Chemistry Olympiad
Kevin Kolack

Week 1

Class & test overview

Math, atomic structure

Class logistics

- 1PM – 3PM every week
- 25 weeks
- Will give you notes if you miss a week
  - www.kevinkolack.com (chemistry link)
  - use Olympiad notes

Test logistics

- Local exam
  - 110 minutes for 60 multiple choice questions.
  - NO penalty for wrong answers.
  - Covers a full-year introductory college course in chemistry with laboratory.
  - No order of difficulty (don’t start easy and get hard).
  - No order to topics covered.
  - Non-programmable calculators allowed.
  - Given between March 1 and April 2, 2011.
  - Are given a periodic table and equation sheet

ABBREVIATIONS AND SYMBOLS					
amount of substance	*n*	Faraday constant	*F*	molar	M
ampere	A	free energy	*G*	molar mass	*M*
atmosphere	atm	frequency	ν	mole	mol
atomic mass unit	u	gas constant	*R*	Planck's constant	*h*
Avogadro constant	N_A	gram	g	pressure	*P*
Celsius temperature	°C	hour	h	rate constant	*k*
centi– prefix	c	joule	J	reaction quotient	*Q*
coulomb	C	kelvin	K	second	s
density	d	kilo– prefix	k	speed of light	*c*
electromotive force	*E*	liter	L	temperature, K	*T*
energy of activation	E_a	measure of pressure	mmHg	time	*t*
enthalpy	*H*	milli– prefix	m	volt	V
entropy	*S*	molal	*m*	volume	*V*
equilibrium constant	*K*				

CONSTANTS

$R = 8.314\ \text{J·mol}^{-1}\text{·K}^{-1}$

$R = 0.0821\ \text{L·atm·mol}^{-1}\text{·K}^{-1}$

$1\ F = 96{,}500\ \text{C·mol}^{-1}$

$1\ F = 96{,}500\ \text{J·V}^{-1}\text{·mol}^{-1}$

$N_A = 6.022 \times 10^{23}\ \text{mol}^{-1}$

$h = 6.626 \times 10^{-34}\ \text{J·s}$

$c = 2.998 \times 10^{8}\ \text{m·s}^{-1}$

$0\ °\text{C} = 273.15\ \text{K}$

PERIODIC TABLE OF THE ELEMENTS

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.008																	2 **He** 4.003
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
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
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** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
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
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.8	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)
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 **Ds** (281)	111 **Rg** (272)	112 Uub (277)	113 (Uut)	114 (Uuq)	115 (Uup)	116 (Uuh)	117 (Uus)	118 (Uuo)

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
90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	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)

Test logistics (cont'd)

- National exam
  - Given between April 14 and April 18, 2011
  - Top 20 students attend study camp
  - Teams attend international competition in Turkey
  - Part 1
    - 90 minutes
    - 60 multiple choice questions
  - Part 2
    - 105 minutes
    - 8 written questions- free response
    - Multi-step problems requiring in depth knowledge of chemical theories and models
  - Part 3
    - 75 minutes
    - 2 laboratory practicals
    - Involves problem solving in the laboratory

Test logistics (cont’d)

- http://acs.org
  - Registration, sample questions, scoring, etc.

Exam strategy

- Don’t read the instructions – that’s what practice exams are for!
- No penalty for wrong answers, so always guess!

End of intro

Why are we here?

- Legislation is passed, judgments are made, about what to make, what to eat, how to produce food and materials, etc, etc, without any knowledge of the science behind the emotion.
- OK… also, to get a perfect score and get ahead.

Chemistry

- The study of the COMPOSITION, STRUCTURE, and PROPERTIES of matter and the CHANGES that occur in matter.

THE BIG SECRET

- Treat chemistry as a second language.
- IF YOU EVER DON'T UNDERSTAND A WORD YOU READ OR A WORD I SAY IN CLASS, LOOK IT UP OR ASK FOR CLARIFICATION.

Matter

- Matter
  - Everything in the physical world....everything we see, touch, taste, etc.
- *Macro*scopic
  - Able to be seen with the naked eye. Normally, we are dealing with things too small to be seen (*MICRO*SCOPIC) so we "scale up" our discussion to numbers and/or sizes we can "put our hands on".

Atom

- Smallest DISTINCTIVE unit of matter.
- Composed of protons (positively charged), electrons (negatively charged), and neutrons (no charge)).
- An atom is the smallest unit of matter which retains the same properties as the bulk element.
- There are other subatomic particles (generally studied in advanced Physical Chemistry or Particle Physics) which we do not cover.

