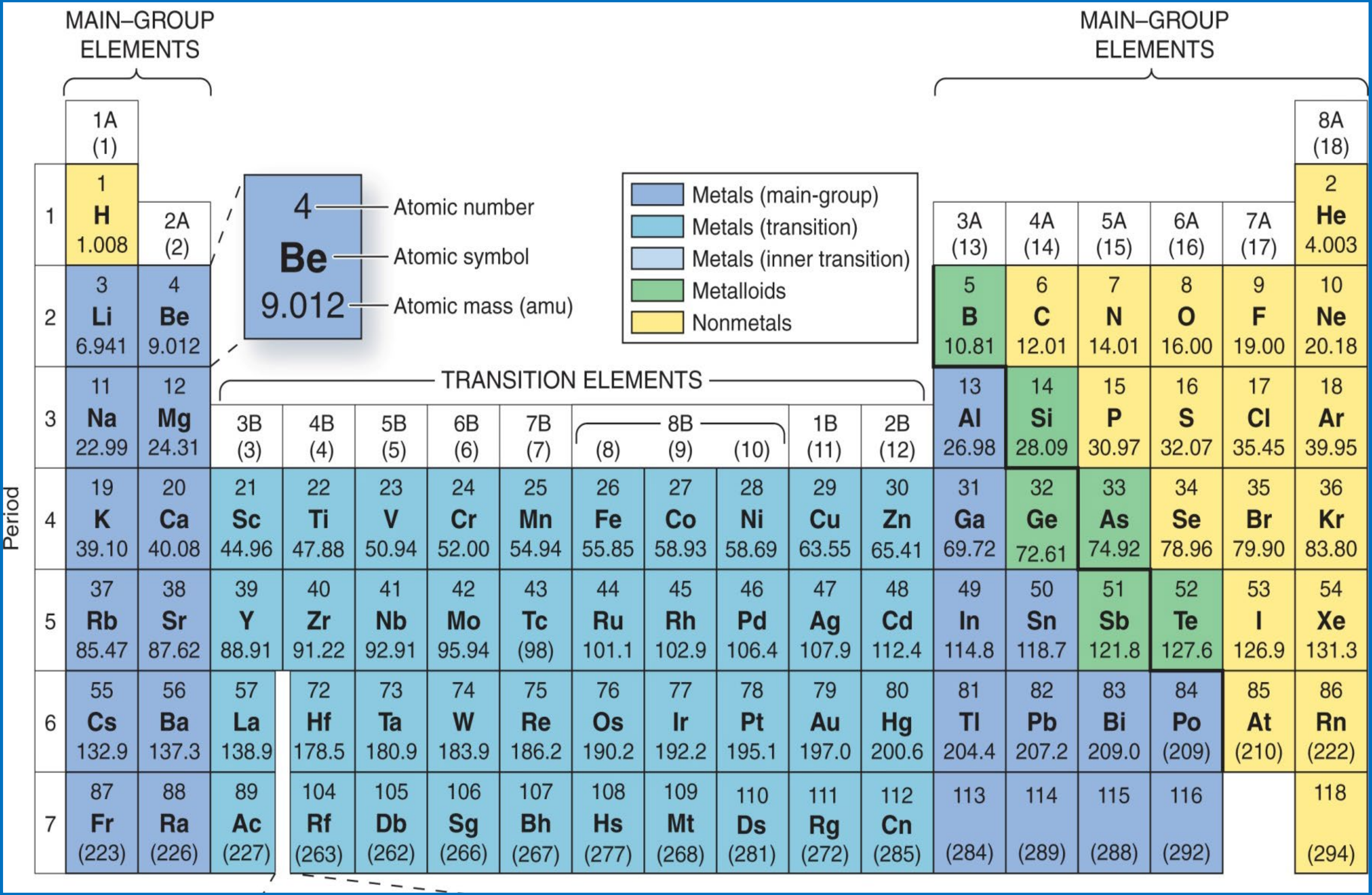
b. Calcium is a metal in Group 2A(2)

It loses 2 electrons to have the same number of electrons as $_{18}$Ar (Ca^{2+}),
i.e, Ar is in row 3 while Ca is in row 4

c. Aluminum is a metal in Group 3A(13)

It loses 3 electrons to have the same number of electrons as $_{10}$Ne (AL^{3+}),
i.e., Ne is in row 2 while Al is in row 3

