CHEMISTRY 109 – Help Sheet #2
REVIEW (Part II): Atoms, Molecules, and Ions

***** Review the appropriate topics for your lecture*****

Prepared by Dr. Tony Jacob
https://clc.chem.wisc.edu *(Resources page)*

Nuggets: *Atomic Structure; Isotopes; Counting neutrons, protons, electrons; Average Atomic Mass; Ionic versus molecular compounds; Naming chemicals; Writing formulas from names; Polyatomic ions; Coulomb's law*

EXPERIMENTS

Rutherford's Au Foil Experiment: Mass of atom is concentrated in a highly dense nucleus that was positively charged; the rest of the atom has only a minimal of mass but determines the atom's volume

ATOMIC STRUCTURE

Nucleus: contains nearly all the atom's mass; neutrons and protons located in the nucleus; very small volume of atom; extremely dense; atom is mostly empty space

Elements: ***determined*** by the number of ***protons*** they contain

Masses of all atoms are compared to ***^{12}C which is the standard***;

^{12}C is defined as 12.0000... atomic mass units (exact value) = 12.0000...amu; *(amu = atomic mass units)*

1 amu = $^1/_{6.022 \times 10^{23}}$ = 1.6605×10^{-24}g

Neutron (n): has a neutral charge; mass = 1amu ≈ 1×10^{-24}g (1.6749×10^{-24}g)

Proton (p^+): has a charge of +1; mass = 1amu ≈ 1×10^{-24}g (1.6726×10^{-24}g)

Electron (e^-): has a charge of -1; mass = 0.0005amu ≈ 1×10^{-27}g (9.1094×10^{-28}g)

Relative masses: $n > p^+ >> e^-$; mass of $n \approx p^+ \approx 1$ with $e^- \approx 1/2000$

ISOTOPES: elements with the same #p^+ (same element) but different #n (different mass)

Isotope Symbol: $^{A}_{Z}$Element Symbol **A = *mass number* = #p^+ + #n; Z = *atomic number* = #p^+**

C isotopes: $^{12}_{6}C$, $^{13}_{6}C$, and $^{14}_{6}C$; the 3 isotopes of C each have Z = 6 (6p^+) but different #n (6, 7, and 8, respectively)

AVERAGE ATOMIC MASS (AAM): weighted average of all isotopes of one element taking into account the abundance of each isotope; units = amu; e.g., average atomic mass Br = 79.90amu

Abundance: percent of one isotope as compared to all atoms of that given element

AVERAGE ATOMIC MASS (AAM) = Σ(mass of isotope) x (fractional abundance)

AAM = $(\text{mass}_{\text{iso1}})(\text{fractional abundance}_{\text{iso1}}) + (\text{mass}_{\text{iso2}})(\text{fractional abundance}_{\text{iso2}}) + \ldots =$

$$\mathbf{AAM = (M_1)(FA_1) + (M_2)(FA_2) + \ldots}$$

Sum of fractional abundances = 1.00 (i.e., 100%); for elements with only 2 isotopes: **$FA_1 + FA_2 = 1$**

Example 1: Calculate the average atomic mass of an element given following data: isotope 1: 27.977amu, 92.21% abundance; isotope 2: 28.976amu, 4.70% abundance; and isotope 3: 29.974amu, 3.09% abundance.

Answer 1: AAM = $(M_1)(FA_1) + (M_2)(FA_2) + (M_3)(FA_3)$ = (27.977)(0.9221) + (28.976)(0.0470) + (29.974)(0.0309) = 28.09amu

Example 2: What are the abundances of the 2 B isotopes (^{10}B mass = 10.0129u, ^{11}B mass = 11.0093amu), if the average atomic mass of B is 10.811amu?

