Periodicity and Nomenclature

"...I have tried to base a system on the magnitudes of the atomic weights of the elements. My first attempt in this respect was the following: I chose the smallest atomic weights and arranged them according to the sizes of their atomic weights. This showed that there existed a periodicity in the properties of these simple substances and that even according to their atomicity [valence] the **elements followed one another in the arithmetical sequence of their atomic weights**."

Dimitri Ivanovich Mcndeleyev (Mendeleev), 1869

Quiz on Friday

TA Office Hours
posted on Blackboard

Laboratory
- **Lab Presentation Link (Laboratory)**
- **Cover Sheet (CS) – Exp 2**

Lecture Notes and Handouts
- **HANDOUTS (FYI)**
- **PRACTICE**
- **Lecture Notes**

REVIEW FROM FRIDAY

Elements to Know (in capital letters)

ACTINIUM	Ac	GOLD	Au	polonium	Po
ALUMINUM	Al	hafnium	Hf	POTASSIUM	K
americium	Am	hassium	Hs	praseodymium	Pr
ANTIMONY	Sb	HELIUM	He	promethium	Pm
ARGON	Ar	holmium	Ho	protactinium	Pa
ARSENIC	As	HYDROGEN	H	RADIUM	Ra
astatine	At	indium	In	RADON	Rn
BARIUM	Ba	IODINE	I	rhenium	Re
berkelium	Bk	iridium	Ir	rhodium	Rh
BERYLLIUM	Be	IRON	Fe	roentgenium	Rg
BISMUTH	Bi	KRYPTON	Kr	RUBIDIUM	Rb
bohrium	Bh	LANTHANUM	La	ruthenium	Ru
BORON	B	lawrencium	Lr	rutherfordium	Rf
BROMINE	Br	LEAD	Pb	samarium	Sa
CADMIUM	Cd	LITHIUM	Li	scandium	Sc
CALCIUM	Ca	livermorium	Lv	seaborgium	Sg
californium	Cf	lutetium	Lu	SELENIUM	Se
CARBON	C	MAGNESIUM	Mg	SILICON	Si
cerium	Ce	MANGANESE	Mn	SILVER	Ag
CESIUM	Cs	meitnerium	Mt	SODIUM	Na
CHLORINE	Cl	mendelevium	Md	STRONTIUM	Sr
CHROMIUM	Cr	MERCURY	Hg	SULFUR	S
COBALT	Co	molybdenum	Mo	tantalum	Ta
copernecium	Cn	moscovium	Mc	technetium	Tc
COPPER	Cu	neodymium	Nd	TELLURIUM	Te
curium	Cm	NEON	Ne	tennessine	Ts
darmstadtium	Ds	neptunium	Np	terbium	Tb
dubnium	Db	NICKEL	Ni	thallium	Tl
dysprosium	Dy	nihonium	Nh	thorium	Th
einsteinium	Es	niobium	Nb	thulium	Tm
erbium	Er	NITROGEN	N	TIN	Sn
europium	Eu	nobelium	No	titanium	Ti
fermium	Fm	oganesson	Og	TUNGSTEN	W
flevorium	Fl	osmium	Os	URANIUM	U
FLUORINE	F	OXYGEN	O	vanadium	V
francium	Fr	palladium	Pd	XENON	Xe
gadolinium	Gd	PHOSPHORUS	P	ytterbium	Yb
gallium	Ga	PLATINUM	Pt	yttrium	Yr
germanium	Ge	PLUTONIUM	Pu	ZINC	Zn
				zirconium	Zr

Seven oldest known metals
Not modern
Spelling
Most common ending: __ium
Few have ending: __um

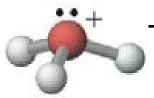
Halogens ending: __ine
Non-halogen diatomic gases (H_2, N_2, O_2): __gen
Noble gases (not He), B, C, Si: __on

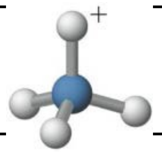
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
				Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
				Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

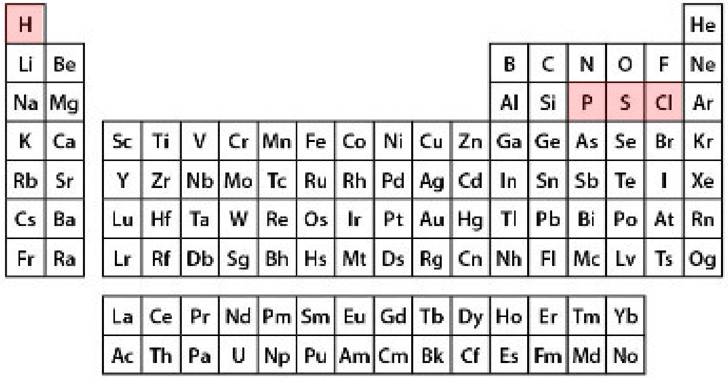
REVIEW FROM FRIDAY

Nomenclature of Some **Monatomic** and Polyatomic Ions (Know)

