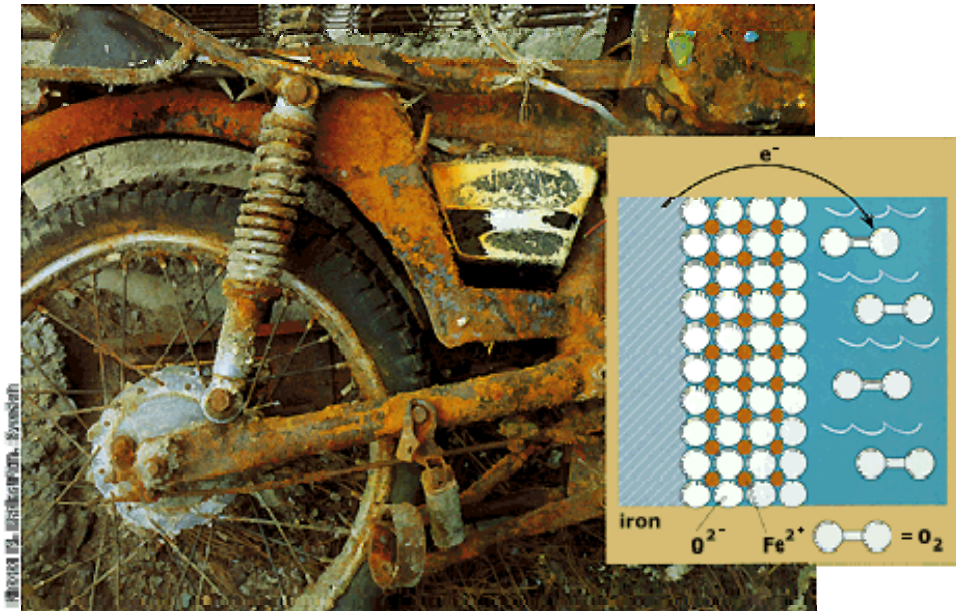
Compounds of Metals

Ionic Bonding and Inorganic Compounds



MODIFIED FROM Dr. Patricia Hill, Millersville University

Compounds of Metals

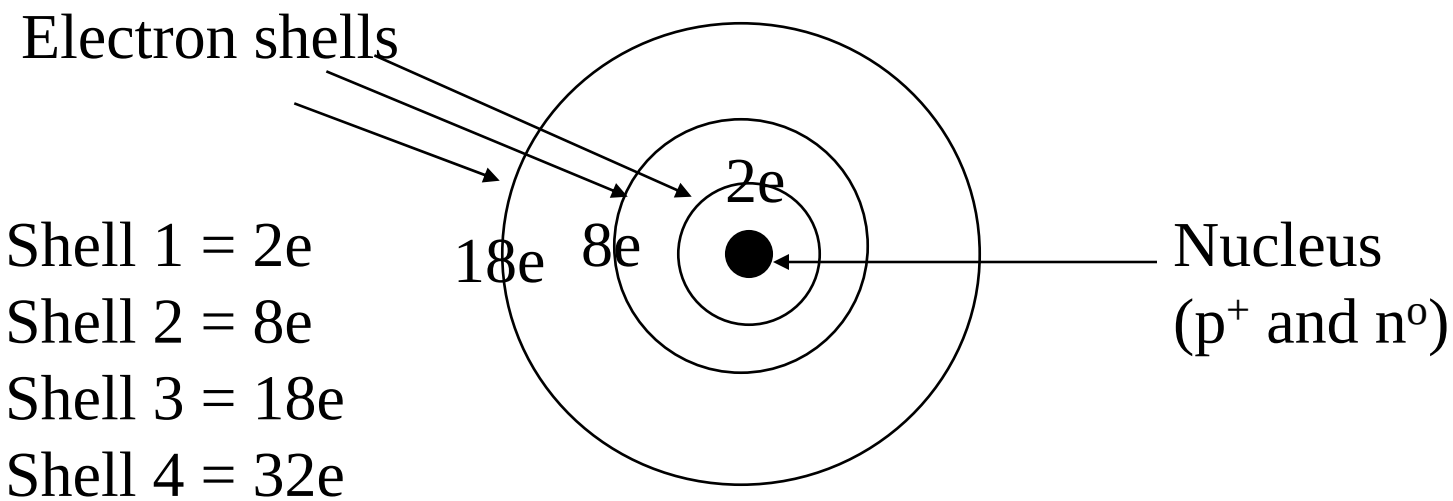
- Ores
  - Hematite
  - Chalcopyrite
  - Bauxite
- Corrosion
  - Rust = iron oxide = Fe_2O_3
  - Alumina = aluminum oxide = Al_2O_3
  - Tarnish = silver sulfide = Ag_2S
  - Darkened white paint = Lead sulfide = PbS
- Metallic salts
  - Sodium chloride = NaCl
  - Copper chloride = $CuCl_2$ and CuCl