Atom (cont'd)

- Protons and neutrons are in the nucleus of the atom and make up the bulk of the mass of an atom
- Electrons are moving around the nucleus and have approx. 1/2000 the mass of a proton or neutron (negligible)

ksk1

Molecules

- Molecule
  - A fixed combination of atoms
- Composition
  - Type and number of atoms in a COMPOUND.
  - All samples of a compound have the same composition.
  - All samples have the same proportions by mass of the elements present according to Proust's Law of Definite Proportions.
- Physical changes (such as changes of state (solid to liquid to gas)) do not change composition .
- Chemical change - the formation and breaking of bonds.
  - The former releases energy, and the latter requires energy. Composition changes.
- Nuclear change
  - A change in the number of protons/neutrons in the nucleus of the atom. The atom becomes a different atom.

Slide 15

ksk1 flow chart?
Kevin Kolack, Ph.D., 7/8/2010

“Substances” and mixtures

- So, a pure “substance” is either an element or a compound if it can’t be separated by physical methods.
  - THIS IS DUMB BUT IT’S IN A LOT OF BOOKS.
- A MIXTURE is exactly what it sounds like- a physical combination of one or more compounds and/or elements.
- If the mixture is uniform throughout, it is homogeneous.
  - Also known as a SOLUTION.
- If the mixture is nonuniform throughout, it is heterogeneous.

States of matter

- Three common states:
  - Solid
  - Liquid
  - Gas
- Others
  - Plasma
  - Liquid crystal

The MKS system

- MKS = meter, kilogram, second
  - Length, mass, time
  - SI (system international) units
- Other basic units
  - Temperature is in Kelvin
  - Amount of something in moles
  - Electric current in Amperes
- Derived units
  - Density $\rho = kg/m^3$
  - Force $N = kg\ m/s^2$
  - Pressure $Pa = N/m^2$
  - Energy $J = kg\ m^2/s^2$
  - Electric charge $C = A\ s$
  - Electric potential difference $V = J/C$

Measurements

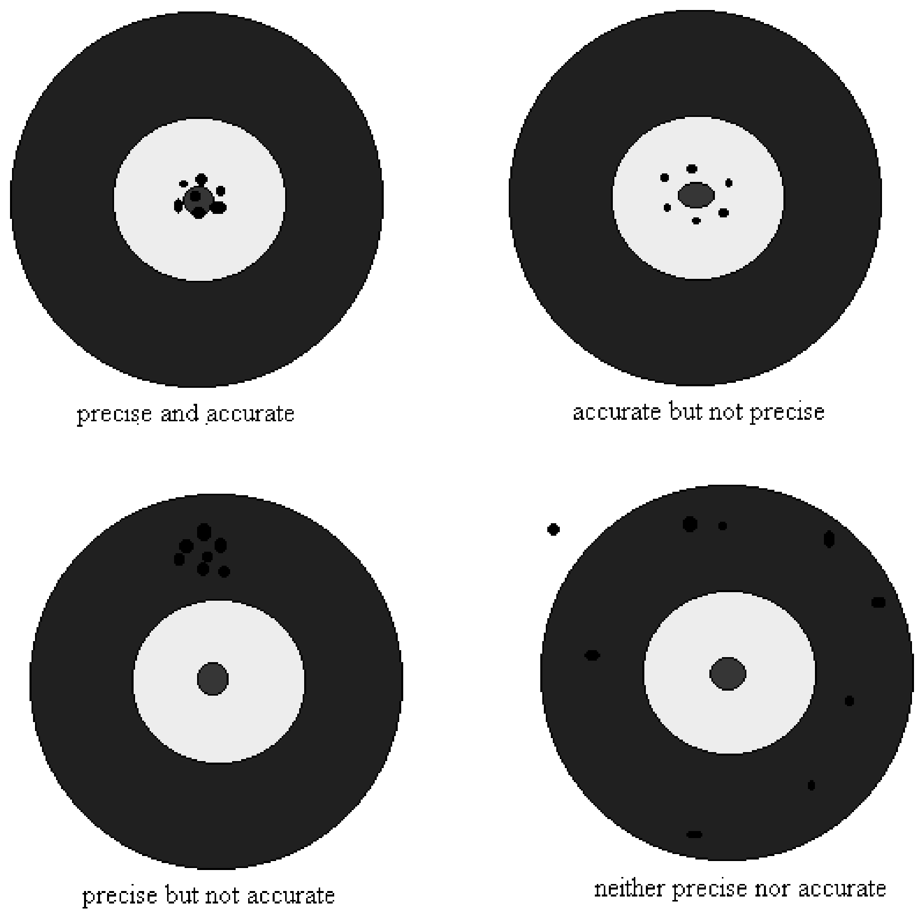
- UNITS, UNITS, UNITS!!!!
  - If your units are correct, the answer will be correct.
  - Use dimensional analysis, factor labeling, whatever you want to call it, to convert what you are given into what you are asked for.