hydride	**H^{-}**	oxide	O^{2-}
fluoride	F^{-}	**sulfide**	**S^{2-}**
chloride	**Cl^{-}**	nitride	N^{3-}
bromide	Br^{-}	**phosphide**	**P^{3-}**
iodide	I^{-}		
hydrox**ide**	OH^{-}	sulfite	SO_3^{2-}
perox**ide**	O_2^{2-}	hydrogen sulfite	HSO_3^{2-}
cyan**ide**	CN^{-}	sulfate	SO_4^{2-}
nitrite	NO_2^{-}	hydrogen sulfate	HSO_4^{2-}
nitrate	NO_3^{-}	chromate	CrO_4^{2-}
carbonate	CO_3^{2-}	dichromate	$Cr_2O_7^{2-}$
hydrogen carbonate	HCO_3^{-}	permanganate	MnO_4^{-}
phosphate	PO_4^{3-}	hypochlorite	ClO^{-}
hydrogen phosphate	HPO_4^{2-}	chlorite	ClO_2^{-}
dihydrogen phosphate	$H_2PO_4^{-}$	chlorate	ClO_3^{-}
arsenate	AsO_4^{3-}	perchlorate	ClO_4^{-}
hydronium	H_3O+	mercury(I)	Hg_2^{2+}
ammonium	NH_4^{+}		


H_3O^{+}


NH_4^{+}



monatomic anions end with **__ide**

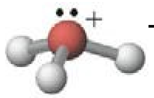
ions obtain **noble gas** electron **configuration**

polyatomic anions also end with **__ide**

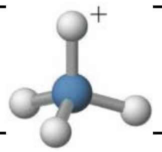
REVIEW FROM FRIDAY

Nomenclature Depending Upon Amount of Oxygen

hydride	H^-	oxide	O^{2-}
fluoride	F^-	sulfide	S^{2-}
chloride	Cl^-	nitride	N^{3-}
bromide	Br^-	phosphide	P^{3-}
iodide	I^-		
hydroxide	OH^-	sulf**ite**	SO_3^{2-}
peroxide	O_2^{2-}	hydrogen sulfite	HSO_3^{2-}
cyanide	CN^-	sulf**ate**	SO_4^{2-}
nitr**ite**	NO_2^-	hydrogen sulfate	HSO_4^{2-}
nitr**ate**	NO_3^-	chromate	CrO_4^{2-}
carbonate	CO_3^{2-}	dichromate	$Cr_2O_7^{2-}$
hydrogen carbonate	HCO_3^-	permanganate	MnO_4^-
phosphate	PO_4^{3-}	**hypo**chlor**ite**	ClO^-
hydrogen phosphate	HPO_4^{2-}	chlor**ite**	ClO_2^-
dihydrogen phosphate	$H_2PO_4^-$	chlor**ate**	ClO_3^-
arsenate	AsO_4^{3-}	**per**chlor**ate**	ClO_4^-
hydronium	H_3O+	mercury(I)	Hg_2^{2+}
ammonium	NH_4^+		