Predicting the Ion and Element Forms



Period	1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	8B (9)	8B (10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.41	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
6	55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (263)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (267)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (281)	111 **Rg** (272)	112 **Cn** (285)	113 (284)	114 (289)	115 (288)	116 (292)		118 (294)

Chemical Bonding – Ionic Compounds

- Coulomb's Law: The energy of attraction (or repulsion) between two particles is directly proportional to the product of the charges and inversely proportional to the distance between them
- Cations – positively charged atoms usually metals from groups I & II)
- Anions – negatively charged nonmetals, usually halogens, oxygen, sulfur, nitrogen from groups V, VI, VII)

Chemical Bonding – Compounds

- The Transfer of electrons between cations and anions forms

Ionic compounds

- The Sharing of electrons between atoms forms

Covalent compounds

- The formation of Ionic and Covalent compounds generate Chemical Bonds, representing the energy of the forces that hold the atoms of elements together in a compound

Chemical Bonding – Ionic Compounds

The strength of the Ionic bond depends on the extent of the net strength of the attractions and repulsions of the ion charges

Ionic Compounds are neutral, continuous arrays of oppositely charged cations & anions, not a collection of individual molecules, e.g., Na^+ & Cl^- ions, not NaCl molecules

Covalent Compounds

- Covalent compounds are formed by the sharing of electrons, normally between nonmetals
- Diatomic Covalent Compounds
  - Hydrogen, as it exists in nature, is a diatomic molecule (H_2) in which the single electron from each atom is shared by the other atom forming a covalent bond at an electrostatically optimum distance
  - Other examples of diatomic molecules with covalent bonds include:

N_2 O_2 F_2 Cl_2 Br_2 I_2

  - Tetratomic and Octatomic molecules also exist and have covalent bonds:

P_4 S_8 Se_8

Covalent Compounds

- Polyatomic Covalent Compounds contain atoms of different elements (usually 2 non-metals) also form covalent compounds
- In Hydrogen Fluoride (HF) the single Hydrogen electron forms a covalent bond with the single valence electron of the Fluoride atom

  Other examples:

  H_2O, NH_3, CO_2, and all organic compounds
- When the maximum attractive force matches the maximum repulsive force between the two approaching atoms, the resulting potential energy of the system is at a minimum, resulting in a stable covalent bond

Covalent Bonds within Ions

- Many Ionic compounds contain polyatomic ions
- Polyatomic ions consist of two or more atoms bonded covalently, usually with a net negative charge

Ex. Calcium Carbonate - $CaCO_3$

An Ionic Compound containing:

monatomic Ca^{++} cation & polyatomic CO_3^{2-} anion

- The Carbonate ion consists of a carbon atom covalently bonded to 3 oxygen atoms plus 2 additional electrons to give the net charge of 2-

Practice Problem

Sodium Oxide combines violently with water

Which of the following gives the formula and the bonding for sodium oxide?

a. NaO ionic compound
b. NaO covalent compound
c. Na_2O ionic compound
d. Na_2O covalent compound
e. Na_2O_2 ionic compound

Ans: c

Sodium is a metal; Oxygen is a nonmetal

Metals & nonmetals usually form ionic compounds

Each Sodium atom loses 1 electron to form a cation

Each Oxygen atom gains two electrons to form anion

Practice Problem

Describe the type and nature of the bonding occurring in a sample of P_4O_6?

a. metal & nonmetal forming ionic bond

b. two nonmetals forming covalent bond

c. two metals forming covalent bond

d. nonmetal & metal forming covalent bond

Ans: b

P (Phosphorus) and O (Oxygen) are both nonmetals

They will bond covalently to form P_4O_6

Nomenclature: Naming of Compounds

- Monatomic cations are named after the element, commonly with an "ium" ending:
  K^+ potassium, Mg^{2+} magnesium, Cs^+ cesium
- If the element can exist in more than one oxidation state (different ionic charges), the element name is followed by the ionic charge in parenthesis:

  Fe^{2+} iron (II), Fe^{3+} iron (III)
- Monatomic anions use the stem from the element name with the –ide suffix

  Cl^- = chloride

  O^{2-} = oxide

  N^{3-} = nitride

  S^{2-} = sulfide

Practice Problem

Name the following ionic compounds from their formulas.

(a) BaO (b) $Cr_2(SO_4)_3$

Ans:

(a) Barium Oxide

(b) Chromium (III) Sulfate

Practice Problem

What is the formula of Magnesium Nitride, which is composed of Mg^{2+} and N^{3-} ions?

