Introduction to Molecules and Ions

Reading: Ch 3 sections 1- 6	Homework: Chapter 3: 23, 25, 27, 29*, 31, 33*, 35*, 39, 43, 49*, 51*, 53

* = 'important' homework question

Molecules, Molecular Elements and Molecular Compounds

Recap: What is a molecule? What is a molecular compound? What is a molecular element?

Molecule:
Molecular Element:
Molecular Compound:

Molecules and their Chemical Formulas

There are two ways of describing the components (i.e. the number and type of atoms) found inside any molecule:

Molecular Formula: the *actual number* and type of atoms in a compound, e.g. hydrogen peroxide = H_2O_2

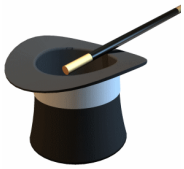
Empirical Formula: the *lowest whole number ratio* of each type of atom in a compound e.g. hydrogen peroxide = HO

Task: Complete the following table

Name	Molecular formula	Empirical formula
Hydrogen peroxide		
Dinitrogen tetroxide	N_2O_4	
Benzene	C_6H_6	
Butane	C_4H_{10}	
Tetraphosphorus decoxide	P_4O_{10}	

Note: Empirical formulas most often pertain to molecular / covalent compounds, as ionic compounds' formulas are typically in their lowest ratio to begin with (this will be discussed further below)

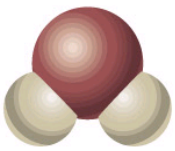
Picturing Molecules – Structural Formulas



A structural formula is simply a more detailed version of the molecule's corresponding molecular formula.

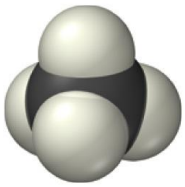
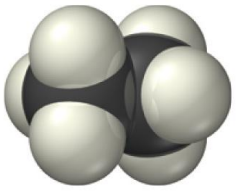
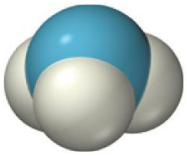
The major difference is that structural formulas also indicate the spatial relationship, and bonding, between atoms in a molecule

Eg:

Name and Molecular Formula	Electron density map of the 'real' molecule	Structural Formula
Water (H_2O)		

Task: Using the electron density maps as a guide, complete the following table

Key

Name and Molecular Formula	Electron density map of the 'real' molecule	Structural Formula
Carbon Dioxide (CO_2)		
Methane (CH_4)		
Ethane (C_2H_6)		
Ammonia (NH_3)		

Naming Molecular Elements and Compounds

Task: Write the formula of *and* name as many molecular elements and compounds as you can

Formula	Name	Formula	Name

Discussion: What relationships do you see between the names and formulas of molecular compounds?



Prefix Table

Number of atoms	Prefix*	Example
1		
2		
3		
4		
5		
6		

*Prefixes are dropped for the first *single* atom in a formula. E.g. CO_2 is named 'Carbon dioxide', not 'Mono Carbon dioxide'.

Tasks:

Name the Following:	
NF_3	
Cl_2O	
P_2O_5	

Write formulas for the following:	
Chlorine dioxide	
Chlorine pentafluoride	
Dihydrogen monosulfide*	

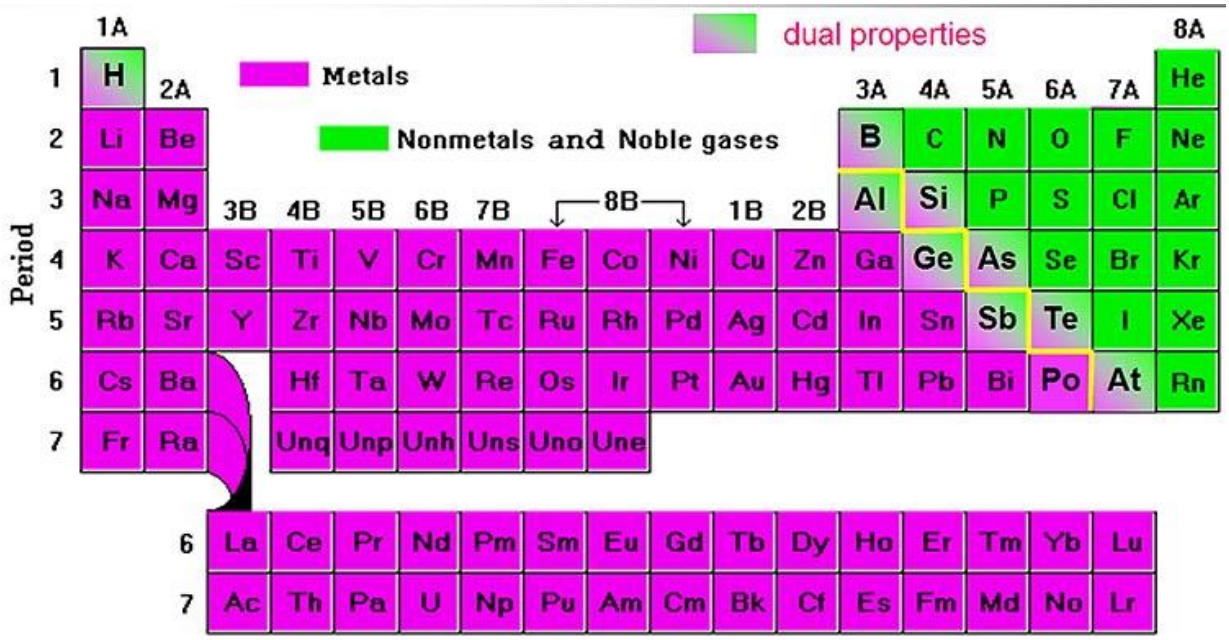
* If named using ionic nomenclature, also known as _____