- How many centimeters are in a mile given that one mile is 5,280 feet and there are 3.28 feet per meter?

Measurements (cont'd)

- Accuracy
  - How close to an accepted value a measurement is.
- Precision
  - How close to each other a series of measurements are.

Precision vs accuracy



Which is more accurate, a scale that weighs things to pounds and ounces or to the pound only?

Significant figures

- All nonzero digits are significant.
- Trailing zeroes AFTER a decimal point are significant.
- Trailing zeroes WITHOUT a decimal point are NOT significant.
- Zeroes between significant figures are significant.
- In an addition or subtraction, the answer has as many digits past the decimal point as the number with the least number of digits past the decimal point in the question.
- In a multiplication or division, the answer has as many significant digits as the number with the least number of significant digits in the question.
- When performing calculations, do NOT limit the number of significant digits in your answer because of a conversion factor.

Exponents & scientific notation

- Chemists are lazy and like shorthand
  - Numbers are expressed showing only the significant digits
  - eg 171,000 = 1.71×10^5
  - eg 0.0092 = 9.2×10^{-3}
  - Exactly 1 digit before the decimal place
- Don’t forget your algebra rules!
  - To add/subtract, you need the same exponent
    - $(A \times 10^x) + (B \times 10^x) = (A+B) \times 10^x$
    - $(A \times 10^x) + (B \times 10^y) =$???
  - For multiplication
    - $(A \times 10^x) \times (B \times 10^y) = (AxB) \times 10^{x+y}$
  - For division
    - $(A \times 10^x) / (B \times 10^y) = (A/B) \times 10^{x-y}$
  - For exponentials
    - $(A \times 10^x)^y = A^y \times 10^{xy}$

Logarithms

- Generally only used when discussing acids/bases (pH) in AP chemistry
- $\log_{base}$ answer = exponent
- eg for 1.0×10^{-10}
  $\log_{10} .0000000001 = -10$
- Negative log (-log) is not the same as inverse log (10 to the whatever power)
- $\ln x = m$ for $x = e^m$

End of section

Lavoisier's Law of Conservation of Mass

- Mercury oxide was heated to produce liquid mercury and oxygen gas.
- He found that the total mass of PRODUCTS = total mass of REACTANTS.
- $2HgO \rightarrow 2Hg + O_2$

Dalton's Law of Multiple Proportions

- An experiment like the electrolysis of water shows us that when elements combine, they do so in the ratio of whole numbers.
- $2H_2 + O_2 \leftrightarrow 2H_2O$

The Atom

- atomic mass unit- an arbitrarily accepted unit equal to 1/12 the mass of a carbon-12 atom
- atomic mass- mass of an element, accounting for the percentage of each naturally occurring ISOTOPE
- atomic number (Z)- number of protons in an atom (and electrons for a neutral atom)
- mass number (A)- number of protons plus neutrons in an atom