Answer 2: AAM = (M1)(FA1) + (M2)(FA2); 10.811 = 10.0129x + 11.0093y; since there are 2 unknowns 2 equations are needed; second equation: FA1 + FA2 = 1 (which is 100%); x + y = 1 → y = 1 - x; substitute this into the first equation: 10.811 = 10.0129x + 11.0093(1-x); solve for x: 10.811 = 10.0129x +11.0093 – 11.0093x → 0.1983 = 0.9964x → x = 0.1990 = 19.90%; y = 1-x = 1-0.1990 = 0.8010 = 80.10%; since x was the abundance for ^{10}B → abundance of ^{10}B = 19.90% and abundance of ^{11}B = y = 80.10%}

IONIC COMPOUNDS: contain metal + nonmetal (can substitute a polyatomic ion for either or both)

Properties: extended solids; not discrete molecules; high melting/boiling points; conducts electricity in molten state; Examples: $NaCl(s)$, $Ca(NO_3)_2(s)$, $NH_4NO_3(s)$, $AgCl(s)$

Ions: atoms or molecules that have lost/gained e^- (charges are not changed by gaining/losing protons!)

Cations: *positively* charged atoms (electrons have been lost)

Anions: *negatively* charged atoms (electrons have been gained)

Polyatomic Ions: "many-atom ions"; these compounds are *not broken up* and are treated as a group:

Name	Formula
Ammonium	NH_4^+
Hydronium	H_3O^+
Hydroxide	OH^-
Cyanide	CN^-
Acetate	CH_3COO^-
Nitrate	NO_3^-
Nitrite	NO_2^-
Permanganate	MnO_4^-
Perchlorate	ClO_4^-
Chlorate	ClO_3^-
Chorite	ClO_2^-
Hypochorite	ClO^-
Carbonate	CO_3^{-2}
Hydrogen carbonate	HCO_3^-
Sulfate	SO_4^{-2}
Hydrogen sulfate	HSO_4^-
Sulfite	SO_3^{-2}
Hydrogen sulfite	HSO_3^-
Chromate	CrO_4^{-2}
Dichromate	$Cr_2O_7^{-2}$
Phosphate	PO_4^{-3}
Monohydrogen phosphate	HPO_4^{-2}
Dihydrogen phosphate	$H_2PO_4^-$

Be familiar with the ions your course requires

Charges on elements *in* Ionic Compounds based on the column of Periodic Table the element resides in:

Group IA: +1 (H^+, Li^+, ...) Group IIA: +2 (Be^{+2}, Mg^{+2}, ...)

Group IIIA: +3 (B^{+3}, Al^{+3}, ...)

Group VA: -3 (N^{-3}, P^{-3}, ...) Group VIA: -2 (O^{-2}, S^{-2}, ...)

Group VIIA: -1 (F^-, Cl^-, ...)

Naming

- **Metal + Nonmetal** → ionic compound; ***metal name followed by nonmetal "root"+"ide"***
  Example 3: What is the name for $CaCl_2$? → ***Answer 3***: calcium chloride (note: not dichloride!)
- **Contains one or two Polyatomic Ions** → ionic compound; ***use polyatomic ion name***
  Example 4: What is the name for $Ca_3(PO_4)_2$? → ***Answer 4***: calcium phosphate
  (note: not tricalcium nor diphosphate!)
  Example 5: What is the name for $(NH_4)_2SO_4$? → ***Answer 5***: ammonium sulfate
  (note: not diammonium!)
- **Contains Transition Metal** → ionic compound; ***metal name (charge in Roman numerals)***
  Example 6: What is the name for $Fe_2(SO_4)_3$? → ***Answer 6***: iron(III) sulfate (see below for process to follow)
  1. ***Transition metals*** have charges that vary so the ***metal charge*** needs to be determined and specified in the name; the charge is written in Roman numerals in parentheses after the metal name
  2. Find charge on Fe. First, SO_4 charge is -2 (*memorized*); total negative charge: 3(-2) = -6 from the 3 SO_4^{-2}; since the compound is neutral the 2 Fe must total +6 → therefore, each Fe = +3 = Fe^{+3}; the Roman numeral for 3 = III

Writing Formulas

1. Take metal name or polyatomic ion and write formula including charge
   - If metal has a Roman numeral, then charge is determined from that numeral (e.g., copper(II) = Cu^{+2})
   - If it does not have a Roman numeral, it is a memorized polyatomic ion (e.g., ammonium = NH_4^+) or determined from the column in the Periodic Table it resides in (e.g., magnesium = Mg^{+2} since it is in column IIA)
2. Take nonmetal name or polyatomic ion and write formula including charge
   - If nonmetal name ends with "ide" it is a ***single atom ion*** with a negative charge with the charge determined from column in Periodic Table it resides in (e.g., chloride = Cl^- since column VIIA has a -1 charge); exceptions: hydrox**ide** (OH^-) and cyan**ide** (CN^-) are polyatomic ions with a name that ends in "ide"
   - If name ends with "ite" or "ate", or starts with "hypo" or "per" it is a memorized polyatomic ion
3. Balance charges within formula

Example 7: Write formula for chromium(III) carbonate.