Ans:

Mg_3N_2

Nomenclature
Binary Molecular Compounds

- Formed by 2 nonmental or metalloid atoms bonded together
- The name of the compound has the elements in order of convention
- Name the 1st element using element name
- Name the 2nd element by writing the stem of the element with –ide suffix (as if an anion in ionic)
- Add Greek prefix for each element as needed to correspond to formula

H_2O = dihydrogen oxide (water, of course!)

N_2O = dinitrogen oxide (laughing gas)

P_2O_5 = diphosphorus pentoxide (no "a" in penta)

Examples of Binary Molecular Compounds

BF_3

Boron Trifluoride

IBr

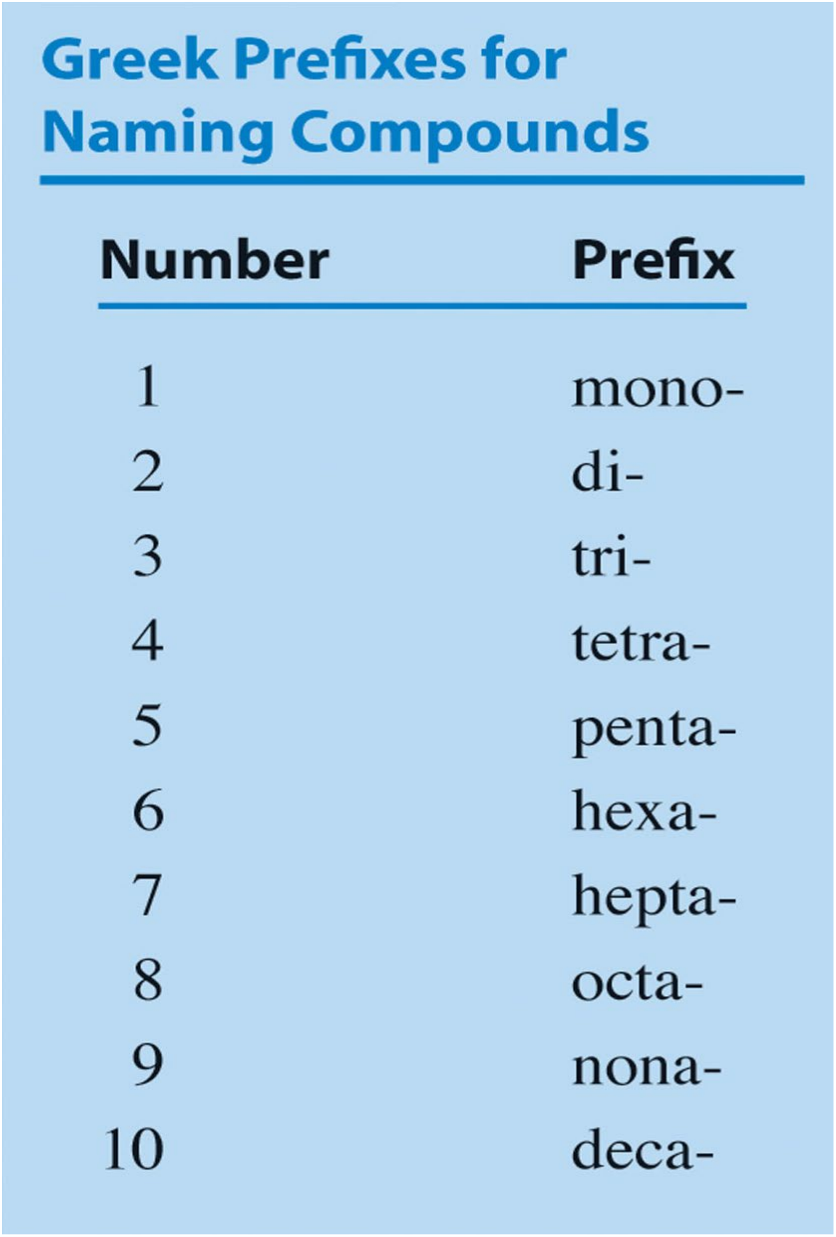
Iodine Monobromide

SO_2

Sulfur Dioxide

$SiCl_4$

Silicon Tetrachloride



Greek Prefixes for Naming Compounds

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

Practice Problem

Give the formula for each of the binary compounds

(a) Carbon Disulfide (b) Nitrogen Tribromide

(c) Dinitrogen Tetrafluoride

Ans:

(a) CS_2

(b) NBr_3

(c) N_2F_4

Nomenclature - Polyatomic Oxoanions

- Polyatomic ion: 2 or more atoms bonded together forming an ion
- Oxoanions: polyatomic anions with a *nonmetal* bonded to 1 or more Oxygen atoms
- Oxoanions have the suffix *–ite* or *–ate*

ate – oxoanion with most oxygen

ite – oxoanion with fewer oxygen

NO_2^- = Nitrite SO_3^{2-} = Sulfite

NO_3^- = Nitrate SO_4^{2-} = Sulfate

Nomenclature - Polyatomic anoxions

- In cases where more than 2 forms exist, use *hypo-* and *per-* prefixes in addition to the *–ate & -ite* suffixes
  - Ion with most O atoms has prefix *per-*, the nonmetal *root*, and suffix –ate

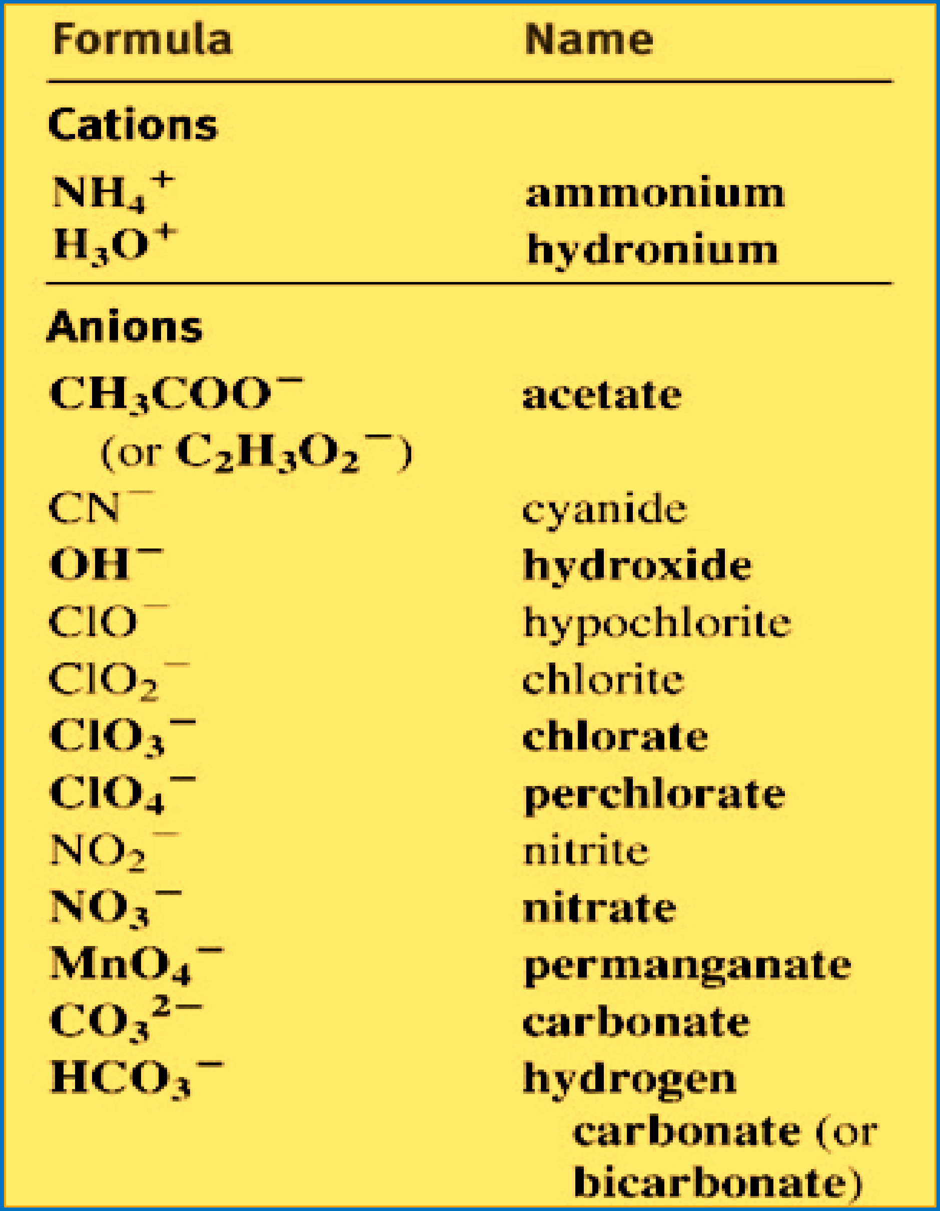
    ClO_4^- (Perchlorate)
  - Ion with one fewer O has nonmetal root & suffix –ate