hematite

bauxite

Bohr Model of the Atom

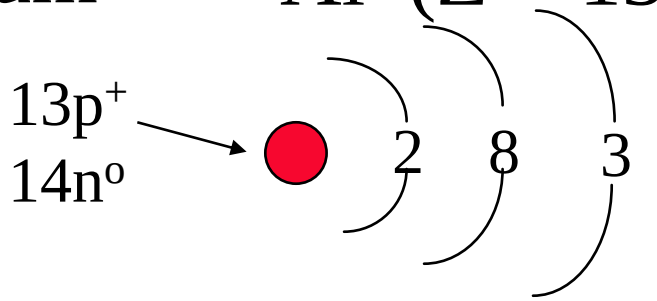
- Planetary model of electron location
- Energy **shells** contain maximum number of electrons — $2n^2$



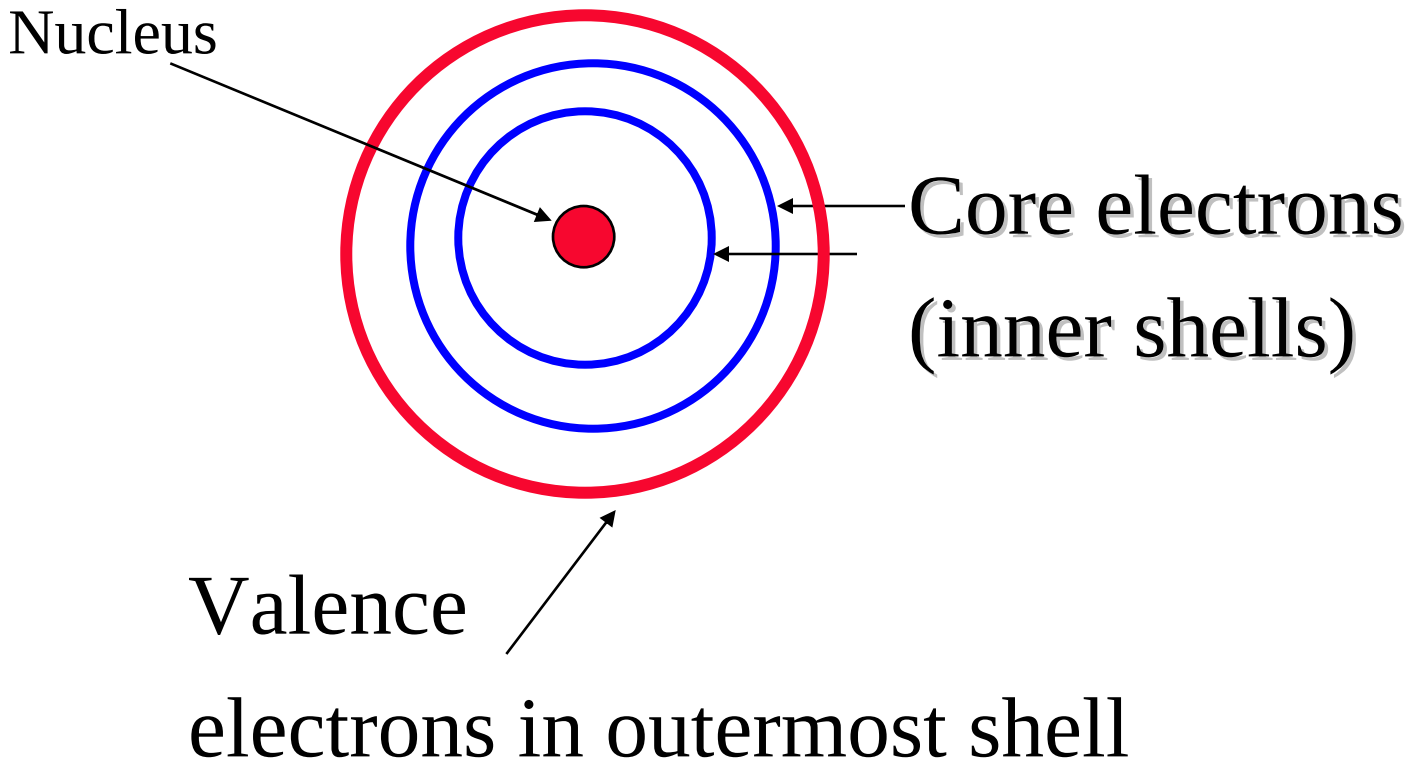
Shell 1 = 2e
Shell 2 = 8e
Shell 3 = 18e
Shell 4 = 32e

Bohr Diagrams of Atoms

- Need to know
  - Symbol of element
  - Number of p^+, n^o, and e^-
  - How many electrons in each shell
- Aluminum Al (Z = 13, A = 27)



What Are Valence Electrons?



