Chapter 2

Atoms, Molecules and Ions

I) Atoms

A) Dalton's Atomic Theory

1) Elements composed of minute, indivisible particles called,

Atoms

2) Atoms of an element are identical & different from atoms of any other elements

- have different properties & different masses

3) Atoms combine in whole numbers to form compounds (molecules)

Law of Multiple Proportions

4) Compounds are composed of atoms of diff. elements chemically combined.

- relative number of each type of atom is constant

Law of Constant Composition

5) In chemical rxn's, atoms are rearranged, but the number & kind of atoms is unchanged

Law of Conservation of Mass

II) Sizes of Atoms

A) Mass

mass of H = 1.67×10^{-24} g

Define atomic mass unit

1 amu = 1.6603×10^{-24} g

Masses of atoms: 1 - 260 amu

B) Radius (Volume)

Atoms pictured as spherical

Radii

0.5×10^{-8} cm → 2.4×10^{-8} cm

Use nm,

0.05 nm → 0.24 nm

Also use angstrom, Å

$1\ Å = 10^{-10}\ m = 10^{-8}\ cm$

$\therefore$ 0.5 Å → 2.4 Å

III) Subatomic Particles

Atom is composed of smaller subatomic particles

Atom: smallest particle of an element that retains properties of that element

A) Electron, e^-

charge = -1.6022×10^{-19} C (coulomb)

$m_{e^-} = 9.1094 \times 10^{-28}$ g

$= 5.486 \times 10^{-4}$ amu

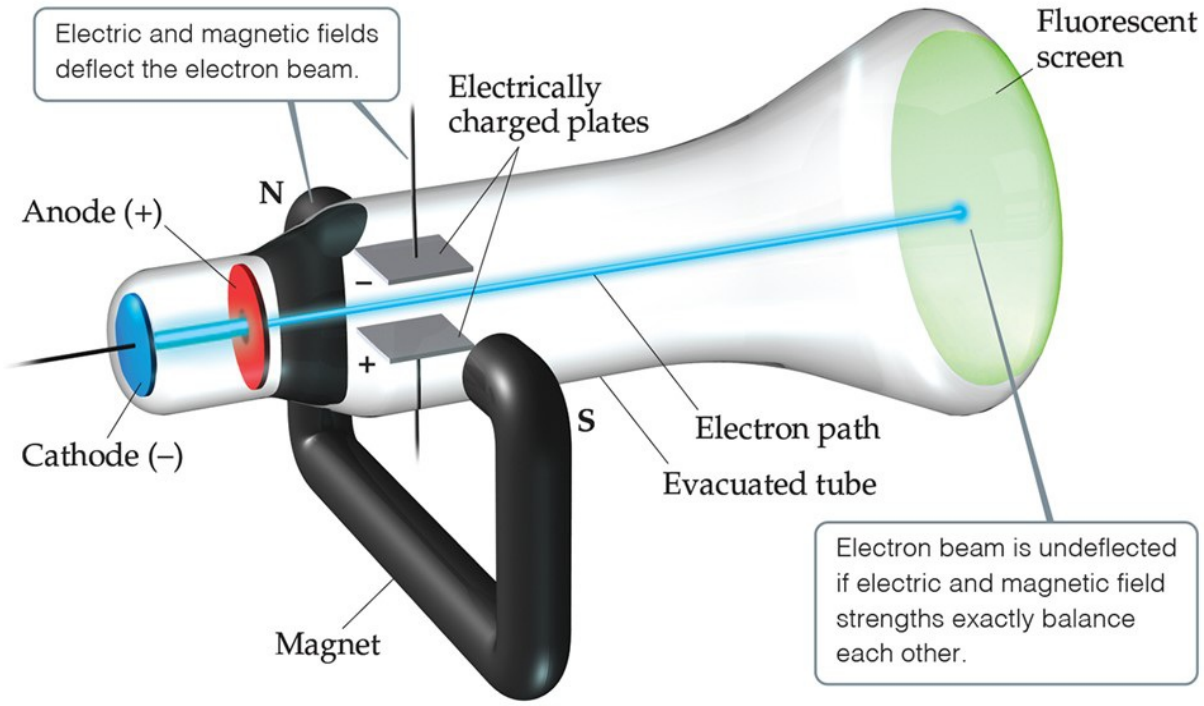
1) Discovery

a) J. J. Thompson

Passed e^- through a hole in the anode of a cathode ray tube placed in a magnetic and an electric field.

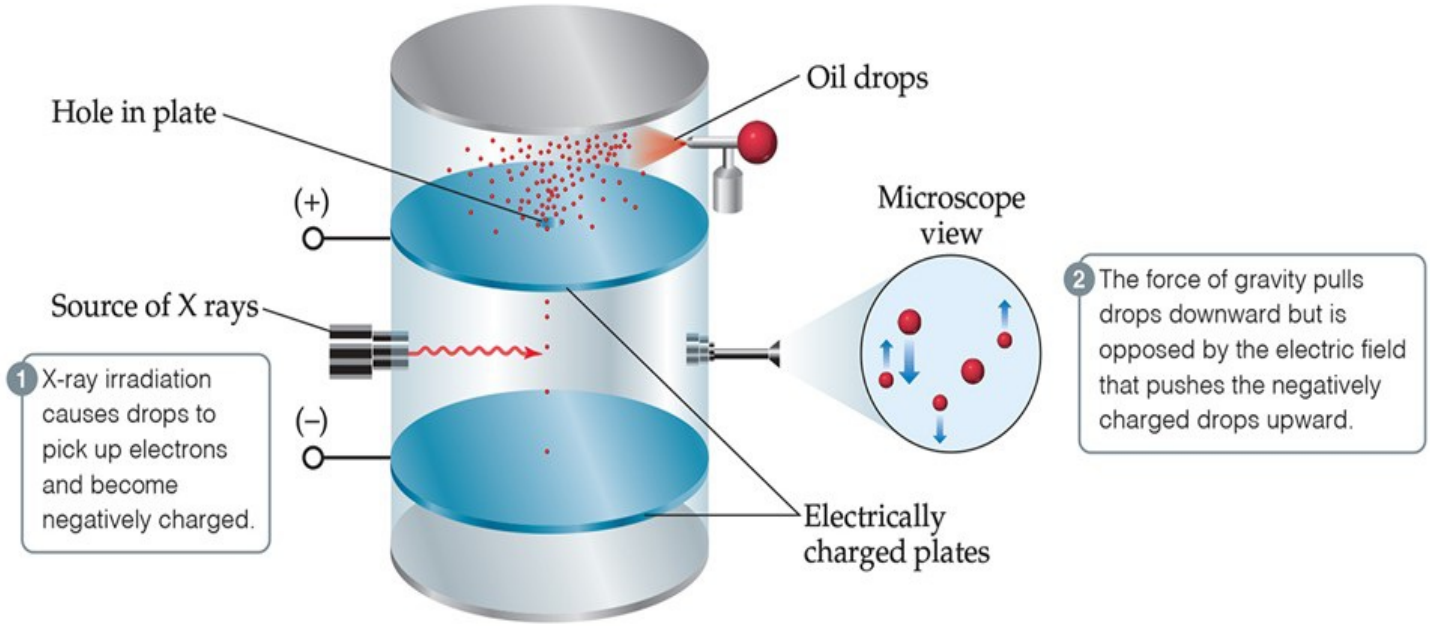
Adjusted the field strengths so the e^- would travel in a straight line.

charge to mass ratio of: 1.76×10^8 C/g



b) Millikan

Oil-drop exp - determined charge on an e^- and the mass.