Location, Location, Location!

ONLY a non-metal bonded to another non-metal (top RHS p. table) make *molecular materials* with *covalent bonds*. E.g. CO, H_2O, SO_3

THESE MATERIALS ARE NAMED IN ACCORDANCE WITH THE ABOVE 'MOLECULAR' RULES

Metallic vs Non metallic Elements in the Periodic Table



ONLY a non-metal (top RHS) bonded to metal (LHS) make *giant compounds with ionic bonds*. E.g. NaCl, CaO

THESE MATERIALS ARE NAMED IN ACCORDANCE WITH THE 'IONIC' RULES DISCUSSED IMMEDIATELY BELOW

Ions and Ionic Compounds

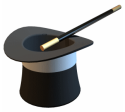
Questions: What are ions? How are they made?

Ion:

***Atomic Ions:**

** Ask me to tell you a very poor ion joke…..*

Atomic (*micro*) scale diagram of Ionization and *macro* scale crystal growth (slide)



In reality, electron(s) are EXCHANGED between atoms in order to become ionic compounds. I.E. what is lost by the metal (to become an M^{n+} cation) is gained by the non-metal (to become A^{n-} anion)

Making and Naming Ionic Formulas

List of Common atomic ions (must learn): See appendixes

Group I	Group VII
Group II	Group VI
Group III	Group V

Naming atomic ions: An atomic (+ve) cation has the same name as the metal it was formed from. An atomic (-ve) anion has the *same root* as the non-metal it was formed from, **but** and *–ide ending.* Examples:

Metal atom	**Metal cation**	**Non-metal atom**	**Non-metal anion**
Na		**Cl**	
Mg		**O**	

Ionic formulas are made by combining ANY cation (+ve) with any anion (-ve).

The order in ANY ionic formula is cation first, anion second, in *both* formula and name. i.e. (cation)(anion)

Examples: NaCl (sodium chloride)

LiF ( )

Ionic formulas ALWAYS have a ZERO net charge – i.e. the (+) and (-) ionic charges in ANY formula cancel.

If the above rule is followed, the ionic compound must exist and is probably sitting on a shelf in the chemistry stock room!

Task: Construct and name as many ionic compounds as possible from the following ions:

Li^{+} Ca^{2+} Al^{3+} Cl^{-} O^{2-} N^{3-}

List of Common molecular ions (must learn): See attached handout.

Trick – many *molecular ions* appear on the data sheet (see handout). Just keep using (homework) and/or looking (fridge) at the rest

Naming molecular ions:

There is ONLY one molecular cation – $(NH_4)^{+}$, ammonium.

Molecular anions with NO (or very few*) oxygen atoms in their structure have the –*ide* ending. Examples: ^{-}OH (hydrox*ide*)*, CN^{-} (cyan*ide*)

Molecular anions with 'lots' of oxygen atoms in their structure have the –*ate* ending. Examples: $(SO_4)^{2-}$ (sulf*ate*), $(NO_3)^{-}$ (nitr*ate*), $(CO_3)^{2-}$ (carbon*ate*), $(PO_4)^{3-}$ (phosph*ate*)

Recall: Ionic formulas ALWAYS have a ZERO net charge – i.e. the ionic charges in ANY formula cancel.