H_3O^+



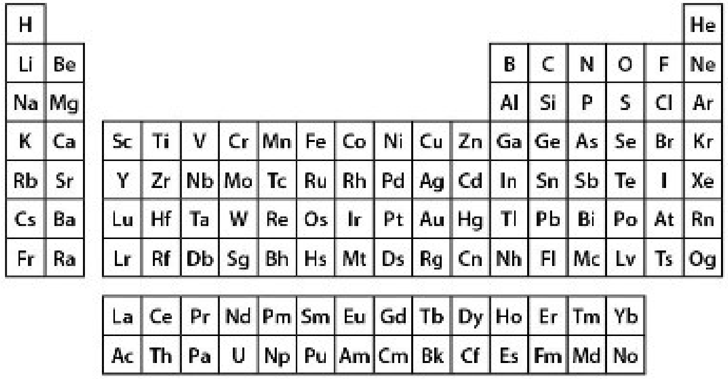
NH_4^+

least

less

more

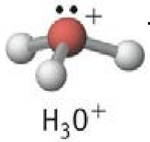
most

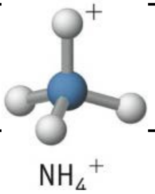


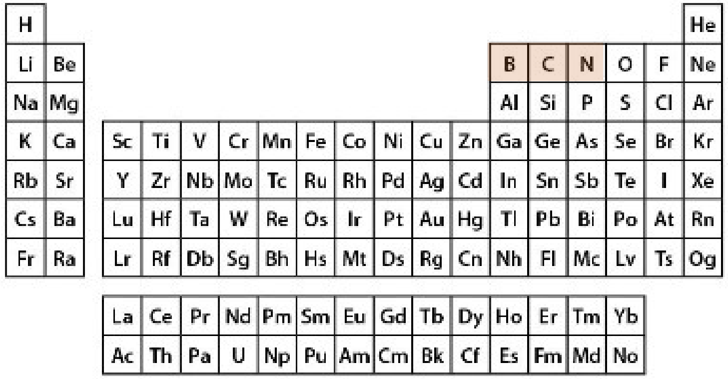
REVIEW FROM FRIDAY

Nomenclature Depending Upon Amount of Oxygen

hydride	H^-	oxide	O^{2-}
fluoride	F^-	sulfide	S^{2-}
chloride	Cl^-	nitride	N^{3-}
bromide	Br^-	phosphide	P^{3-}
iodide	I^-		
hydroxide	OH^-	sulfite	SO_3^{2-}
peroxide	O_2^{2-}	hydrogen sulfite	HSO_3^{2-}
cyanide	CN^-	**sulfate**	$\mathbf{SO_4^{2-}}$
nitrite	NO_2^-	hydrogen sulfate	HSO_4^{2-}
nitrate	$\mathbf{NO_3^-}$	**chromate**	$\mathbf{CrO_4^{2-}}$
carbonate	CO_3^{2-}	dichromate	$Cr_2O_7^{2-}$
hydrogen carbonate	HCO_3^-	**permanganate**	$\mathbf{MnO_4^-}$
phosphate	$\mathbf{PO_4^{3-}}$	hypochlorite	ClO^-
hydrogen phosphate	HPO_4^{2-}	chlorite	ClO_2^-
dihydrogen phosphate	$H_2PO_4^-$	chlorate	ClO_3^-
arsenate	$\mathbf{AsO_4^{3-}}$	**perchlorate**	$\mathbf{ClO_4^-}$
hydronium	H_3O+	mercury(I)	Hg_2^{2+}
ammonium	NH_4^+		

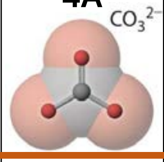
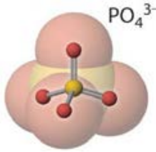
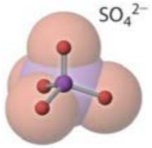






charge increases →

size increases ↓

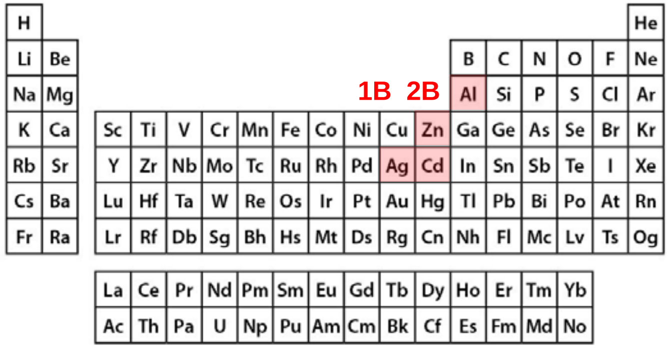
3A	4A	5A	6A	7A
borate BO_3^{3-}	 CO_3^{2-}	nitrate NO_3^-		
aluminate AlO_4^{5-}	silicate SiO_4^{4-}	 PO_4^{3-}	 SO_4^{2-}	perchlorate ClO_4^-
		arsenate AsO_4^{3-}		
		5B vanadate VO_4^{3-}	**6B** chromate CrO_4^{2-}	**7B** permanganate MnO_4^-
		XO_4^{3-}	XO_4^{2-}	XO_4^-

second period different

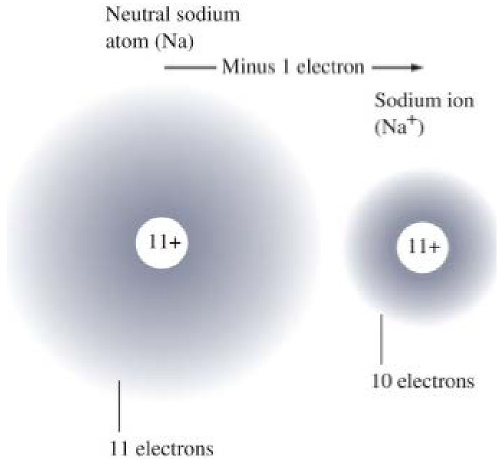
REVIEW FROM FRIDAY

Positive Ions (Cations)

Monatomic		Polyatomic
Only One Ion Possible	More Than One Ion Possible	
Rule: Name of element + "ion". **Examples:** Na^{+} sodium ion Mg^{2+} magnesium ion H^{+} hydrogen ion **Al^{3+} aluminum ion** **Ag^{+} silver ion** **Zn^{2+} zinc ion** **Cd^{2+} cadmium ion** **Comment:** The number of positive charges is not indicated in the name because it is not necessary, e.g., Group I elements (1+) and Group II elements (2+).	**Rule:** a) Newer rule: positive charges indicated by a roman numeral. **Examples:** Fe^{2+} iron(II) ion Fe^{3+} iron(III) ion Cu^{+} copper(I) ion Cu^{2+} copper(II) ion b) Older rule (but still used): Latin stem for the element + "ous" for the lesser charge and + "ic" for the greater charge. (We will use newer rule except coordination compounds) **Examples**: Fe^{2+} ferrous ion Fe^{3+} ferric ion	**Rule:** **Special cases.** **Examples:** NH_4^{+} ammonium ion H_3O^{+} hydronium ion Hg_2^{2+} mercury(I) ion **Comment:** Hg_2^{2+} is Hg^{+} – Hg^{+} but Hg^{+} does not exist, therefore mercury(I) ion is Hg^{+}. (Hg^{2+} is mercury(II) ion, but that is a monatomic ion.)