The atom

$$^{A}_{Z}E$$

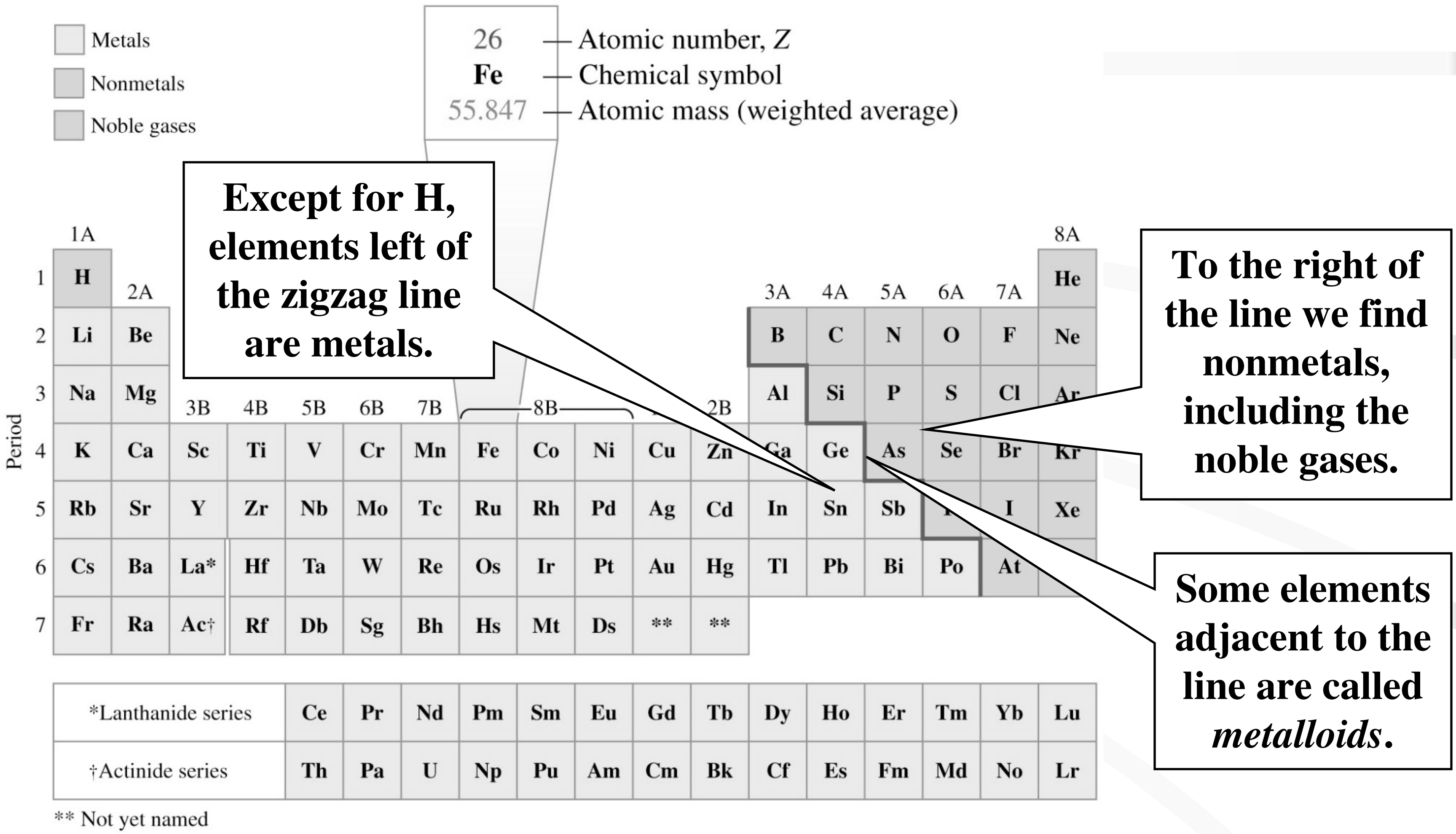
- A is the mass number
- Z is the atomic number
  - Redundant if element symbol is used

- $m_e = 9.1x10^{-31}$ kg
- 1/1836 (0.0005447) that of m_p
- $m_p = 1.67076x10^{-27}$ kg

The Periodic Table

- Mendeleev- noticed that certain properties had trends and repeated themselves from element to element to element
- arranged elements with similar properties in rows (PERIODS) and columns (GROUPS)
- metals, nonmetals, and metalloids, oh, my!!

The modern periodic table



Compounds

- chemical formula- shows actual number of each type of element in a compound....order of elements *may* give some hint at how they are connected
- empirical formula- the smallest whole number ratio of elements in a compound (*ex*- CO_2 is the chemical formula for carbon dioxide, but also the empirical formula for C_2O_4 and C_3O_6)
- structural formula (CD- Representing Substances)

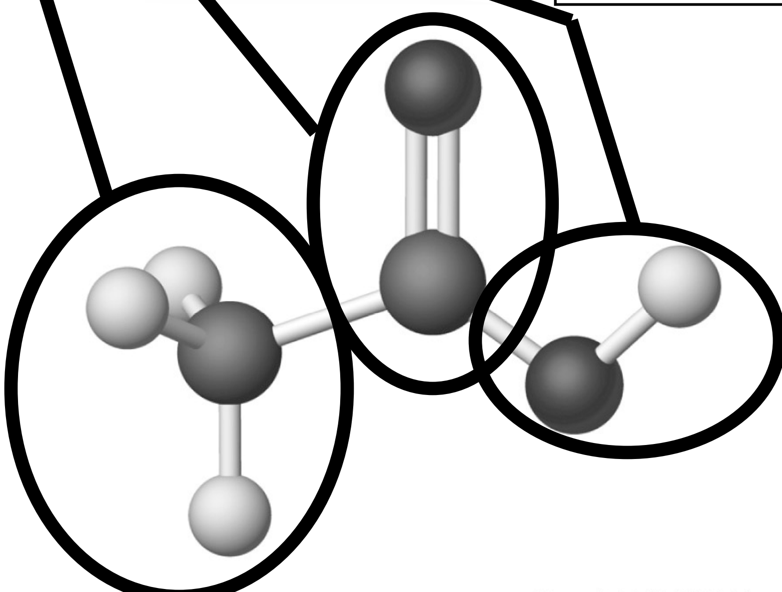
Structural formulas

- Give an idea of the shape of the molecule, in 2D or 3D

Structural formulas and models

The condensed structural formula for acetic acid is CH_3COOH.