This is true for molecular ions too – just treat the whole molecular ion as if it were an atomic ion when making the formula. Name the resulting compound in a similar way also.

Task: Construct and name as many ionic compounds as possible from the following ions:

Li^{+} Mg^{2+} $(NH_4)^{+}$ $(NO_3)^{-}$ $(SO_4)^{2-}$ $(PO_4)^{3-}$

Naming Ionic compounds containing a cation of variable charge

Metallic elements from the center of the periodic table (the *transition series*, between groups II and III) can form atomic ions with a range of +ve charges. Examples: Fe^{2+} and Fe^{3+}, Cu^{+} and Cu^{2+}.

Question: Can you see a potential problem with regard to writing the names and formulas of ionic compounds containing such cations?

Answer:

Ionic formulas featuring a variable charge (oxidation state) cation include the charge of the cation (written in Roman numerals) in the formula name. E.g.: Cu_2O = Copper(I) oxide

Task: Complete the following table:

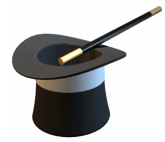
Name	Formula	Name	Formula
Iron (II) Sulfate		Copper (I) Phosphate	
	$Cu(NO_3)_2$		$FeCl_3$

Acids and bases

Discussion: Are acids and bases typically ionic or molecular compounds (trick question!)? What is 'special' about them and their formulas?

Naming acids and bases: There are two ways of naming acids, and one way for bases:

1. Just use the standard approach for naming ionic compounds:



Remember:

H^+ = 'hydrogen' ion, ^-OH = 'hydroxide' ion.

Task: Name the following acids and bases using standard ionic compound nomenclature:

HCl NaOH

H_2SO_4 $Ca(OH)_2$

HNO_3 $Al(OH)_3$

2. Using common nomenclature (chemical 'nicknames', must learn too)

Rules: Acids with *–ide* anions (e.g. Chloride, Cl^-) have a '*hydro*' prefix and an '*–ic'* ending, followed by 'acid'.

Example: HCl = *Hydro*chlor*ic* acid

Task: name the following acids:

HBr HI

HCN H_2S

Acids with molecular *'–ate'* anions, such as nitrate, $(NO_3)^-$, and sulfate, $(SO_4)^{2-}$, simply become *'–ic* acids':

Example: $H(NO_3)$ = nitr*ic* acid

Task: name the following acids:

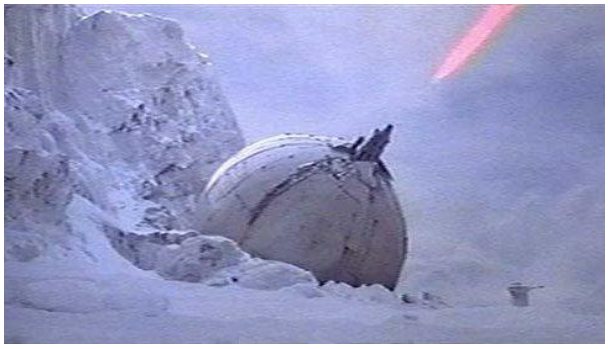
H_2SO_4 H_3PO_4

H_2CO_3

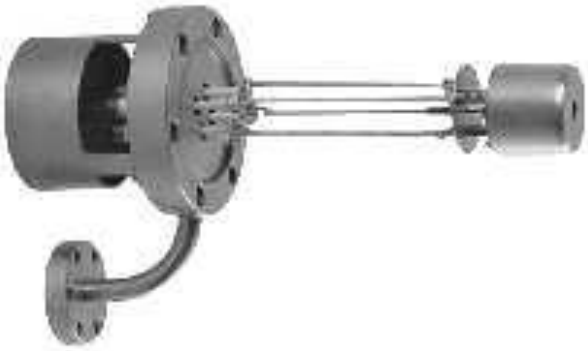
Ions in the Movies – Science fact or Science fiction?

Discussion: What makes for a good sci-fi movie? Why was *Star Wars* 'good' and *Battlestar Galactic* (released at the same time) 'bad'??

'Bad Guy' Brian Cox



An ion cannon, as seen in *The Empire Strikes Back* has a lot in common with a computer technician's static-guard wrist strap – electrical discharges can 'fry' sensitive electronics



Actual ion guns, used in surface science research and microchip manufacture.

Discussion: Would a commercially available ion gun be any use for 'home defense'??

"Ionic"

The following question were taken from your 1st practice midterm:

Write the formulas and names of nine ionic compounds that may be formed through combining the anions and cations ions listed immediately below.