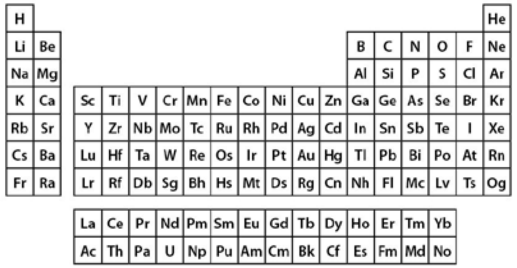
know these oxidation states

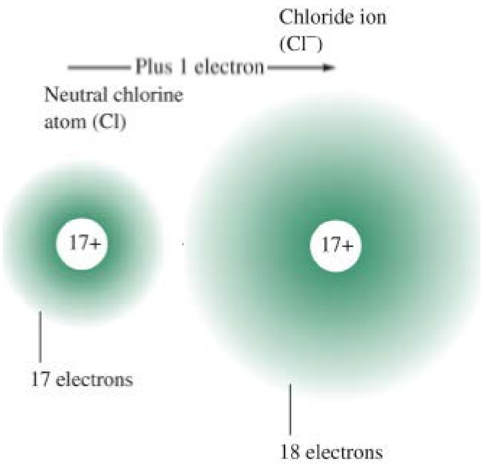


REVIEW FROM FRIDAY

Negative Ions (Anions)

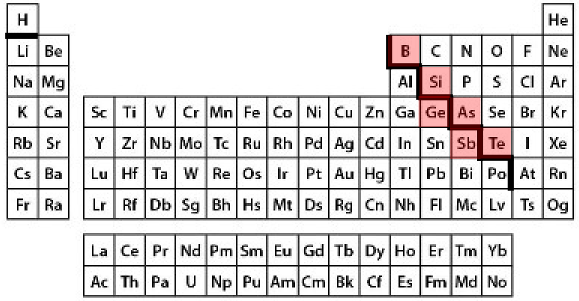
Monatomic	Oxyanions (Containing Oxygen)		Others and Exceptions
	(Without Hydrogen)	Containing Hydrogen	
Rule: Stem of the element name + "ide". **Examples:** H^- hydride ion F^- fluoride ion O^{2-} oxide ion N^{3-} nitride ion	**Rule:** least oxygen: hypo_ite ion less oxygen: _ite ion more oxygen: _ate ion most oxygen: per_ate ion **Examples:** ClO^- hypochlorite ion ClO_2^- chlorite ion ClO_3^- chlorate ion **ClO_4^- perchlorate ion** SO_3^{2-} sulfite ion **SO_4^{2-} sulfate ion** **Comment:** Halogens (except F) form all four ions. When only two of the four ions exist, they are the -ite and the -ate ions. **Cl Group 7A** **S Group 6A**	**Rule:** H - oxyanion: "hydrogen" + name of oxyanion or "bi" + oxyanion H_2 - oxyanion: "dihydrogen" + name of oxyanion **Examples:** HCO_3^- hydrogen carbonate (or bicarbonate) ion HSO_4^- hydrogen sulfate (or bisulfate) ion HPO_4^{2-} hydrogen phosphate $H_2PO_4^-$ dihydrogen phosphate ion **Comment:** H_2CO_3 is not named according to this rule because it is a compound and not an ion.	**Rule:** These items do not follow any rules: they must be memorized. **Examples:** OH^- hydroxide ion O_2^{2-} peroxide ion CN^- cyanide ion **AsO_4^{3-} arsenate ion** **MnO_4^- permanganate ion** **CrO_4^{2-} chromate ion** $Cr_2O_7^{2-}$ dichromate ion **Comment:** Note that arsenate is a Group V element and forms a polyatomic ion with oxygen identical to phosphorus. **Mn Group 7B** **Cr Group 6B** **As Group 5A, like PO_4^{3-}**





Compounds (Metalloid Can Be Substituted for Nonmetal)