What was done and found?

1) Small drops allowed to fall between electrically charged plates.

   Measured how varying voltage affected rate of fall.

2) Calculated charge on drops.

3) Always a integral multiple of:

   1.602×10^{-19} C

   This was charge on e^-.

4) From this and Thompson's charge:mass ratio determined mass of e^-,

   9.1094×10^{-28} g

B) Proton, p

Matter is neutral:

removal of e^- leaves a (+) charged particle

remove e^- from H

$\Rightarrow H^+$, a proton (p)

- fundamental particle

charge = $+ 1.6022 \times 10^{-19}$ C

$m_p = 1.6726 \times 10^{-24}$ g

$= 1.0073$ amu

$m_p \approx 1836\ m_{e^-}$

Other atoms contain > 1 p

Number of protons in atom
characteristic of element

Atoms are neutral,

$$\# p = \# e^-$$

C) Neutron, n

Only about ½ of mass of atoms accounted for by protons

charge = 0

$m_n = 1.6749 \times 10^{-24}$ g

$= 1.0088$ amu

$m_n \approx m_p$

D) Summary of Subatomic Particles

particle	symbol	mass (amu)	relative charge
electron	e^-	0.0005486	−1
proton	p	1.0073	+1
neutron	n	1.0088	0

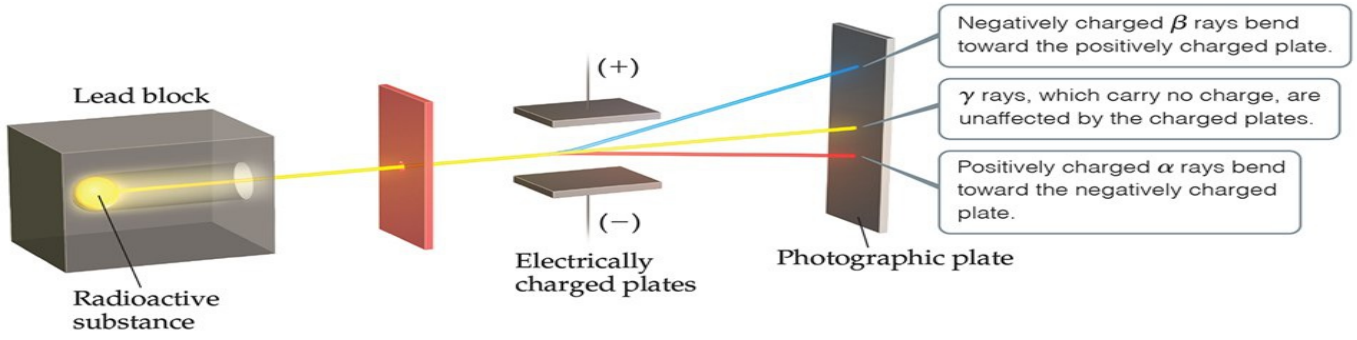
$$m_n \approx m_p >> m_{e^-}$$

E) Nuclear Model of the Atom

1) Rutherford

a) Radioactivity

Spontaneous emission of radiation from the nucleus.



Beta particle, β: electron, e^-

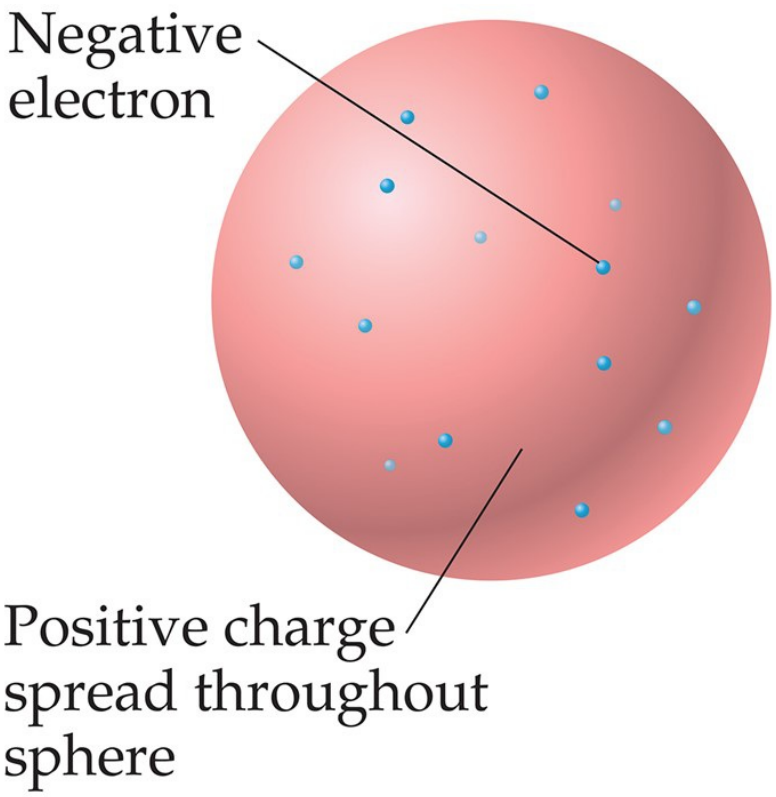
Alpha particle, α: helium nucleus, He^{2+}