Finding Valence Electrons

Look at the Periodic Table

1A	2A											3A	4A	5A	6A	7A	8A
1e																	2e
1e	2e											3e	4e	5e	6e	7e	8e
1e	2e											3e	4e	5e	6e	7e	8e
1e	2e											3e	4e	5e	6e	7e	8e

For Main Group Elements (A)

Group Number = number of valence electrons

	I A s1	II A s2											III A s2 p1	IV A s2 p2	V A s2 p3	VI A s2 p4	VII A s2 p5	0 s2 p6
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh		

Transition elements

	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB
	d1 s2	d2 s2	d3 s2	d5 s1	d5 s2	d6 s2	d7 s2	d8 s2	d10 s1	d10 s2

Inner Transition Elements

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Legend

Metals	Metalloids
Non-Metals	Inert Gases

Periodic Table of the Elements

Group new → 1 IA ← Group old
Symbol → K ← Atomic number
Name → Potassium
Atomic mass (averaged according to occurrence on earth) → 39.0983
Electron configuration → 4s¹

Metals — Metalloids — Nonmetals

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
H 1 Hydrogen 1.00794 1s¹																	He 2 Helium 4.00260 1s²
Li 3 Lithium 6.941 2s¹	Be 4 Beryllium 9.012182 2s²											B 5 Boron 10.81 2p¹	C 6 Carbon 12.011 2p²	N 7 Nitrogen 14.0067 2p³	O 8 Oxygen 15.9994 2p⁴	F 9 Fluorine 18.9984 2p⁵	Ne 10 Neon 20.179 2p⁶
Na 11 Sodium 22.989768 3s¹	Mg 12 Magnesium 24.3050 3s²											Al 13 Aluminum 26.9815 3p¹	Si 14 Silicon 28.0855 3p²	P 15 Phosphorus 30.9738 3p³	S 16 Sulfur 32.06 3p⁴	Cl 17 Chlorine 35.453 3p⁵	Ar 18 Argon 39.948 3p⁶
K 19 Potassium 39.0983 4s¹	Ca 20 Calcium 40.078 4s²	Sc 21 Scandium 44.955910 3d¹4s²	Ti 22 Titanium 47.88 3d²4s²	V 23 Vanadium 50.9415 3d³4s²	Cr 24 Chromium 51.9961 3d⁵4s¹	Mn 25 Manganese 54.93805 3d⁵4s²	Fe 26 Iron 55.847 3d⁶4s²	Co 27 Cobalt 58.933200 3d⁷4s²	Ni 28 Nickel 58.69 3d⁸4s²	Cu 29 Copper 63.546 3d¹⁰4s¹	Zn 30 Zinc 65.39 3d¹⁰4s²	Ga 31 Gallium 69.723 4p¹	Ge 32 Germanium 72.61 4p²	As 33 Arsenic 74.92159 4p³	Se 34 Selenium 78.96 4p⁴	Br 35 Bromine 79.904 4p⁵	Kr 36 Krypton 83.80 4p⁶
Rb 37 Rubidium 85.4678 5s¹	Sr 38 Strontium 87.62 5s²	Y 39 Yttrium 88.90585 4d¹5s²	Zr 40 Zirconium 91.224 4d²5s²	Nb 41 Niobium 92.90638 4d⁴5s¹	Mo 42 Molybdenum 95.94 4d⁵5s¹	Tc 43 Technetium (98) 4d⁵5s²	Ru 44 Ruthenium 101.07 4d⁷5s¹	Rh 45 Rhodium 102.90550 4d⁸5s¹	Pd 46 Palladium 106.42 4d¹⁰5s⁰	Ag 47 Silver 107.8682 4d¹⁰5s¹	Cd 48 Cadmium 112.411 4d¹⁰5s²	In 49 Indium 114.82 5p¹	Sn 50 Tin 118.710 5p²	Sb 51 Antimony 121.75 5p³	Te 52 Tellurium 127.60 5p⁴	I 53 Iodine 126.9045 5p⁵	Xe 54 Xenon 131.30 5p⁶
Cs 55 Cesium 132.90543 6s¹	Ba 56 Barium 137.327 6s²	*57 - 71 Lanthanide series*	Hf 72 Hafnium 178.49 5d²6s²	Ta 73 Tantalum 180.9479 5d³6s²	W 74 Tungsten 183.85 5d⁴6s²	Re 75 Rhenium 186.207 5d⁵6s²	Os 76 Osmium 190.2 5d⁶6s²	Ir 77 Iridium 192.22 5d⁷6s²	Pt 78 Platinum 195.08 5d⁹6s¹	Au 79 Gold 196.96654 5d¹⁰6s¹	Hg 80 Mercury 200.59 5d¹⁰6s²	Tl 81 Thallium 204.3833 6p¹	Pb 82 Lead 207.2 6p²	Bi 83 Bismuth 208.98037 6p³	Po 84 Polonium (209) 6p⁴	At 85 Astatine (210) 6p⁵	Rn 86 Radon (222) 6p⁶
Fr 87 Francium (223) 7s¹	Ra 88 Radium (226) 7s²	*89 - 103 Actinide series*	Unq 104 Unnilquadium (261) 6d²7s²	Unp 105 Unnilpentium (262) 6d³7s²	Unh 106 Unnilhexium (263) 6d⁴7s²	Uns 107 Unnilseptium (262)	108	109									