Ionic (Cation-Anion)	Covalent (Nonmetals)		
	Nonmetal-Nonmetal	Compounds Containing Hydrogen	
		H-Nonmetal	H-Oxyanion
Rule: Name of cation + name of anion (word "ion" dropped). **Examples:** $ZnSO_4$ zinc sulfate $NaNO_2$ sodium nitrite $CaCl_2$ calcium chloride Fe_3N_2 iron(II) nitride Li_2CO_3 lithium carbonate NH_4I ammonium iodide $Cu(IO_3)_2$ copper(II) iodate BaH_2 barium hydride **Comment:** The name does not indicate the numbers of cations and anions because there is only one possibility for the ions to combine to form a compound.	**Rule:** a) Less electronegative element generally first (exception: when one of the elements is hydrogen) b) Greek prefixes give number of atoms of each kind c) Initial prefix mono dropped **Prefixes:** 1 = mono 6 = hexa 2 = di 7 = hepta 3 = tri 8 = octa 4 = tetra 9 = nona 5 = penta 10 = deca **Examples:** SCl_6 sulfur hexachloride N_2O_4 dinitrogen tetroxide CO carbon monoxide CO_2 carbon dioxide NO_2 nitrogen dioxide N_2O dinitrogen monoxide **Comment:** Tetraoxide becomes tetroxide, monooxide becomes monoxide, etc., so name sounds better	**Rule 1:** (without the presence of H_2O) hydrogen _ide **Examples**: HCl hydrogen chloride HF hydrogen fluoride H_2S hydrogen sulfide H_2Se hydrogen selenide **Rule 2:** H acids (when dissolved in H_2O) hydro_ic acid **Examples:** HCl hydrochloric acid HF hydrofluoric acid H_2S hydrosulfuric acid H_2Se hydroselenic acid **Comment:** (a) These H-containing compounds are named as if they were ionic. (b) Often the (aq) in the formulas of the acids is omitted when it is obvious from the context that they are acids.	**Rule 1:** (without the presence of H_2O) like ionic compounds: cation + anion hydrogen hypo_ite hydrogen _ite hydrogen _ate hydrogen per_ate **Rule 2:** HO acids (when dissolved in H_2O) hypo_ous acid _ous acid _ic acid per_ic acid **Examples:** HClO hypochlorous acid $HClO_2$ chlorous acid $HClO_3$ chloric acid $HClO_4$ perchloric acid HNO_2 nitrous acid HNO_3 nitric acid H_2SO_3 sulfurous acid H_2SO_4 sulfuric acid H_3PO_4 phosphoric acid **Comment:** The (*aq*) is usually omitted.



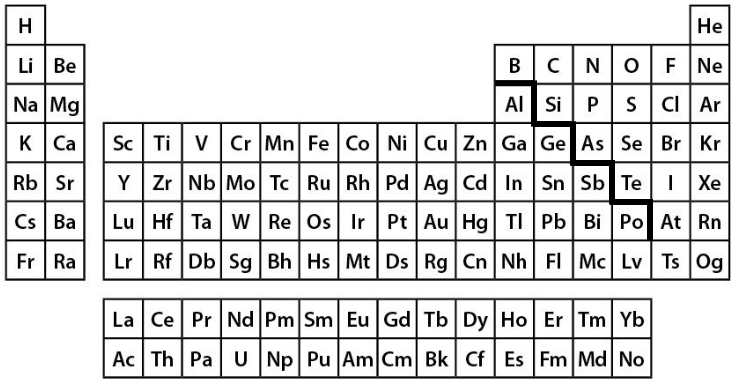
ordering of elements in formula of binary molecular compounds: order according to Group number, bottom to top; for any pair, element furthest right behaves as the “anion” (H, O need to be memorized):

FOR LATER

Ordering Elements in Binary Compounds

Ordering of elements in formula of binary molecular compounds: order according to Group number, bottom to top; for any pair, element furthest right behaves as the "anion" (**H**, **O** need to be memorized):

	B	Ge Si C	Sb As P N	**H**	Te Se S	I Br Cl	**O**	F
Group #:	3A	4A	5A		6A	7A		



C, Si **SiC**

H, Te **H_2Te**

Stoichiometry________________________________ Z Ch 3, H Ch 1-4, 22-1

""Stoichiometry is the science of measuring the quantitative proportions or mass ratios in which chemical elements stand to one another." **Jeremias Benjamin Richter, 1792**

Richter introduced the word stoichiometry (Greek, *stoicheion*- element and *metron*- measure)

- Relative Atomic Mass
- Mass Spectrometry
- Atoms and the Mole
- Composition of Compounds
- Determining the Formulas of Compounds
- CHEMICAL EQUATIONS
  - Balancing
  - Stoichiometry Calculations
  - Yields

The number of electrons and protons increases with atomic number

Does atomic mass always increase with atomic number?