$C_2H_4O_2$: two C atoms, four H atoms, two O atoms. CH_3COOH shows how the atoms are *arranged*.



Ball-and-stick model

Space-filling model

Naming compounds

- “Nomenclature” is systematic
- Binary compounds- which element goes first?
- Prefixes and suffixes

Table 2.3 Numeric Prefixes in Names of Binary Molecular Compounds

Number of Atoms	Prefix	Examples[a]
1	mono	NO nitrogen monoxide
2	di	NO_2 nitrogen dioxide
3	tri	N_2O_3 dinitrogen trioxide
4	tetra	N_2O_4 dinitrogen tetroxide
5	penta	N_2O_5 dinitrogen pentoxide
6	hexa	SF_6 sulfur hexafluoride
7	hepta	IF_7 iodine heptafluoride
8	octa	P_4O_8 tetraphosphorus octoxide
9	nona	P_4S_9 tetraphosphorus nonasulfide
10	deca	As_4O_{10} tetraarsenic decoxide

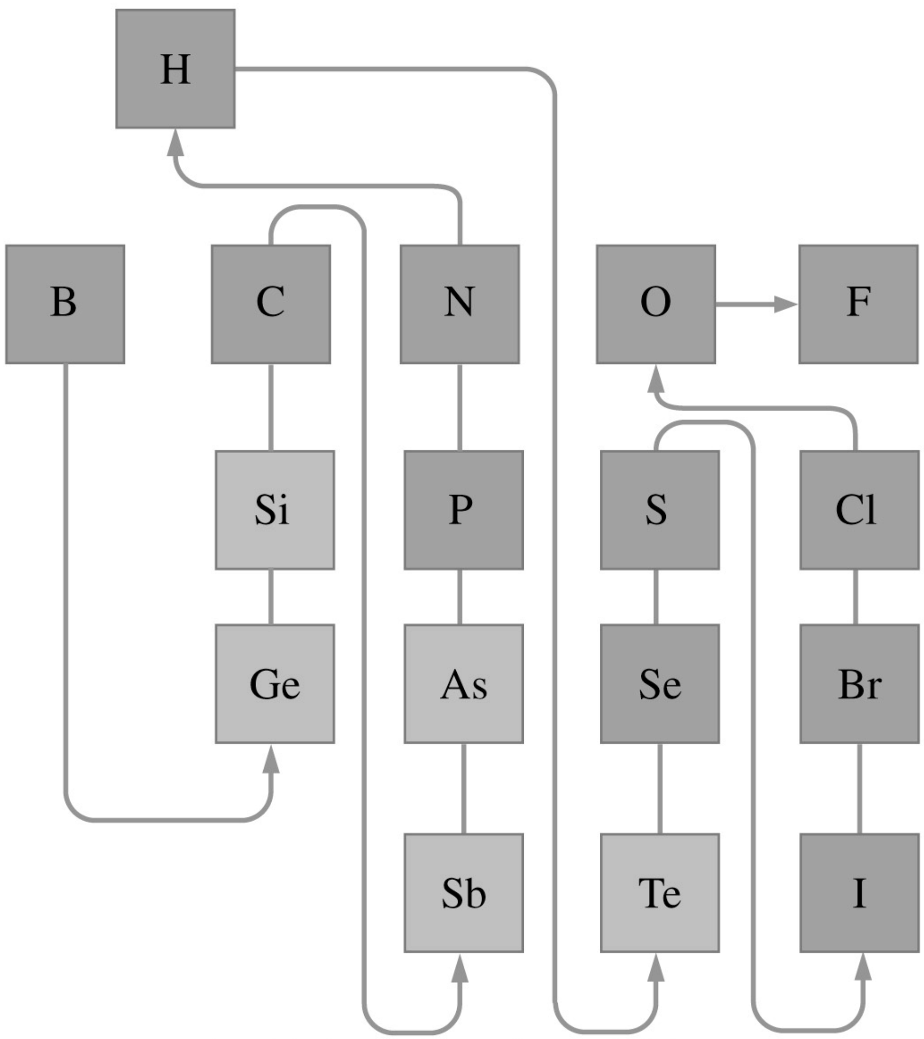
[a] When the prefix ends in "a" or "o" and the element name begins with "a" or "o," the final vowel of the prefix is usually dropped for ease of pronunciation. For example, nitrogen *mon*oxide and not nitrogen *mono*oxide, and