Answer 7: charge on Cr is → Cr^{+3} from Roman numeral; carbonate = CO_3^{-2} (*memorized*) → $Cr_x(CO_3)_y$; choose x and y to balance the charge: x = 2 → [2(+3) = +6] and y = 3 → [3(-2) = -6]; +6 balances -6 → $\mathbf{Cr_2(CO_3)_3}$

MOLECULAR COMPOUNDS: contain 2 nonmetal elements;

Properties: low melting/boiling points; discrete molecules; do not conduct electricity

Examples: $CO(g)$, $CO_2(g)$, $N_2O_4(g)$

***Naming:* Prefix (if greater than 1)+1st nonmetal name & Prefix(always)+2nd nonmetal root+"ide"**

Prefixes: mono (1), di (2), tri (3), tetra (4), penta (5), hexa (6), hepta (7), octa (8), nona (9), deca (10)

Example 8: What is the name for NO? (Has 2 nonmetals → molecular compound)

Answer 8: Has one N → no prefix → ***nitrogen***; has one O → prefix always used = mono; ***monoxide*** → answer: **nitrogen monoxide**

Example 9: What is the name for N_2O? (Has 2 nonmetals → molecular compound)

Answer 9: Has two N → use prefix = di → ***dinitrogen***; has one O → prefix always used = mono; ***monoxide*** → **dinitrogen monoxide**

Writing Formulas - translate name with prefixes

Example 10: What is the formula for disulfur trioxide?

Answer 10: disulfur → 2 S atoms; trioxide → 3 O atoms; answer: S_2O_3

ACIDS

Naming *– chemicals named as acids are* *<u>neutral</u>* *compounds (e.g., SO_4^{-2} and HSO_4^{-2} are not named as acids but H_2SO_4 is named as an acid)*

Acids that contain anions ending in

"ide": change "ide" to "ic", add "hydro" in front and "acid" at end; e.g., Cl^- = chloride; HCl = ***hydro**chlor**ic acid***

"ate": change "ate" to "ic" and add "acid" at the end; e.g., SO_4^{-2} = sulfate; H_2SO_4 = sulfur***ic acid***

Common acids to know: Strong acids: HCl (hydrochloric acid), HBr (hydrobromic acid), HI (hydroiodic acid), HNO_3 (nitric acid), H_2SO_4 (sulfuric acid), $HClO_4$ (perchloric acid);

Common Weak acids: HF (hydrofluoric acid), HCN (hydrocyanic acid), H_3PO_4 (phosphoric acid), CH_3COOH (acetic acid), H_2CO_3 (carbonic acid)

---

1. Determine the number of protons, neutrons, and electrons present in each of the following atoms/ions.

a. ${}^{53}_{24}Cr$ b. ${}^{55}_{25}Mn$ c. ${}^{28}_{13}Al^{+3}$ d. ${}^{59}_{28}Ni^{+2}$ e. ${}^{36}_{17}Cl^{-}$

2. Write the complete ***isotopic symbol*** with mass and atomic number for each question.

a. a neutral atom with 28 protons and 30 neutrons
b. a neutral atom contains 22 protons and 21 neutrons
c. an oxygen atom with 10 neutrons and the same number of electrons as protons
d. chromium atom with a mass number of 54 and no charge
e. a halogen with 35 protons, 35 electrons, and 44 neutrons
f. an alkali metal with the fewest protons and 4 neutrons and no charge
g. an iron atom with mass number of 56 and 3 more protons than electrons
h. sulfide ion with 17 neutrons

3. How many p^+, n, and e^- are in the isotopic sulfate (SO_3^{-2}) ion: ${}^{33}S{}^{16}O{}^{18}O{}^{18}O^{-2}$?

4. Oxygen exists as three isotopes: ${}^{18}_{8}O$, ${}^{17}_{8}O$, and ${}^{16}_{8}O$. If the average atomic weight of oxygen is 15.9994, what do you expect the abundance of ${}^{18}_{8}O$ to be approximately?