1A (1)	2A (2)	2B (3)	3B (4)	4B (5)	5B (6)	6B (7)	7B (8)	(9)	8B (10)	(11)	1B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1 H 1.008																	2 He 4.0026
3 Li 6.94	4 Be 9.0122											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.085	15 P 30.974	16 S 32.06	17 Cl 35.45	18 Ar 39.95
19 K 39.098	20 Ca 40.08	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.85	27 Co 58.933	28 Ni 58.693	29 Cu 63.55	30 Zn 65.4	31 Ga 69.723	32 Ge 72.63	33 As 74.922	34 Se 78.97	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.22	41 Nb 92.906	42 Mo 95.95	43 Tc (97/8)	44 Ru 101.1	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.6	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57 La 138.91	72 Hf 178.5	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (267)	105 Db (268)	106 Sg (269)	107 Bh (271)	108 Hs (277)	109 Mt (276/7)	110 Ds (281)	111 Rg (282)	112 Cn (285)	113 Nh (286)	114 Fl (289)	115 Mc (290)	116 Lv (293)	117 Ts (294)	118 Og (294)

Lanthanides	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.96	64 Gd 157.3	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
Actinides	90 Th 232.04	91 Pa 231.04	92 U 238.03	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)

Relative Atomic Masses

particle	charge	mass (u)
electron	-1	0.00054857
proton	+1	1.00727646
neutron	0	1.00866491

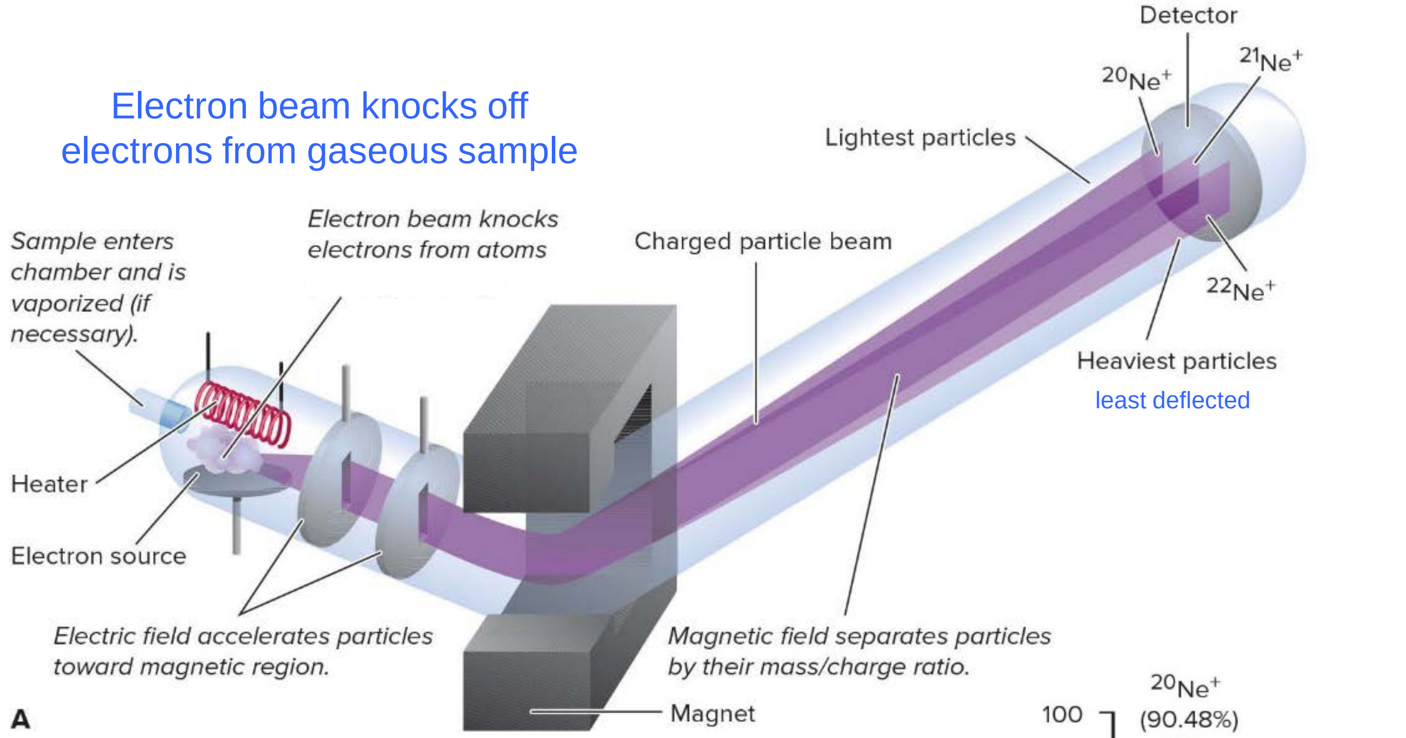
isotope	#p	#n	mass (u)	mol fract
^{20}Ne	10	10	19.992440	0.9048
^{21}Ne	10	11	20.993846	0.0027
^{22}Ne	10	12	21.991385	0.0925