Table 2.4 Some Common Polyatomic Ions

Name	Formula	Typical Compound
Cation		
Ammonium ion	NH_4^+	NH_4Cl
Anions		
Acetate ion	[a]$C_2H_3O_2^-$	$NaC_2H_3O_2$
Carbonate ion	CO_3^{2-}	Li_2CO_3
Hydrogen carbonate ion (or bicarbonate ion)[b]	HCO_3^-	$NaHCO_3$
Hypochlorite ion	ClO^-	$Ca(ClO)_2$
Chlorite ion	ClO_2^-	$NaClO_2$
Chlorate ion	ClO_3^-	$NaClO_3$
Perchlorate ion	ClO_4^-	$KClO_4$
Chromate ion	CrO_4^{2-}	K_2CrO_4
Dichromate ion	$Cr_2O_7^{2-}$	$(NH_4)_2Cr_2O_7$
Cyanate ion	OCN^-	$KOCN$
Thiocyanate ion[c]	SCN^-	$KSCN$
Cyanide ion	CN^-	KCN
Hydroxide ion	OH^-	$NaOH$
Nitrite ion	NO_2^-	$NaNO_2$
Nitrate ion	NO_3^-	$NaNO_3$
Oxalate ion	$C_2O_4^{2-}$	CaC_2O_4
Permanganate ion	MnO_4^-	$KMnO_4$
Phosphate ion	PO_4^{3-}	Na_3PO_4
Hydrogen phosphate ion	HPO_4^{2-}	Na_2HPO_4
Dihydrogen phosphate ion	$H_2PO_4^-$	NaH_2PO_4
Sulfite ion	SO_3^{2-}	Na_2SO_3
Hydrogen sulfite ion (or bisulfite ion)[b]	HSO_3^-	$NaHSO_3$
Sulfate ion	SO_4^{2-}	Na_2SO_4
Hydrogen sulfate ion (or bisulfate ion)[b]	HSO_4^-	$NaHSO_4$
Thiosulfate ion[c]	$S_2O_3^{2-}$	$Na_2S_2O_3$

[a] The acetate ion is also represented as CH_3COO^-. [b] The prefix "bi-" means that the ion contains a replaceable H atom. This should not be confused with the prefix "di-," which means two (usually used to represent a doubling of a simpler unit). [c] The prefix "thio-" means that a sulfur atom has replaced an oxygen atom.

Which element is named first?



Begin with boron and follow the line to determine the order of naming.

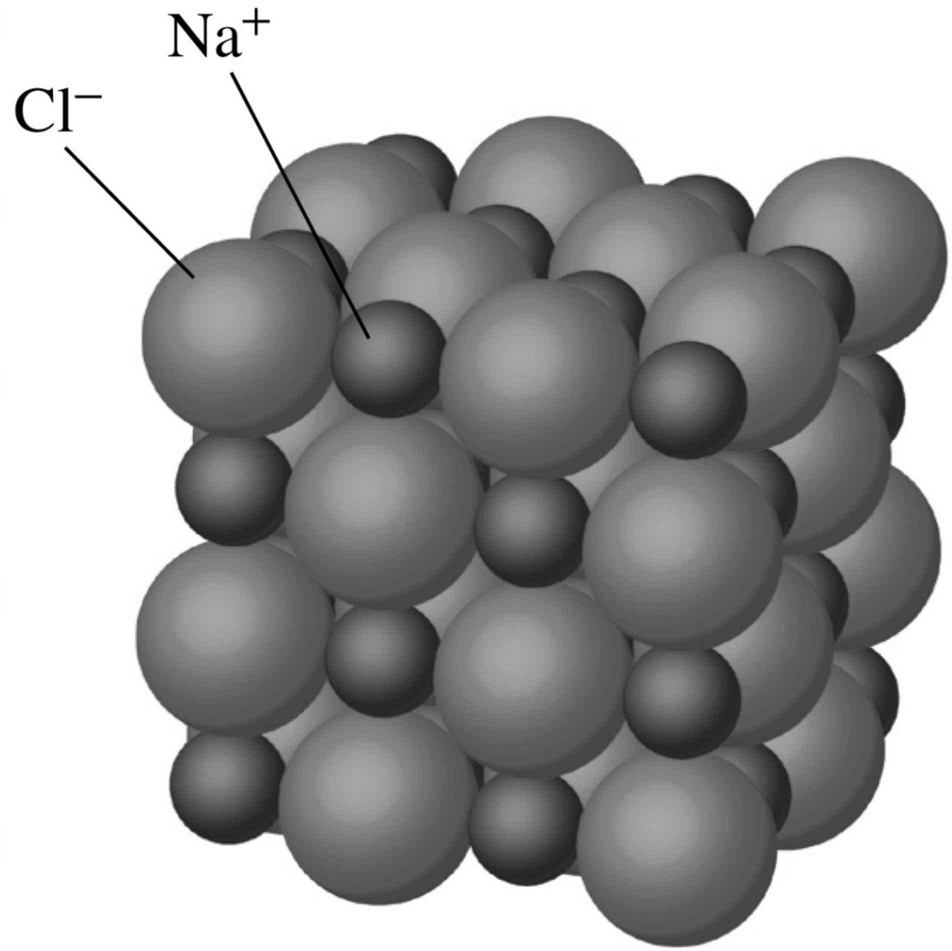
Rule of thumb: the element that is farthest *down* and to the *left* on the periodic table is usually written first.