    ClO_3^- (Chlorate)
  - Ion with two fewer O has nonmetal root & suffix –ite

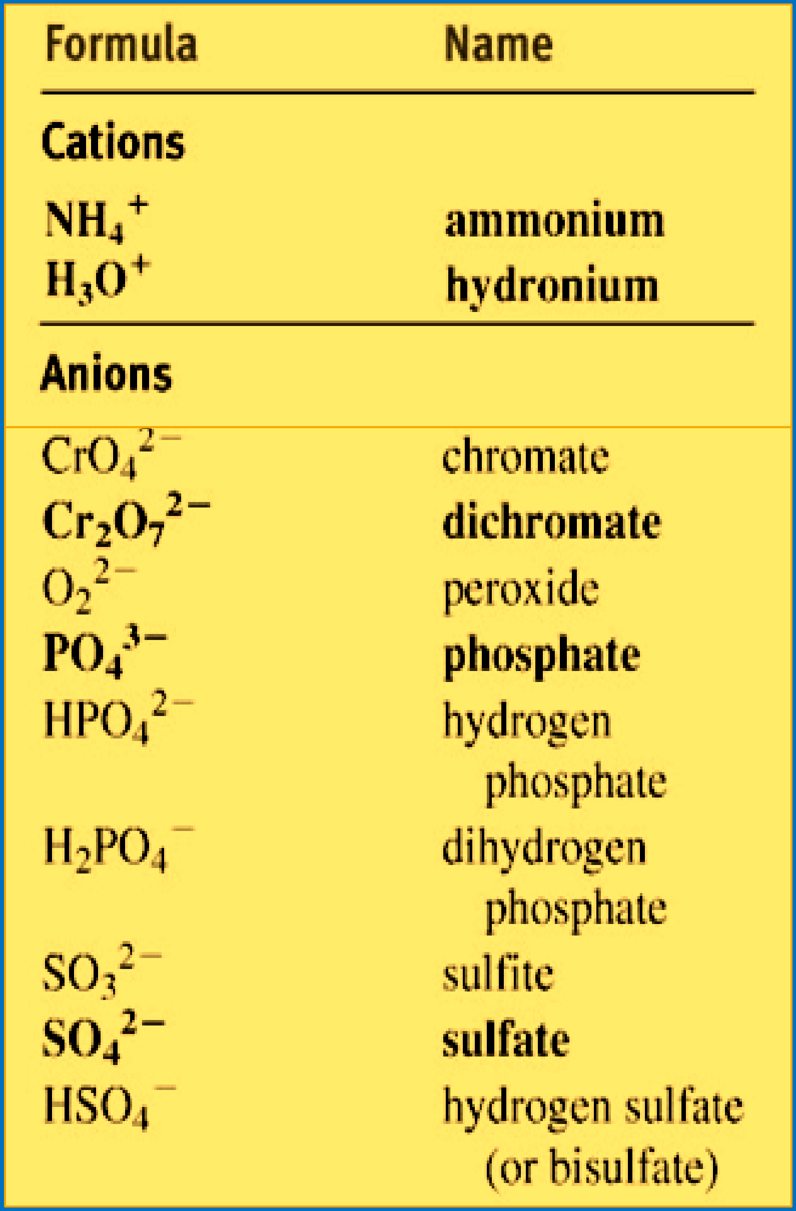
    ClO_2^- (Chlorite)
  - Ion with three fewer O has prefix hypo, nonmetal root, and suffix –ite

    ClO^- (Hypochlorite)

Common Polyatomic Ions



Formula	**Name**
Cations	
NH_4^+	ammonium
H_3O^+	hydronium
Anions	
CH_3COO^- (or $C_2H_3O_2^-$)	acetate
CN^-	cyanide
OH^-	hydroxide
ClO^-	hypochlorite
ClO_2^-	chlorite
ClO_3^-	chlorate
ClO_4^-	perchlorate
NO_2^-	nitrite
NO_3^-	nitrate
MnO_4^-	permanganate
CO_3^{2-}	carbonate
HCO_3^-	hydrogen carbonate (or bicarbonate)