Relative **A**tomic **M**ass

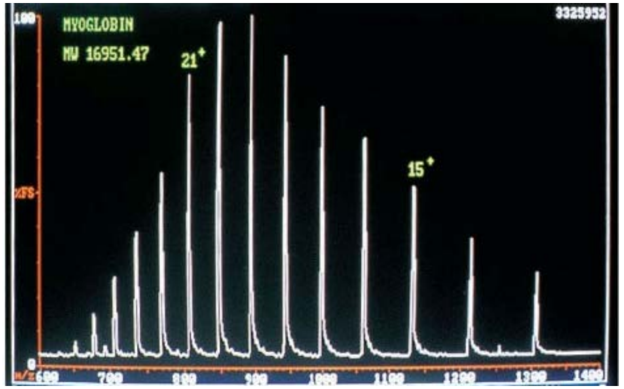
$$\text{RAM} = \sum_i m_i f_i$$

Separating the Neon Isotopes

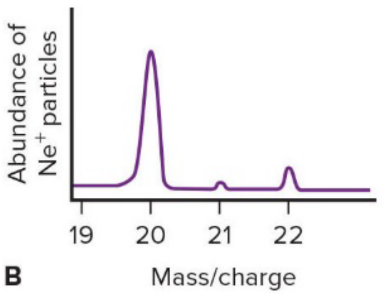
Electron beam knocks off electrons from gaseous sample

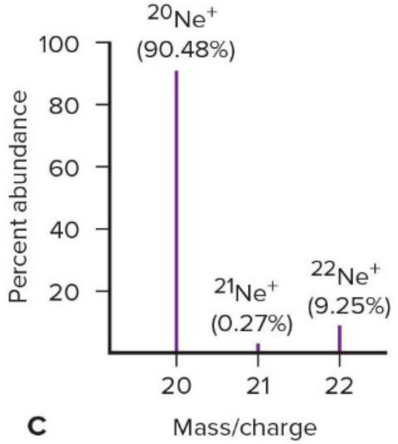


least deflected



Horse myoglobin – common MW calibrant for mass spectrometers





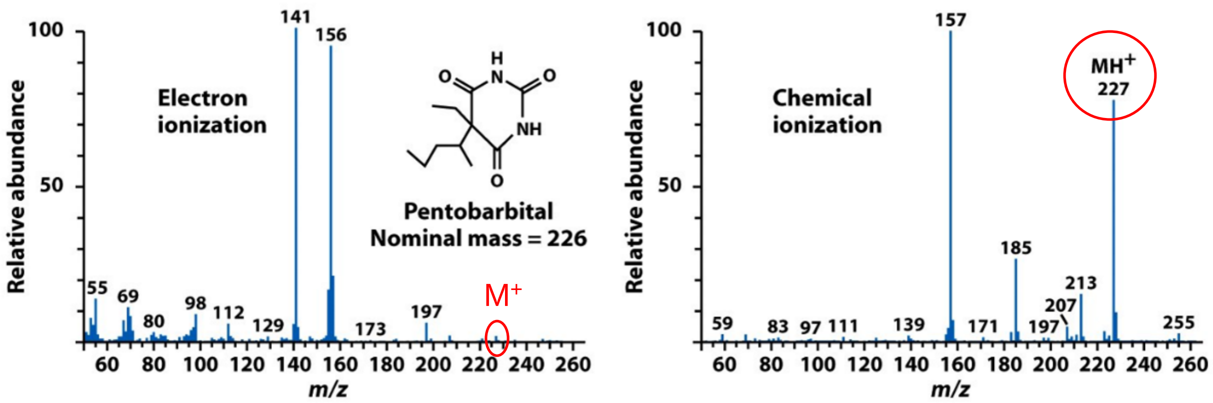
Some Types of Mass Spec

EI – electron ionization

impact by very high energy e^-

$M + e^- \rightarrow M^{+\cdot} + e^-$ (lower energy)