Gamma ray: energy (no charge)

b) Gold-foil exp

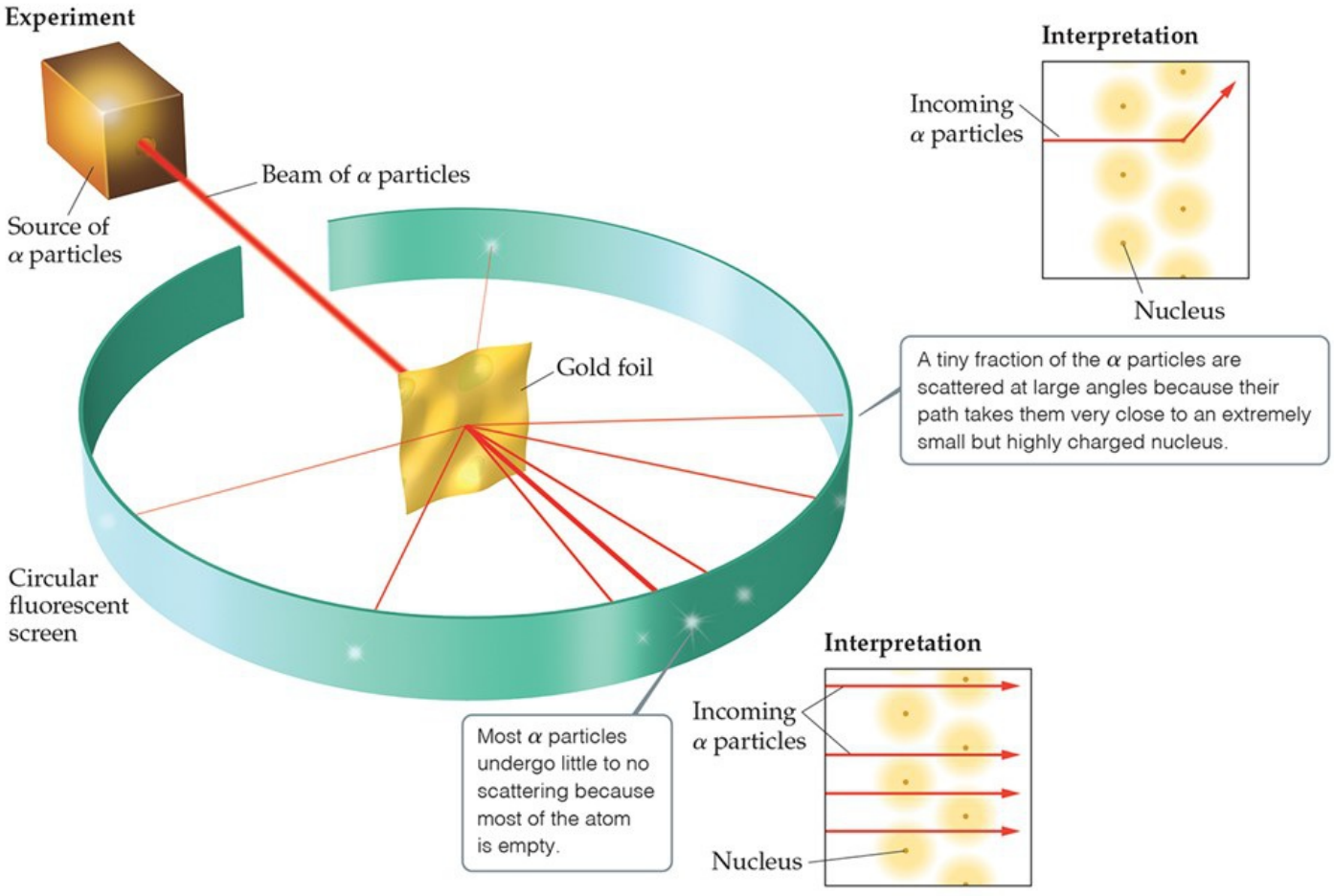
Thompson - plum pudding model

atoms have uniform (+) chg in which e^- are embedded like plums in pudding.



Rutherford:

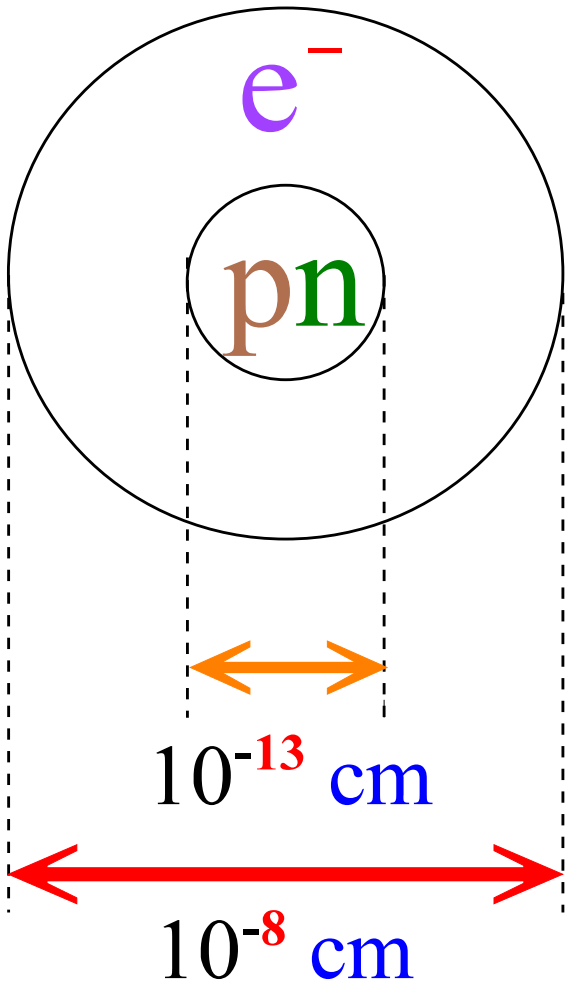
Deflection of α-particle beams by sheets of gold foil.



α-particles deflected at large angles

c) Nuclear Model

Atom composed of dense nucleus, containing protons & neutrons & most of atom's mass surrounded by e^- in motion in mostly empty space



diameter of atoms very small

IV) Composition of Atoms

A) Atomic Number, Z

Z = # of protons

Distinguishes atoms of one element from those of another

Whole number in block w. chemical symbol in P.T.

Elements in P.T. ordered by inc. atomic no.

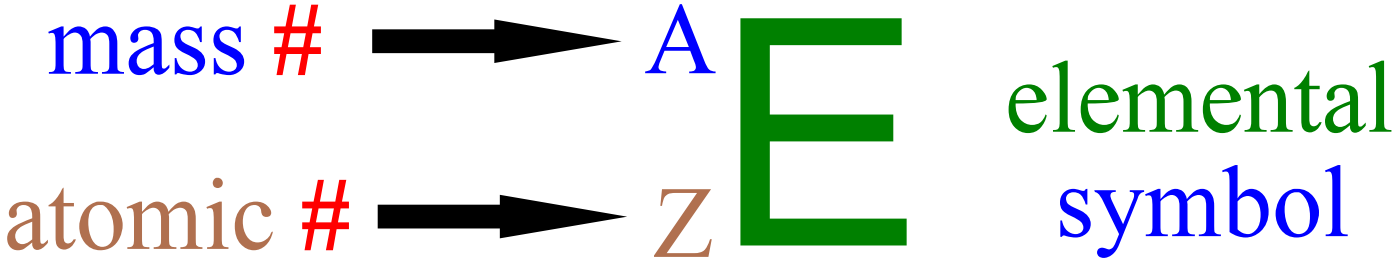
In neutral atom, # p = # e^-

B) Mass Number, A

A = # p + # n

C) Elemental Symbol

Describes composition of nucleus



1) Ex 1: What does the following symbol represent?