Formula	**Name**
Cations	
NH_4^+	ammonium
H_3O^+	hydronium
Anions	
CrO_4^{2-}	chromate
$Cr_2O_7^{2-}$	dichromate
O_2^{2-}	peroxide
PO_4^{3-}	phosphate
HPO_4^{2-}	hydrogen phosphate
$H_2PO_4^-$	dihydrogen phosphate
SO_3^{2-}	sulfite
SO_4^{2-}	sulfate
HSO_4^-	hydrogen sulfate (or bisulfate)

Practice Problem

Name the Following Compounds

Na_2SO_4

Sodium Sulfate

Na_2SO_3

Sodium Sulfite

AgCN

Silver Cyanide

$Cd(OH)_2$

Cadmium Hydroxide

$Ca(OCl)_2$

Calcium Hypochlorite

$KClO_4$

Potassium Perchlorate

Practice Problem

The formula for Copper(II) Phosphate is:

a. $CoPO_4$

b. $CuPO_4$

c. $Co_2(PO_4)_3$

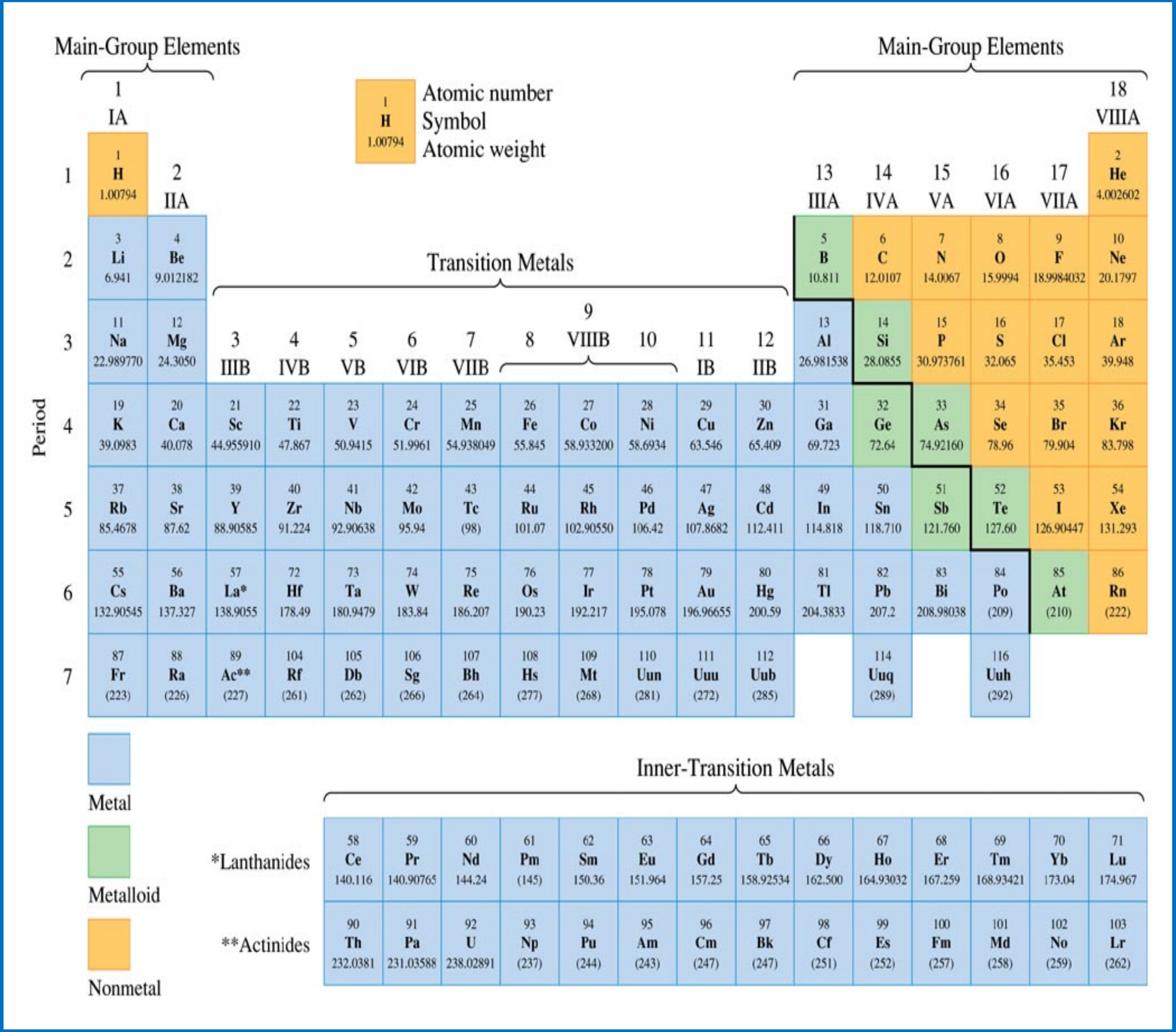
d. $Cu_2(PO_4)_3$

e. $Cu_3(PO_4)_2$

Ans: e

Cu^{+2} $(3x2^{+}) = +6$

PO_4^{-3} $(2x3^{-}) = -6$



Main-Group Elements — Transition Metals — Main-Group Elements

1
H
1.00794 — Atomic number, Symbol, Atomic weight

Period	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 **H** 1.00794																	2 **He** 4.002602
2	3 **Li** 6.941	4 **Be** 9.012182											5 **B** 10.811	6 **C** 12.0107	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984032	10 **Ne** 20.1797
3	11 **Na** 22.989770	12 **Mg** 24.3050											13 **Al** 26.981538	14 **Si** 28.0855	15 **P** 30.973761	16 **S** 32.065	17 **Cl** 35.453	18 **Ar** 39.948
4	19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.955910	22 **Ti** 47.867	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.938049	26 **Fe** 55.845	27 **Co** 58.933200	28 **Ni** 58.6934	29 **Cu** 63.546	30 **Zn** 65.409	31 **Ga** 69.723	32 **Ge** 72.64	33 **As** 74.92160	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.798