Lanthanide series	La 57 Lanthanum 138.9055 5d¹6s²	Ce 58 Cerium 140.115 4f¹5d¹6s²	Pr 59 Praseodymium 140.90765 4f³6s²	Nd 60 Neodymium 144.24 4f⁴6s²	Pm 61 Promethium (145) 4f⁵6s²	Sm 62 Samarium 150.36 4f⁶6s²	Eu 63 Europium 151.965 4f⁷6s²	Gd 64 Gadolinium 157.25 4f⁷5d¹6s²	Tb 65 Terbium 158.92534 4f⁹6s²	Dy 66 Dysprosium 162.50 4f¹⁰6s²	Ho 67 Holmium 164.93032 4f¹¹6s²	Er 68 Erbium 167.26 4f¹²6s²	Tm 69 Thulium 168.93421 4f¹³6s²	Yb 70 Ytterbium 173.04 4f¹⁴6s²	Lu 71 Lutetium 174.967 4f¹⁴5d¹6s²

Actinide series	Ac 89 Actinium (227) 6d¹7s²	Th 90 Thorium 232.0381 6d²7s²	Pa 91 Protactinium 231.03588 5f²6d¹7s²	U 92 Uranium 238.0289 5f³6d¹7s²	Np 93 Neptunium (237) 5f⁴6d¹7s²	Pu 94 Plutonium (244) 5f⁶6d⁰7s²	Am 95 Americium (243) 5f⁷6d⁰7s²	Cm 96 Curium (247) 5f⁷6d¹7s²	Bk 97 Berkelium (247) 5f⁹6d⁰7s²	Cf 98 Californium (251) 5f¹⁰6d⁰7s²	Es 99 Einsteinium (252) 5f¹¹6d⁰7s²	Fm 100 Fermium (257) 5f¹²6d⁰7s²	Md 101 Mendelevium (258) 5f¹³6d⁰7s²	No 102 Nobelium (259) 6d⁰7s²	Lr 103 Lawrencium (260) 6d¹7s²

Importance of Valence Electrons

- **Valence** electrons — in outermost shell
  - Account for chemical properties and reactivity of elements
  - Allow atoms to form chemical bonds
  - Group number of A elements

Lewis Dot Structures of Elements

Hydrogen $H^{\bullet}$

Aluminum $\cdot\dot{\underset{\cdot}{\mathrm{Al}}}\cdot$

- Show only the valence electrons
- Need to know
  - Symbol of element
  - Number of valence electrons

Lewis Dot Structures

- Draw the correct dot structures for

Sodium

Calcium

Carbon

Chlorine

Oxygen

Nitrogen

Chemical Bonding

- Holds all matter together
- The key players are

VALENCE electrons

What Are Chemical Bonds?