$^{107}_{47}Ag$

Sometimes only show mass #

^{107}Ag silver - 107

2) Ex 2:

$^{197}_{79}Au$

D) Isotopes

Atoms of same element which have different numbers of neutrons

∴ same atomic #, Z
different mass #, A

"A" distinguishes between isotopes of the same element

Note: Isotopes of the same element have the same chemical properties

1) Ex: Naturally occurring boron consists of 2 isotopes

$^{10}_{5}B$

$^{11}_{5}B$

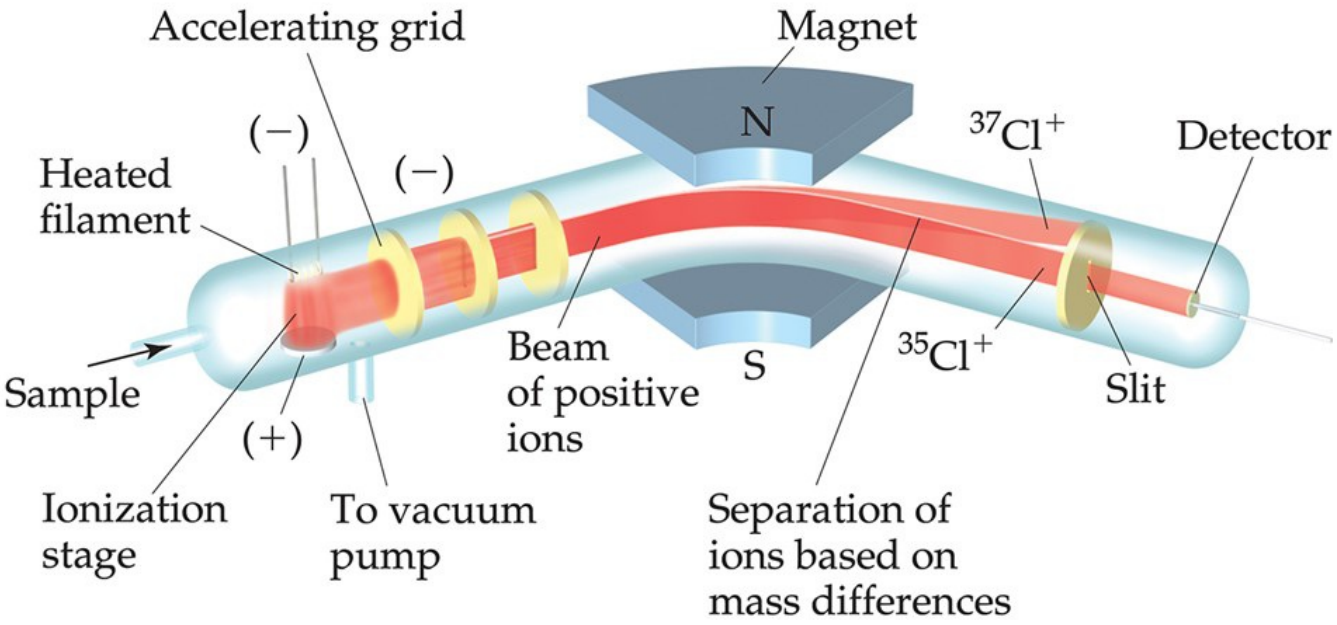
B) Atomic Weight

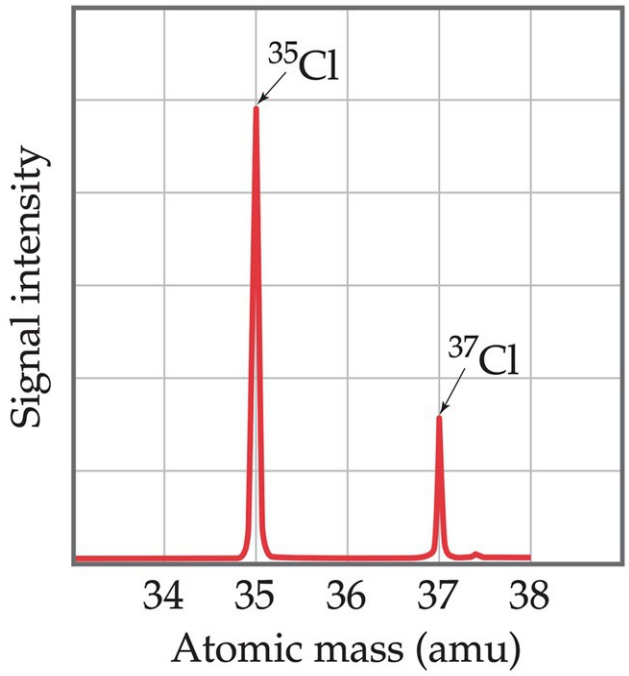
A.W. scale based on assignment of exactly 12 amu to $^{12}_{6}C$

A.W. is weighted average of naturally occurring isotopes expressed in amu

1) Ex: The two isotopes of silver are ^{107}Ag and ^{109}Ag, having natural abundances of 51.35% and 48.65%, respectively. Their isotopic masses are 106.916 & 108.914 amu, respectively. Determine the A.W. of Ag.

2) Mass Spectrometer and Isotopes





V) Periodic Table

A) Periodic Law

Mendeleev: table based on idea that properties of elements are periodic functions of their A.W.

- exceptions: I & Te ; Ar & K

Moseley: proper correlation is with atomic number

1) Modern Periodic Law

Properties of the elements are periodic functions of their

Atomic Number

B) Modern Periodic Table

Arrangement of elements in order of inc. atomic no., placing those with similar chem. and phys. prop. in columns.