Ions

- CATIONS ("cat-eye-ons") are POSITIVELY charged atoms or groups
- ANIONS ("an-eye-ons") are NEGATIVELY charged atoms or groups

Ions and ionic compounds

In an ionic compound, oppositely charged ions are attracted to each other such that the compound has no net charge.



There are no distinct *molecules* of sodium chloride.
NaCl simply consists of sodium ions and chloride ions, regularly arranged.

Monatomic ions

- Group IA metals form ions of 1+ charge.
- Group IIA metals form ions of 2+ charge.
- Aluminum, a group IIIA metal, forms ions with a 3+ charge.
- *Nonmetal* ions of groups V, VI, and VII usually have charges of 3–, 2–, and 1–, respectively.
- Group B metal ions (transition metal ions) often have more than one possible charge. A Roman numeral is sometimes used to indicate the actual charge.
- A few transition elements have only one common ion (Ag, Zn, Cd), and a Roman numeral is not often used.

Symbols and periodic table locations of some monatomic ions

Copper forms either copper(I) or copper(II) ions.

Titanium forms both titanium(II) and titanium(IV) ions.

1A	2A	3B	4	5B	6B	7B	8B			1	2B	A	4A	5A	6A	7A	8A
Li^+														N^{3-}	O^{2-}	F^-	
Na^+	Mg^{2+}											Al^{3+}		P^{3-}	S^{2-}	Cl^-	
K^+	Ca^{2+}	Sc^{3+}	Ti^{2+} Ti^{4+}	V^{2+} V^{3+}	Cr^{2+} Cr^{3+}	Mn^{2+} Mn^{4+}	Fe^{2+} Fe^{3+}	Co^{2+} Co^{3+}	Ni^{2+}	Cu^+ Cu^{2+}	Zn^{2+}				Se^{2-}	Br^-	
Rb^+	Sr^{2+}									Ag^+	Cd^{2+}		Sn^{2+}			I^-	
Cs^+	Ba^{2+}									Au^+ Au^{3+}			Pb^{2+}				

What is the charge on a zirconium(IV) ion?

Hydrates

- Compounds which exist with one or more molecules of water in the FORMULA UNIT (not a topic we will discuss in depth)

Acids, bases, salts

- Arrhenius definitions
  - Acids dissolve in water releasing H^+
  - Bases dissolve in water releasing OH^-
- Bronsted-Lowry definitions
  - Acids are proton donors
  - Bases are proton acceptors
- Lewis definitions
  - Acids are electron pair acceptors
  - Bases are electron pair donors

Acids

- Taste sour, if diluted with enough water to be tasted safely.
- May produce a pricking or stinging sensation on the skin.
- Turn the color of litmus or indicator paper from blue to red.
- React with many metals to produce ionic compounds and hydrogen gas.
- Also react with bases, thus losing their acidic properties.

Bases

- Taste bitter, if diluted with enough water to be tasted safely.
- Feel slippery or soapy on the skin. (WHY?)
- Turn the color of litmus or indicator paper from red to blue.
- React with acids, thus losing their basic properties.