5	37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.90585	40 **Zr** 91.224	41 **Nb** 92.90638	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.90550	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.411	49 **In** 114.818	50 **Sn** 118.710	51 **Sb** 121.760	52 **Te** 127.60	53 **I** 126.90447	54 **Xe** 131.293
6	55 **Cs** 132.90545	56 **Ba** 137.327	57 **La*** 138.9055	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.84	75 **Re** 186.207	76 **Os** 190.23	77 **Ir** 192.217	78 **Pt** 195.078	79 **Au** 196.96655	80 **Hg** 200.59	81 **Tl** 204.3833	82 **Pb** 207.2	83 **Bi** 208.98038	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 **Ac**** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Uun** (281)	111 **Uuu** (272)	112 **Uub** (285)		114 **Uuq** (289)		116 **Uuh** (292)		

Inner-Transition Metals

*Lanthanides	58 **Ce** 140.116	59 **Pr** 140.90765	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.964	64 **Gd** 157.25	65 **Tb** 158.92534	66 **Dy** 162.500	67 **Ho** 164.93032	68 **Er** 167.259	69 **Tm** 168.93421	70 **Yb** 173.04	71 **Lu** 174.967
**Actinides	90 **Th** 232.0381	91 **Pa** 231.03588	92 **U** 238.02891	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

🟦 Metal

🟩 Metalloid

🟧 Nonmetal

Nomenclature - Acids and Oxoacids

- Acids are compounds that yield H^+ ions in solution
- Oxoacid: acid containing hydrogen, oxygen and one other nonmetal element (central atom)
- Oxoacids names are related to names of oxoanions