H^+ Cu^{2+} Al^{3+} Cl^- SO_4^{2-} PO_4^{3-}

Ionic Formula	Name of Ionic Compound

Appendix: Table of Common Ions (Tro)

TABLE 3.2 Metals Whose Charge Is Invariant from One Compound to Another

Metal	Ion	Name	Group Number
Li	Li^+	Lithium	1A
Na	Na^+	Sodium	1A
K	K^+	Potassium	1A
Rb	Rb^+	Rubidium	1A
Cs	Cs^+	Cesium	1A
Be	Be^{2+}	Beryllium	2A
Mg	Mg^{2+}	Magnesium	2A
Ca	Ca^{2+}	Calcium	2A
Sr	Sr^{2+}	Strontium	2A
Ba	Ba^{2+}	Barium	2A
Al	Al^{3+}	Aluminum	3A
Zn	Zn^{2+}	Zinc	*
Sc	Sc^{3+}	Scandium	*
Ag**	Ag^+	Silver	*

TABLE 3.3 Some Common Anions

Nonmetal	Symbol for Ion	Base Name	Anion Name
Fluorine	F^-	fluor	Fluoride
Chlorine	Cl^-	chlor	Chloride
Bromine	Br^-	brom	Bromide
Iodine	I^-	iod	Iodide
Oxygen	O^{2-}	ox	Oxide
Sulfur	S^{2-}	sulf	Sulfide
Nitrogen	N^{3-}	nitr	Nitride
Phosphorus	P^{3-}	phosph	Phosphide

TABLE 3.4 Some Metals That Form Cations with Different Charges

Metal	Ion	Name	Older Name*
Chromium	Cr^{2+}	Chromium(II)	Chromous
	Cr^{3+}	Chromium(III)	Chromic
Iron	Fe^{2+}	Iron(II)	Ferrous
	Fe^{3+}	Iron(III)	Ferric
Cobalt	Co^{2+}	Cobalt(II)	Cobaltous
	Co^{3+}	Cobalt(III)	Cobaltic
Copper	Cu^+	Copper(I)	Cuprous
	Cu^{2+}	Copper(II)	Cupric
Tin	Sn^{2+}	Tin(II)	Stannous
	Sn^{4+}	Tin(IV)	Stannic
Mercury	Hg_2^{2+}	Mercury(I)	Mercurous
	Hg^{2+}	Mercury(II)	Mercuric
Lead	Pb^{2+}	Lead(II)	Plumbous
	Pb^{4+}	Lead(IV)	Plumbic

TABLE 3.5 Some Common Polyatomic Ions

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

Chart of the Common Ions (Learn)

+1 ions	**+2 ions**	**+3 ions**	**-3 ions**	**-2 ions**	**-1 ions**
H^+	Mg^{2+}	Al^{3+}	N^{3-}	O^{2-}	F^-
Li^+	Ca^{2+}	Fe^{3+}		S^{2-}	Cl^-
Na^+	Sr^{2+}	Cr^{3+}	PO_4^{3-}		Br^-
K^+	Ba^{2+}		(phosph*ate*)	SO_4^{2-}	I^-
Au^+	Cu^{2+}			(sulf*ate*)	
Ag^+	Zn^{2+}			CO_3^{2-}	^-OH (hydrox*ide*)
Cu^+	Fe^{2+}			(carbon*ate*)	NO_3^- (nitr*ate*)
NH_4^+	Pb^{2+}				CN^- (cyan*ide*)
(ammonium)					

Solubility rules (will be supplied):

Soluble Compounds		Exceptions
Compounds containing	NO_3^-	None
	Cl^-	Ag^+, Hg^{2+},Pb^{2+}
	Br^-	Ag^+, Hg^{2+},Pb^{2+}
	I^-	Ag^+, Hg^{2+},Pb^{2+}
	SO_4^{2-}	Ba^{2+}, Hg^{2+},Pb^{2+}

Insoluble Compounds		Exceptions
Compounds containing	CO_3^{2-}	NH_4^+ & group IA cations
	PO_4^{3-}	NH_4^+ & group IA cations
	OH^-	group IA cations Ca^{2+},Sr^{2+}, Ba^{2+} & NH_4^+

Tricks:

Group # = ion charge for metal ions, e.g. Li (group 1) = +1

-(8 –group #) = ion charge for atomic non-metal ions, e.g. O = -(8-6) = -2

Formulas for most molecular ions appear on the solubility chart (supplied in data sheet).