<5% 25% 50% 75% 90%

5. An element has two naturally occurring isotopes with the following abundances and masses:

Isotope	Atomic Mass (amu)	Fractional Abundance
1	84.912	0.7215
2	86.909	0.2785

What is the average atomic mass of this element? What is the identity of the element?

6. Silver is found commonly as two isotopes: ^{107}Ag (mass = 106.91amu) and ^{109}Ag (mass = 108.90amu). The average atomic mass of silver is 107.869amu. What are the percent abundances of the two isotopes, ^{107}Ag and ^{109}Ag?

7. There are 3 isotopes of magnesium: ^{24}Mg (mass = 23.985amu), ^{25}Mg (mass = 24.986amu), and ^{26}Mg (mass = 25.983amu). If the abundance of ^{25}Mg is 10.00% what are the percent abundances of the other two isotopes of magnesium?

8. Name the following molecules.
a. NO b. PCl_3 c. KBr d. Na_2CO_3 e. N_2O_4 f. K_2SO_4 g. HNO_3 h. $Ca_3(PO_4)_2$ i. Cu_2O
j. $Mn_3(PO_4)_2$ k. $Co(CH_3COO)_3$ l. $(NH_4)_2Cr_2O_7$ m. H_3PO_4 n. $CoSO_4$ o. HBr p. HNO_2 q. $KMnO_4$
r. CH_4

9. Write the chemical formula for the following names.
a. sulfur trioxide b. calcium fluoride c. chlorine monobromide d. sulfuric acid e. sodium sulfate
f. ammonium nitrate g. lithium carbonate h. calcium nitrate i. manganese(III) sulfate
j. chromium(VI) oxide k. magnesium permanganate l. titanium(IV) sulfide

ANSWERS

1. a. 24 p^+, 24 e^-, 29 n {bottom number = atomic number = $\#p^+$ = 24; top number = mass number = #n + $\#p^+$; 53 = #n + 24; #n = 29; #e = $\#p^+$ because the isotope is neutral (charge = 0); $\#e^-$ = 24}

b. 25 p^+, 25 e^-, 30 n {bottom number = atomic number = $\#p^+$ = 25; top number = mass number = #n + $\#p^+$; 55 = #n + 25; #n = 30; #e = $\#p^+$ because the isotope is neutral (charge = 0); $\#e^-$ = 25}

c. 13 p^+, 10 e^-, 15 n {bottom number = atomic number = $\#p^+$ = 13; top number = mass number = #n + $\#p^+$; 28 = #n + 13; #n = 15; charge = +3; +3 = #p(+1) + #e(-1); 3 = 13 – x; x = #e = 10}

d. 28 p^+, 26 e^-, 31 n {bottom number = atomic number = $\#p^+$ = 28; top number = mass number = #n + $\#p^+$; 59 = #n + 28; #n = 31; charge = +2; +2 = #p(+1) + #e(-1); 2 = 28 – x; x = #e = 26}

e. 17 p^+, 18 e^-, 19 n {bottom number = atomic number = $\#p^+$ = 17; top number = mass number = #n + $\#p^+$; 36 = #n + 17; #n = 19; charge = -1; -1 = #p(+1) + #e(-1); -1 = 17 – x; x = #e = 18}

2. a. $^{58}_{28}Ni$ {$28p^+$ = Ni; bottom number = atomic number = $\#p^+$ = 28; neutral = charge = 0;
top number = mass number = $\#n + \#p^+$ = 30 + 28 = 58; $^{58}_{28}Ni$ }

b. $^{43}_{22}Ti$ {$22p^+$ = Ti; bottom number = atomic number = $\#p^+$ = 22; neutral = charge = 0;
top number = mass number = $\#n + \#p^+$ = 21 + 22 = 43; $^{43}_{22}Ti$ }

c. $^{18}_{8}O$ {O = $8p^+$ = bottom number = atomic number = $\#p^+$ = 8; neutral = charge = 0;
top number = mass number = $\#n + \#p^+$ = 10 + 8 = 18; $^{18}_{8}O$ }