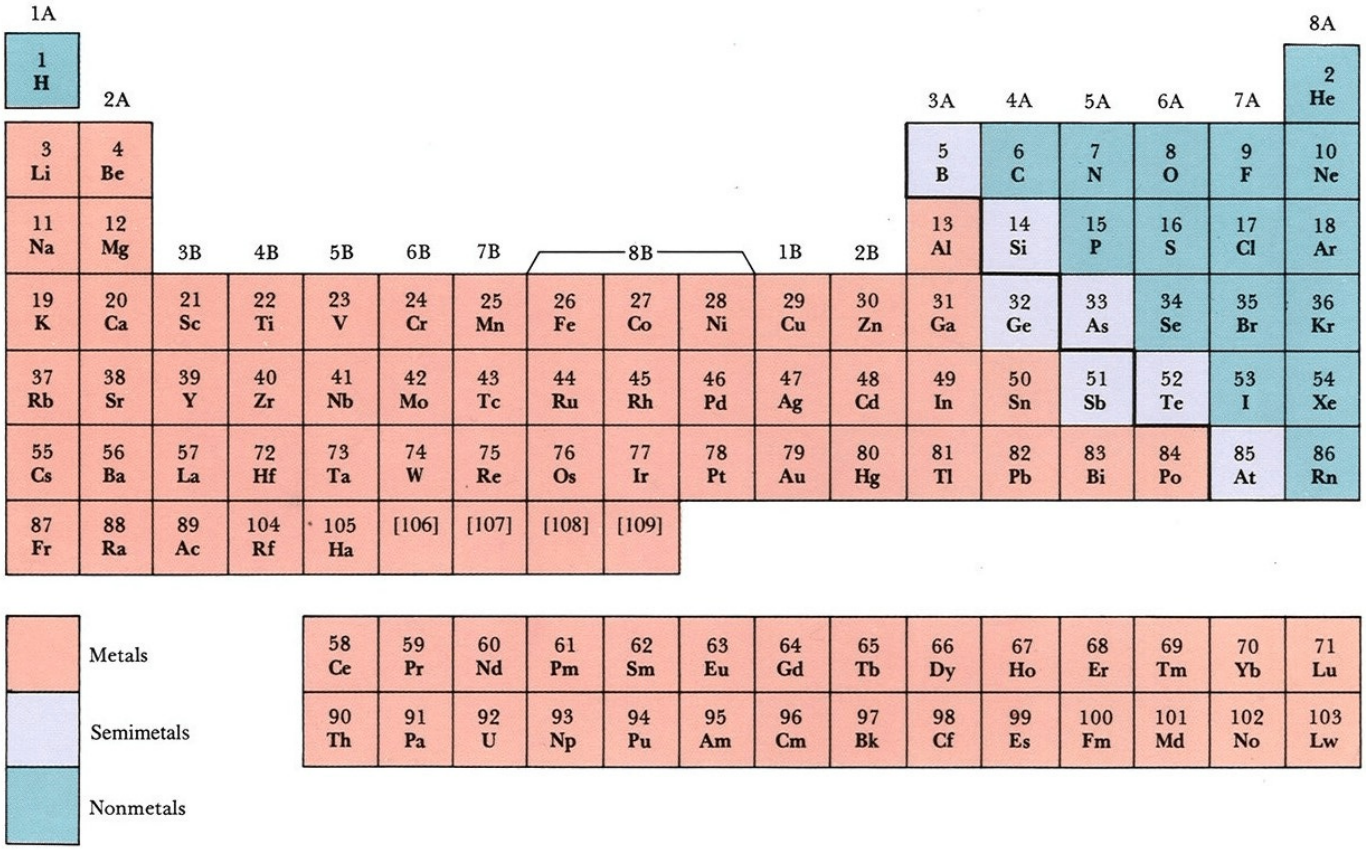
1) Groups

Vertical columns called groups or families

- elements within a group have similar prop.

Labeled at top of column by Roman numerals (I - VIII) or Arabic numerals (1 - 8) and letter, A or B

Transparency 13 Figure 2.16 Periodic table divided into metals, nonmetals, and semimetals



CHEMISTRY: THE CENTRAL SCIENCE
by Brown/Le May/Bursten

a) Representative Elements

(main-group elements)

1 A - 8 A

1) Specific Group Names

1 A	alkali metals
2 A	alkaline earth metals
7 A	halogens
8 A	noble or rare gases

b) Transition Metal Elements

1 B - 8 B

- metals

2) Periods

Horizontal rows called periods

Two long rows below main body of table are:

Inner transition elements
- lanthanides & actinides

1st period	H - He	2 elements
2nd period	Li - Ne	8 elements
3rd period	Na - Ar	8 elements
4th period	K - Kr	18 elements
5th period	Rb - Xe	18 elements
6th period	Cs - Rn	32 elements

Metals	Nonmetals
solids (except Hg)	gases or solids (except Br)
metallic luster	variety of color & appearance
malleable & ductile	solids are brittle
good conductors of heat & electricity	poor conductors (insulators)
oxides:	oxides:
nonvolatile	volatile
high melting	low melting
MgO, Na_2O	CO, CO_2, SO_2

VI) Molecular Elements & Compounds

A) Molecular Substances

Group of chemically bonded atoms which has the characteristic properties of the substance

1) Molecular Elements

a) Diatomics

Contain 2 atoms

H_2 2 H atoms bonded together

H—H

other diatomic elements

N_2, O_2, F_2, Cl_2, Br_2, I_2

b) Polyatomics

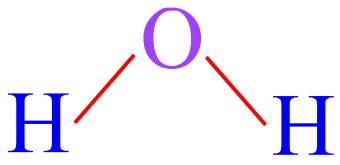
P_4 & S_8

O_3 - allotrope of O_2

2) Molecular Compounds

Molecules of compounds contain 2 or more diff. elements

H_2O



2 H atoms &
1 O atom

CO_2 carbon dioxide

1 C atom &
2 O atoms

3) Molecular Formula

Actual number of each kind of atom in a molecule

C_6H_6 Benzene
C_2H_5OH Ethanol

4) Empirical Formula

Relative number of atoms of each kind in a molecule

- smallest whole-number ratio of atoms

C_1H_1 Benzene or acetylene

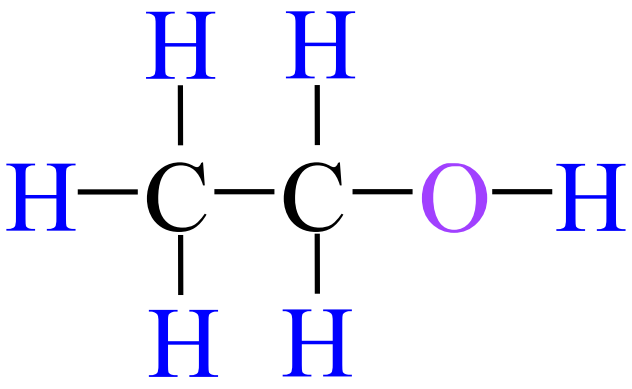
Subscripts in a molecular formula are always some integer multiple of subscripts in empirical formula