Today's mantra

Acid plus base makes salt plus water

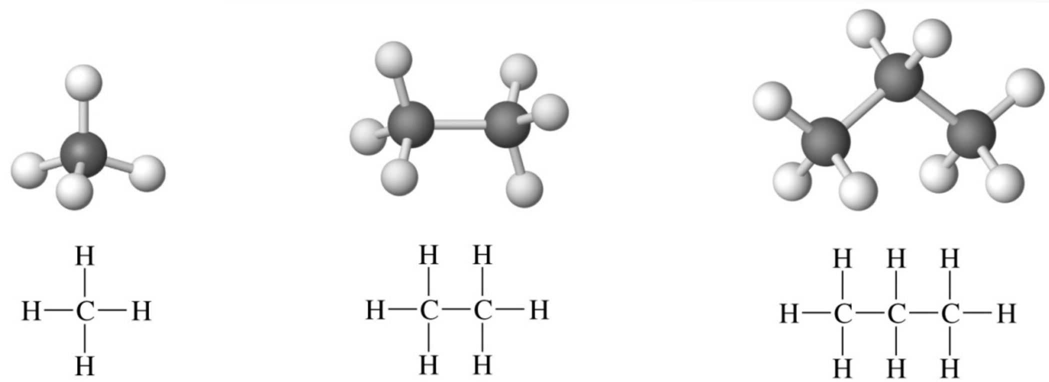
Organic compounds

- *Compounds based on carbon*
- May have other elements, including metals, and still be called organic
- IMHO: The word ORGANIC now wins the prize for the most abused word in the English language...it has *absolutely nothing* to do with how “natural” something is.

Alkanes

- Contain only C and H- general formula C_nH_{2n+2}
- Example- octane...When burned in an *ideal world*, alkanes produce only water and carbon dioxide... unfortunately, the world we live in is not ideal
- CYCLIC alkanes have the *carbon chain* in a ring, and have the general formula C_nH_{2n}
- Become comfortable with the "line drawing" shorthand of structural formulas
- ALL carbons must have 4, and exactly 4, bonds to them (4 single bonds, 2 single and a double, 1 single and a triple, etc.)

Alkanes



Methane, CH_4 — Ethane, C_2H_6 — Propane, C_3H_8

- Octane?

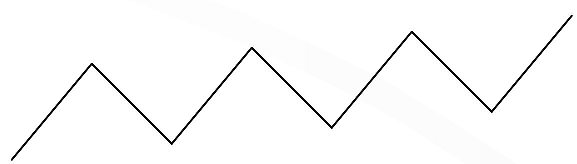


Table 2.6 Word Stems Indicating the Number of Carbon Atoms in Simple Organic Molecules

Stem	Number of C Atoms
meth-	1
eth-	2
prop-	3
but-	4
pent-	5
hex-	6
hept-	7
oct-	8
non-	9
dec-	10

Alkenes

- Contain only C and H with at least one double bond in the carbon chain- general formula C_nH_{2n}
- Example- ethylene used to make polyethylene bottles

Alkynes

- Contain only C and H with at least one triple bond in the carbon chain- general formula C_nH_{2n-2}
- Example- acetylene used for welding

Functional groups

- Groups of atoms seen in many compounds... these groups of atoms give the resulting compounds similar properties and/or reactivity

Alcohols

- General formula R-OH, where R is any organic group
- Examples-
  - methanol (methyl alcohol)
    - "wood alcohol"- causes blindness/death at very low dosages
  - ethanol (ethyl alcohol)
    - drinking alcohol
  - isopropanol (isopropyl alcohol)
    - rubbing alcohol

Ethers

- General formula R-O-R', where R and R' may be the same organic groups or different
- Examples
  - engine starter
  - the anesthetics of old

Aldehydes

- General formula R-CO-H, where there is an oxygen with a double bond to C attached to a single R group (and an H)
- Example- formaldehyde

Ketones

- General formula R-CO-R', where there is an oxygen with a double bond to C attached to two (same or differing) R groups
- Example- acetone (paint thinner/nail polish remover)

Carboxylic acids

- General formula R-COOH, where there is an oxygen with a double bond to C and an OH attached to the same C
- Example- acetic acid (vinegar)

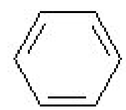
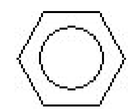
Esters

- General formula R-COOR', where there is an oxygen with a double bond to C and an OR' group attached to the same C
- Example- almond and vanilla extract

Amines

- General formula R-NH_2
- Example- ammonia, a.k.a. Windex©, or glass cleaner; trimethylamine (fishy smell)
- Question: Is $NH_3(g)$ the blue stuff in the Windex© bottle (or even the clear generic)? (You might need to know this in the lab...)

Aromatics (quick preview)

- The aromatic functional group normally refers to C_6H_5 bonded to something
- Represented as Ar,  or 
- More generally, something *aromatic* (so called originally due to their odor) has an alternating series of double and single bonds

Isomers have the same formula but different structures

- *Structural* isomers have the atoms connected differently

  CH_3OCH_3 and CH_3CH_2OH

- *Geometric* isomers have atoms arranged differently around a double bond

  (*cis* and *trans*?)

  (ever hear of *E* and *Z*?)

  (how about *L* and *D*? (actually different- *optical* isomers))