d. $^{54}_{24}Cr$ {Cr = $24p^+$ = bottom number = atomic number = $\#p^+$ = 24; neutral = charge = 0;
top number = mass number = $\#n + \#p^+$ = 54; $^{54}_{24}Cr$ }

e. $^{79}_{35}Br$ {$35p^+$ = Br; bottom number = atomic number = $\#p^+$ = 35; $\#p^+ = \#e^-$ = charge = 0;
top number = mass number = $\#n + \#p^+$ = 44 + 35 = 79; $^{79}_{35}Br$ }

f. $^{7}_{3}Li$ {alkali metal = Group IA; fewest protons = $3p^+$ = Li; bottom number = atomic number = $\#p^+$ = 3; $\#p^+ = \#e^-$ = charge = 0;
top number = mass number = $\#n + \#p^+$ = 4 + 3 = 7; $^{7}_{3}Li$ }

g. $^{56}_{26}Fe^{+3}$ {iron = Fe = $26p^+$ = bottom number = atomic number = $\#p^+$ = 26; 3 extra p^+ than e^-:
charge = #p(+1) + #e(-1) = 26(+1) + 23(-1) = +3; charge = +3; top number = mass number = $\#n + \#p^+$ = 56; $^{56}_{26}Fe^{+3}$ }

h. $^{33}_{16}S^{-2}$ {sulfide = S = $16p^+$ = bottom number = atomic number = $\#p^+$ = 16; ion means charged; Group VIA has a charge of -2
(memorized); top number = mass number = $\#n + \#p^+$ = 17 + 16 = 33; $^{33}_{16}S^{-2}$ }

3. protons = 40; neutrons = 45; electrons = 42 {S: $16p^+$; O: $8p^+$ x 3 = $24p^+$; $\#p^+$ = 16 + 24 = $40p^+$;
#n: add mass numbers: 33 + 16 + 18 + 18 = 85 = $\#n + \#p^+$; #n = 85 – 40 = 45; charge = #p(+1) + #e(-1); -2 = 40 - x; x = 42 = $\#e^-$}

4. <5% {since the average atomic weight of O = 15.9994 ≈ 16, then the abundance of ^{16}O must be close to 100% since the average weight is close to 16 and therefore the abundance of ^{18}O must be very close to zero otherwise the average atomic mass would be higher than 16}

5. 85.47amu; Rb {(84.912)(0.7215) + (86.909)(0.2785) = 85.468amu}

6. ^{107}Ag: 51.8%, and ^{109}Ag: 48.2% {107.869 = 106.91(x) + 108.90(1 - x); x = abundance ^{107}Ag;
107.869 = 106.91x + 108.90 – 108.90x; -1.031 = -1.990x; x = 0.5181 = ^{107}Ag abundance;
^{109}Ag abundance = 1 – x = 1 – 0.5181 = 0.4819}

7. ^{24}Mg = 78.99%; ^{26}Mg = 11.01% {x = abundance ^{24}Mg; y = abundance ^{26}Mg; sum of fractional abundances:
1.000 = x + 0.1000 + y; y = 1.000 – 0.1000 – x; 24.3050 = 23.985(x) + 24.986(0.1000) + 25.983(1 – 0.1000 – x);
24.3050 = 23.985x + 2.4986 + 23.3847 – 25.983x; 24.3050 = 25.8833 – 1.998x; –1.5783 = –1.998x; x = 0.7899 = ^{24}Mg abundance = 78.99%; ^{26}Mg abundance = 100.00 – 10.00 – 78.99 = 11.01%}

8. a. nitrogen monoxide b. phosphorus trichloride c. potassium bromide d. sodium carbonate
e. dinitrogen tetroxide f. potassium sulfate g. nitric acid h. calcium phosphate
i. copper(I) oxide j. manganese(II) phosphate k. cobalt(III) acetate l. ammonium dichromate
m. phosphoric acid n. cobalt(II) sulfate o. hydrobromic acid p. nitrous acid q. potassium permanganate
r. methane (organic name)

9. a. SO_3 b. CaF_2 c. ClBr d. H_2SO_4 e. Na_2SO_4 f. NH_4NO_3 g. Li_2CO_3 h. $Ca(NO_3)_2$ i. $Mn_2(SO_4)_3$
j. CrO_3 k. $Mg(MnO_4)_2$ l. TiS_2