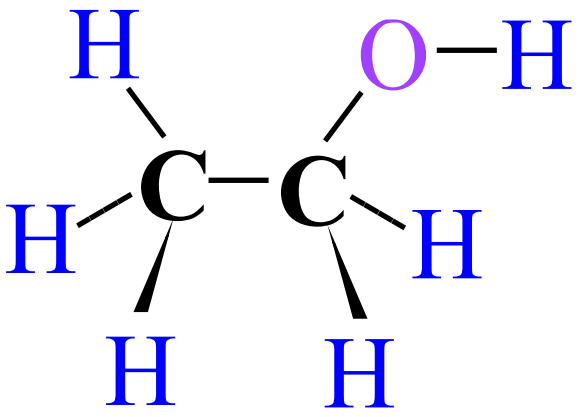
5) Structural Formula

Gives an idea about the structure of the molecule

Ethanol

C_2H_6O or C_2H_5OH





VII) Ionic Substances

A) Ions

particle that contains more or fewer e^- than protons

$\therefore$ Has NET electrical charge

$$\text{Total charge} = \#\,p - \#\,e^-$$

1) Anion

Negative ion resulting from gain of 1 or more e^- by neutral atom

a) Ex:

$$_{35}Br + e^- \rightarrow Br^-$$

Br^- has 1 extra e^- than Br

(# p does NOT change)

b) Ex:

$_{16}S + 2\,e^- \rightarrow S^{2-}$

* Formation of anions is a property of nonmetals

2) Cation

Positive ion resulting from loss of 1 or more e^- by neutral atom

a) Ex:

$_{19}K \rightarrow K^+ + e^-$

$_{30}Zn \rightarrow Zn^{2+} + 2\,e^-$

* Formation of cations is a property of metals

3) Predicting Charge Using P.T.

Representative Elements

I A – VIII A

gain or lose e^- to achieve same # e^- as nearest noble gas

Br^- 36 e^- ⇛ Kr

S^{2-} , Cl^- , K^+ , Ca^{2+} 18 e^- ⇛ Ar

isoelectronic series

(same # e^-)

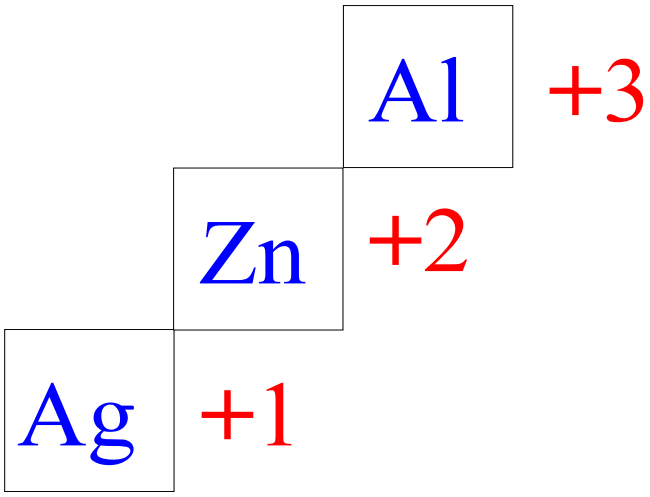
a) Cation Groups

charge = group #

I A = + 1 Li^{+}

II A = + 2 Mg^{2+}

a) Special Cations



2) Anion Groups

charge = group # – 8

V A = – 3 N^{3-}

VI A = – 2 O^{2-}

VII A = – 1 F^{-}

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1.008 **H** 1																	4.003 **He** 2
2	6.941 **Li** 3	9.012 **Be** 4											10.81 **B** 5	12.011 **C** 6	14.007 **N** 7	15.999 **O** 8	18.998 **F** 9	20.179 **Ne** 10
3	22.990 **Na** 11	24.305 **Mg** 12											26.98 **Al** 13	28.09 **Si** 14	30.974 **P** 15	32.06 **S** 16	35.453 **Cl** 17	39.948 **Ar** 18
4	39.098 **K** 19	40.08 **Ca** 20	44.96 **Sc** 21	47.88 **Ti** 22	50.94 **V** 23	52.00 **Cr** 24	54.94 **Mn** 25	55.85 **Fe** 26	58.93 **Co** 27	58.69 **Ni** 28	63.546 **Cu** 29	65.38 **Zn** 30	69.72 **Ga** 31	72.59 **Ge** 32	74.92 **As** 33	78.96 **Se** 34	79.904 **Br** 35	83.80 **Kr** 36
5	85.47 **Rb** 37	87.62 **Sr** 38	88.91 **Y** 39	81.22 **Zr** 40	92.91 **Nb** 41	95.94 **Mo** 42	98 **Tc** 43	101.07 **Ru** 44	102.91 **Rh** 45	106.42 **Pd** 46	107.87 **Ag** 47	112.41 **Cd** 48	114.82 **In** 49	118.69 **Sn** 50	121.75 **Sb** 51	127.60 **Te** 52	126.90 **I** 53	131.39 **Xe** 54
6	132.91 **Cs** 55	137.33 **Ba** 56	138.91 **La** 57	178.39 **Hf** 72	180.95 **Ta** 73	183.85 **W** 74	186.21 **Re** 75	190.23 **Os** 76	192.22 **Ir** 77	195.08 **Pt** 78	196.97 **Au** 79	200.59 **Hg** 80	204.38 **Tl** 81	207.2 **Pb** 82	208.98 **Bi** 83	209 **Po** 84	210 **At** 85	222 **Rn** 86
7	223 **Fr** 87	226.03 **Ra** 88	227.03 **Ac** 89	261 **Rf** 104	262 **Ha** 105	263 **Sg** 106	262 **Ns** 107	265 **Hs** 108	266 **Mt** 109	269 110	272 111	277 112						

6	Lanthanide Series	140.12 **Ce** 58	140.91 **Pr** 59	144.24 **Nd** 60	145 **Pm** 61	150.36 **Sm** 62	151.96 **Eu** 63	157.25 **Gd** 64	158.93 **Tb** 65	162.50 **Dy** 66	164.93 **Ho** 67	167.26 **Er** 68	168.93 **Tm** 69	173.04 **Yb** 70	173.04 **Lu** 71
7	Actinide Series	232.04 **Th** 90	231.04 **Pa** 91	238.03 **U** 92	237.05 **Np** 93	**Pu** 94	**Am** 95	**Cm** 96	**Bk** 97	**Cf** 98	**Es** 99	**Fm** 100	**Md** 101	**No** 102	**Lr** 103

A PERIODIC CHART OF THE ELEMENTS
(Based on ^{12}C)