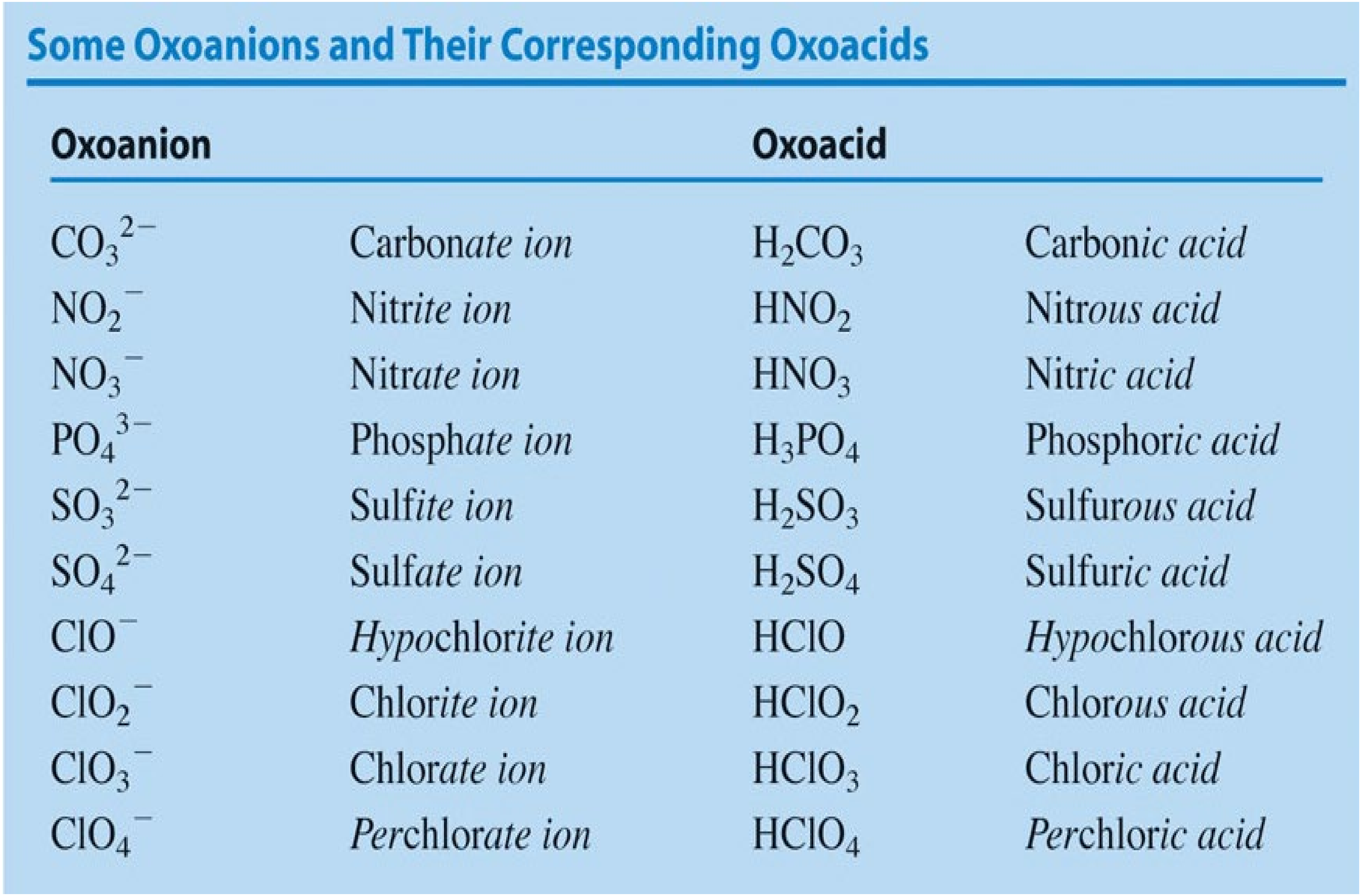
-ide (anion) = -ic (acid)

-ate (anion) = -ic (acid)

-ite (anion) = -ous (acid)

H_2SO_4 = Sulfuric Acid (Sulfate Anion)
H_2SO_3 = Sulfurous Acid (Sulfite Anion)
HCl = Hydrochloric Acid (Chloride Anion)
HClO = Hypochlorous Acid (Hypochorite Anion)
$HClO_4$ = Perchloric Acid (Perchlorate Anion)

Oxoanions / Oxoacids



Some Oxoanions and Their Corresponding Oxoacids

Oxoanion		**Oxoacid**	
CO_3^{2-}	Carbon*ate ion*	H_2CO_3	Carbon*ic acid*
NO_2^-	Nitr*ite ion*	HNO_2	Nitr*ous acid*
NO_3^-	Nitr*ate ion*	HNO_3	Nitr*ic acid*
PO_4^{3-}	Phosph*ate ion*	H_3PO_4	Phosphor*ic acid*
SO_3^{2-}	Sulf*ite ion*	H_2SO_3	Sulfur*ous acid*
SO_4^{2-}	Sulf*ate ion*	H_2SO_4	Sulfur*ic acid*
ClO^-	*Hypo*chlor*ite ion*	$HClO$	*Hypo*chlor*ous acid*
ClO_2^-	Chlor*ite ion*	$HClO_2$	Chlor*ous acid*
ClO_3^-	Chlor*ate ion*	$HClO_3$	Chlor*ic acid*
ClO_4^-	*Per*chlor*ate ion*	$HClO_4$	*Per*chlor*ic acid*

Nomenclature - Hydrates

- A hydrate is a compound that contains water molecules weakly bound in its crystals
- Hydrates are named from the anhydrous (dry) compound, followed by the word "hydrate" with a prefix to indicate the number of water molecules per formula unit of the compound

Ex:

$CuSO_4 \bullet 5\ H_2O$

Copper(II) Sulfate Pentahydrate