$M^{+\cdot}$ detected, fragments



CI – chemical ionization

reagent gas (CH_4, NH_3) in ionization source, protonates molecule

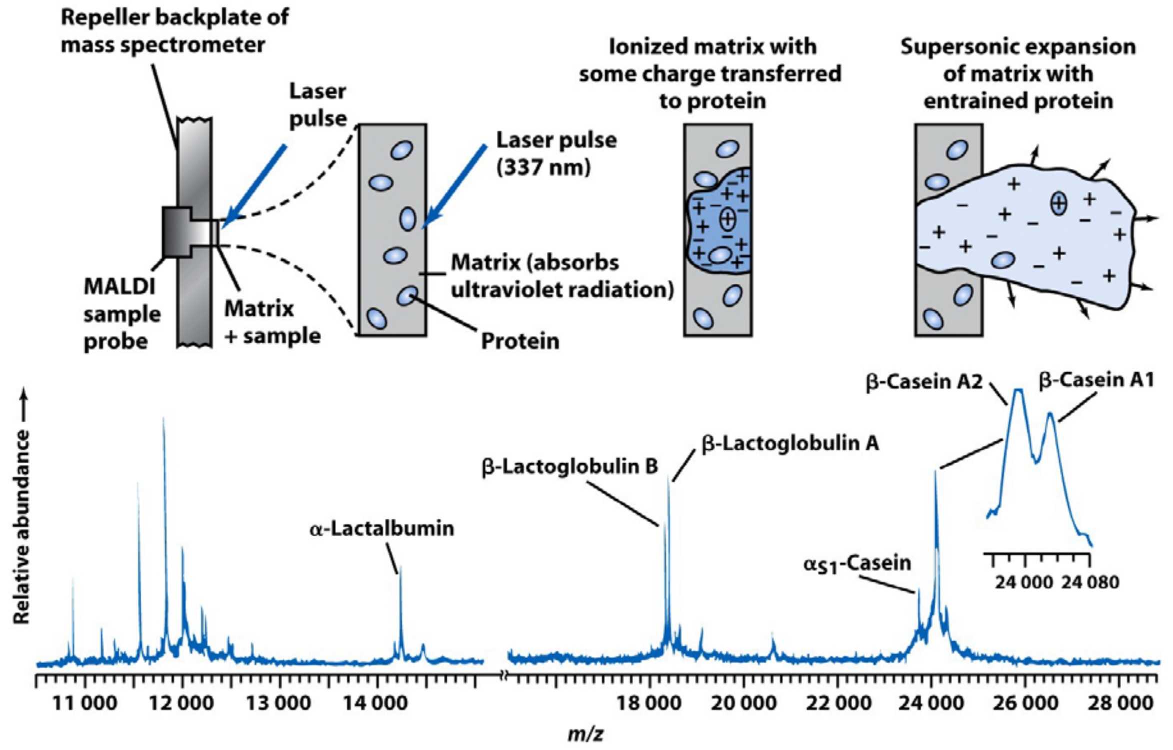
$M + (gas^+) \rightarrow MH^+ + gas$

less fragmentation

MALDI – matrix-assisted laser desorption/ionization

M dissolved in UV absorbing compd, evaporated, UV laser vaporizes matrix into gas phase, M^+ formed

$M \sim 10^6$ g/mol - biomolecules



Working with Isotopic Data

RAM = 10.811

EX 1. From the following data and your periodic table determine the percent natural abundance of the following two isotopes:

isotope	mass	f_i
boron-10	10.01294	x
boron-11	11.00931	$1-x$

$\text{RAM} = \sum_i m_i f_i \quad \Rightarrow \quad 10.811 = 10.01294x + 11.00931(1-x)$

$x = (11.00931-10.811)/(11.00931-10.01294)$

3 decimals

$= 0.19831/0.99837$

$= 0.1990324 \quad \Rightarrow \quad$ 19.9% ^{10}B

80.1% ^{11}B

Working with Isotopic Data

EX 2. Copper has two isotopes. 30.91% of the mass of copper is due to ^{65}Cu whose isotopic mass is 64.9278. Calculate the mass of the other isotope and give its complete symbol.

RAM $= \sum_i m_i f_i = m_{\text{Cu-65}} f_{\text{Cu-65}} + m_x f_x = 63.55$ $\sum_i f_i = 1$

$$m_x = \frac{65.55 - (0.3091)(64.9278)}{1.0000 - 0.3091}$$

$$= (63.55 - 20.0618)/0.6909$$

$$= 62.93$$

Atoms and the Mole

relative atomic mass (RAM) => actual mass of one atom (Lorenzo Romano Amadeo Carlo **Avogadro,** Conte di Quarequa e di Cereto)

Avogado's Number defined to be the number of atoms in exactly 12 g of ^{12}C (1 mole) $\boldsymbol{N_o = 6.02214 \times 10^{23}\ mol^{-1}}$

EX 3. What is the mass of a single carbon-12 atom?

$$(1\ \text{atom}\ 12\ C)(12\ g / 6.02214 \times 10^{23}\ \text{atoms}) = 1.9926466 \times 10^{-23}\ g$$

Atoms and the Mole

EX 4. A single atom of an element has a mass of 2.10730×10^{-22} g. What is the element assuming it has only one isotope?

ratio of RAMs = ratio of masses of atoms

$$\frac{\text{RAM x}}{12} = \frac{2.10730 \times 10^{-22}}{(12\ \text{g} / N_o)}$$

$$\text{RAM x} = 2.10730 \times 10^{-22}\ N_o$$

$$= 126.904 \quad \Rightarrow \quad \text{iodine}$$

Atoms and the Mole

mass of one atom is too small

one mole contains Avogadro's number of things

EX 5. How many moles of Fe are in 8.232 g Fe? M_{Fe} = 55.845 g/mol

(8.232 g Fe)(1mol Fe / 55.845 g) = 0.1474 mol

Atoms and the Mole

EX 6. Lithium has a density of 0.534 g cm^{-3}. Estimate the volume per atom in lithium.

$$d = m/V \Rightarrow V = m/d$$

$$= \frac{6.941\ g / N_o}{0.534\ g\ cm^{-3}}$$

$$= 2.16 \times 10^{-23}\ cm^3$$