B) Ionic Compounds

Oppositely charged ions held together by electrostatic attractions

Combinations of metals & nonmetals

Crystalline solids (salts)

1) Formula Units

Compounds are electrically neutral

total (+) chg = total (−) chg

NaCl neutral

(cation)(anion)

Formula shows simplest ratio of ions

- empirical formula

NOT a molecule

3-D arrangement of ions

a) Ex : Cmpd. formed from Ca^{2+} & CO_3^{2-}

$$Ca\ CO_3$$

cation anion

VIII) Naming Ions

A) Monatomic Ions

1) Cations

Use name of element followed by "ion"

K^+ potassium ion

Zn^{2+} zinc ion

2) Anions

Add "ide" to root of element's name

Br^- bromide ion

S^{2-} sulfide ion

B) Stock System & Older System

Many metals have more than one possible charge

- transition metals
- representative metals

	Stock	Older
Fe^{2+}	iron (II)	ferrous
Fe^{3+}	iron (III)	ferric
Cu^{+}	copper (I)	cuprous
Cu^{2+}	copper (II)	cupric
Sn^{2+}	tin (II)	stannous
Sn^{4+}	tin (IV)	stannic

C) Polyatomic Ions

Group of chemically bonded atoms with an overall charge

SO_4^{2-}

2- ⇐ charge on whole group of atoms

4 ⇑ number of oxygen atoms

1) Polyatomic Anions ending in -ide

OH^- hydroxide ion

CN^- cyanide ion

2) Polyatomic Cations

NH_4^+ ammonium ion

H_3O^+ hydronium ion

Hg_2^{2+} mercury (I) ion

3) Misc. Polyatomic Anions

MnO_4^- permanganate ion

$C_2H_3O_2^-$ acetate ion

CrO_4^{2-} chromate ion

$Cr_2O_7^{2-}$ dichromate ion

4) Polyatomic Anions - Oxyanions

Carbonate	CO_3^{2-}
Chlorate	ClO_3^-
Nitrate	NO_3^-
Phosphate	PO_4^{3-}
Sulfate	SO_4^{2-}

a) Vary Number of Oxygens

Prefixes & suffixes indicate changes made to base anion.

1) Suffixes

-ate base anion

-ite 1 less O-atom than -ate

Nitrite NO_2^-

2) Prefixes

per- (over) 1 more O-atom than -ate

hypo- (under) 1 less O-atom than -ite

3) Ex 1:

ClO_4^-	perchlorate
ClO_3^-	chlorate
ClO_2^-	chlorite
ClO^-	hypochlorite
Cl^-	chloride

4) Ex 2: What is bromate, perbromate, hypoiodite?

5) Ex 3: What is SO_3^{2-} ?

Note: Overall charge on the "family" of anions remains same

b) Addition of H^+ to -2 or -3 Oxyanion

Resulting species still charged
- anions

$CO_3^{2-} + H^+ \rightarrow HCO_3^-$ bicarbonate
or
hydrogen carbonate

$PO_4^{3-} + H^+ \rightarrow HPO_4^{2-}$

monohydrogen phosphate

$HPO_4^{2-} + H^+ \rightarrow H_2PO_4^-$

dihydrogen phosphate

c) Acids

H^+ combines with anion to produce a neutral compound ⇛

Acid

Not ionic but ionize in H_2O to produce H^+ (H_3O^+)

$$HCl\,(g) \xrightarrow{H_2O} H^+\,(aq) + Cl^-\,(aq)$$

1) Binary Acids

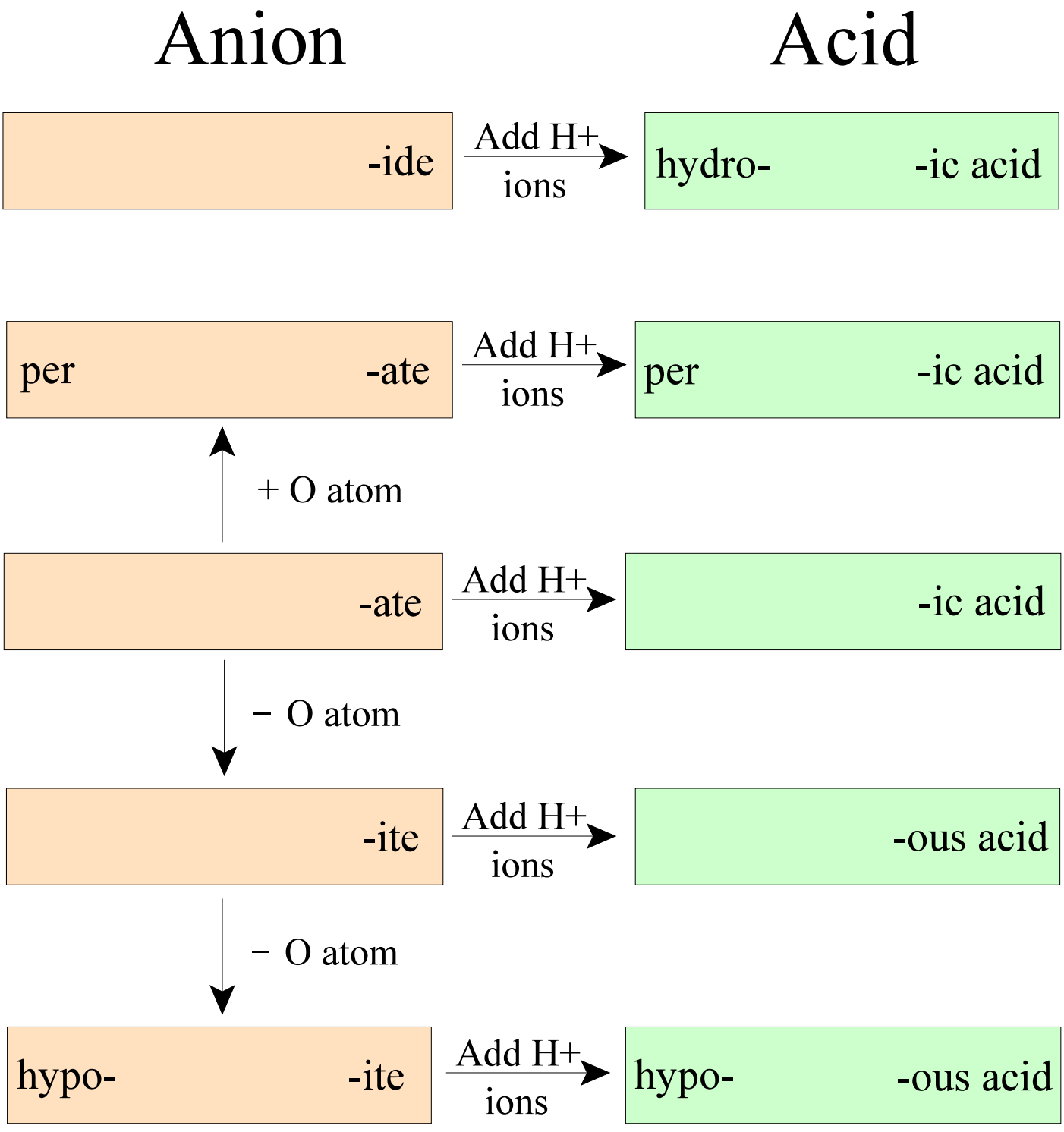
Hydrogen + nonmetal

-ide ⇛ -ic acid

Precede name with hydro-

HF(aq) hydrofluoric acid

Summary of Acid/Anion Naming



IX) Formulas & Names of Ionic Compounds

1) Ex 1: What compound is formed from Ca^{2+} and CO_3^{2-} ?

2) Ex 2: NH_4^+ and S^{2-}

3) Ex 3: Al^{3+} and SO_4^{2-}

4) Ex 4: Sn^{4+} and O^{2-}

5) Ex 5: Write the formula for manganese (IV) oxide.

6) Ex 6: Write the formula for iron(II) sulfite.

X) Binary Molecular Compounds

2 diff. elements

nonmetals

or

nonmetals & semimetals

Usually, element further to left & lower in column in PT (less electronegative) given first

B	Si,C	As,P,N	H	Se,S	I,Br,Cl	O	F
3A	4A	5A	*	6A	7A	*	7A

SiC silicon carbide

NO nitrogen monoxide

H_2S hydrogen sulfide

A) Same Element; Multiple Compounds

Greek prefix indicates number of atoms of each element

N_2O

N_2O_4

SO_2

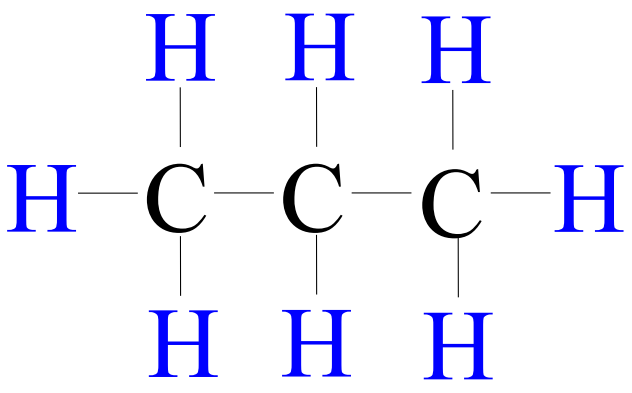
SO_3

XI) Simple Organic Compounds

Hydrocarbons: C & H

A) Alkanes: $C_nH_{(2n+2)}$

methane	CH_4	
ethane	C_2H_6	CH_3CH_3
propane	C_3H_8	$CH_3CH_2CH_3$



but-, pent-, hex-, hept-, oct-, non-, dec-
4 10

B) Functional Groups

Hydrogens replaced with "functional groups"

1) Alkenes:

ethene (ethylene) $CH_2 = CH_2$

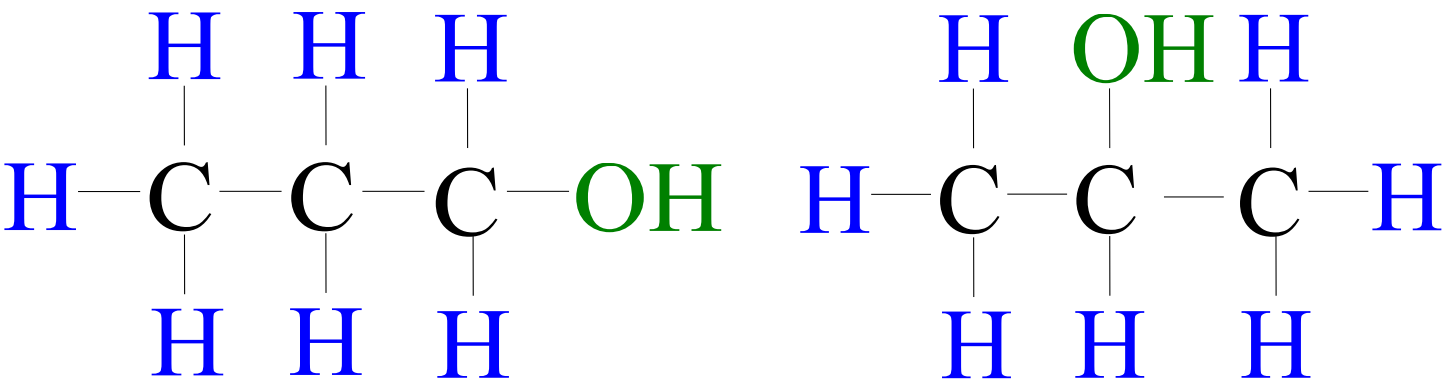
2) Alkynes:

ethyne (acetylene) $CH \equiv CH$

3) Alcohols: R-OH (R = Carbon grp)

methanol (methyl alcohol)	CH_3OH
ethanol (ethyl alcohol)	CH_3CH_2OH
1- propanol (propyl alcohol)	$CH_3CH_2CH_2OH$
2-propanol (isopropyl alcohol)	$CH_3CH(OH)CH_3$

Isomers: Same molecular formula but different arrangement



Structural isomers

4) Ethers: R-O-R

dimethyl ether CH_3OCH_3
(methoxy methane)

diethyl ether $CH_3CH_2OCH_2CH_3$
(ethoxy ethane)

Functional grp isomers w. alcohols

5) Aldehydes: X-CHO (X = H, C grp)

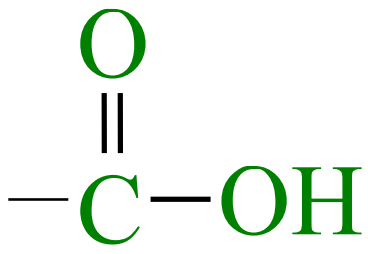
C=O group (carbonyl)

HCHO formaldehyde

6) Ketones: R-CO-R

CH_3COCH_3 acetone

7) Carboxylic acids: X-CO_2H

carboxyl group: 

$H\text{-}CO_2H$ formic acid
(methanoic acid)

CH_3CO_2H acetic acid
(ethanoic acid)

8) Amines: $\text{-}NX_2$ (X = H, C)

Organic analogues of NH_3 (ammonia)

CH_3NH_2 methyl amine
(amino methane)

$(CH_3)_2NH$ dimethyl amine