- 5 Types of chemical bonds hold all matter together
  - * **Covalent** Bonding
  - * **Ionic** Bonding
  - * **Metallic** Bonding
  - * **Hydrogen** Bonding
  - * **Van der Waals** Forces

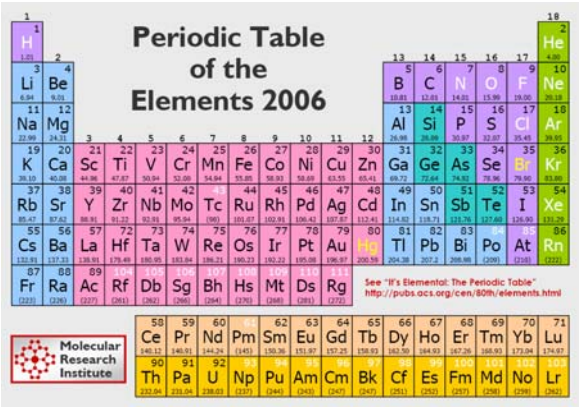
Strongest

Weakest

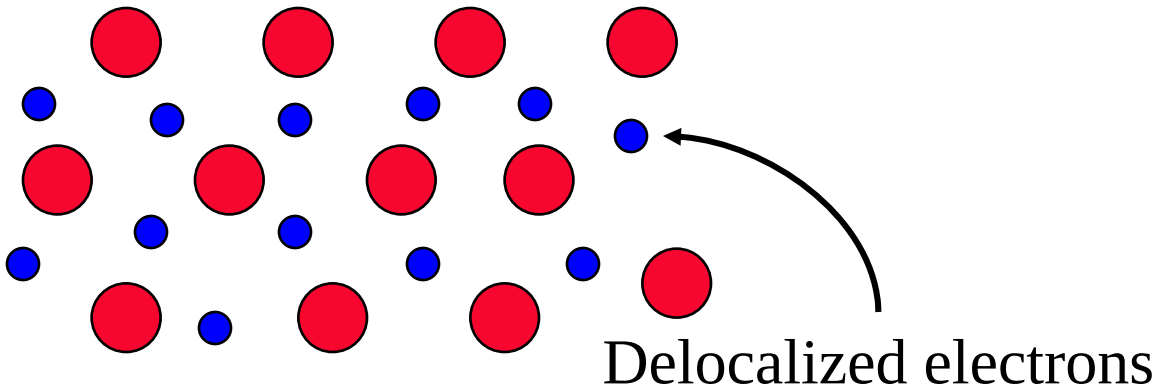
The Top Three Types of Bonds

- covalent bonds = sharing of electrons
- **ionic bonds** = exchange of electrons
- metallic bonds = delocalization of electrons

Metallic Bonding



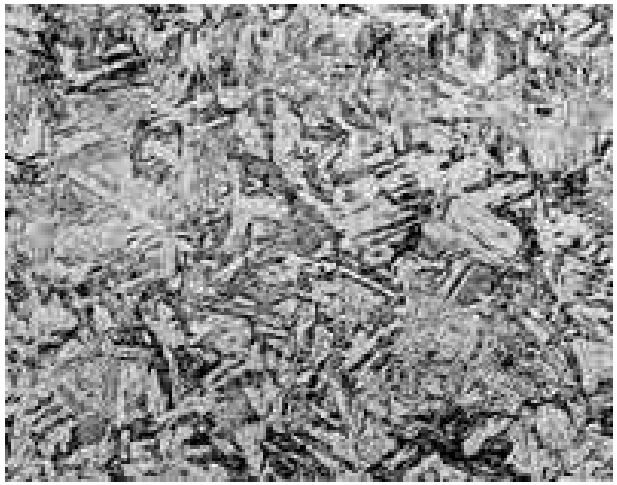
- Metals have 1, 2, or 3 valence electrons
- Valence electrons shared by all metal atoms
- metal **cations** arranged in regular array



- "**sea of electrons**" surround metal **cations**

Delocalized Electrons in Metals

- Provide metallic properties
  - conduction and luster
  - density and strength
  - crystalline structure
  - ability to easily form alloys



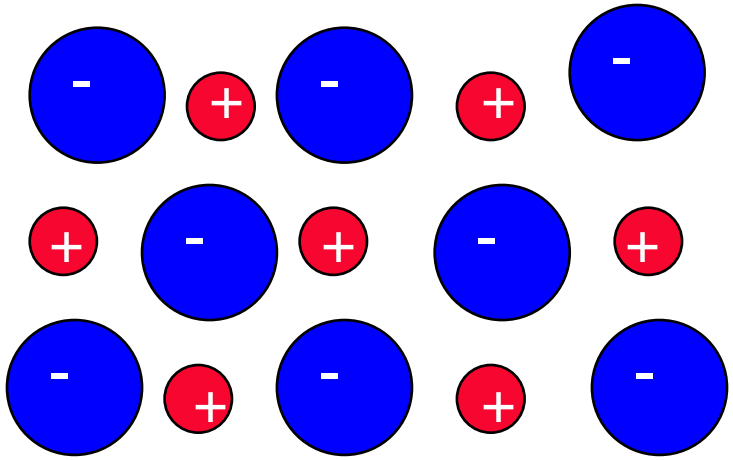
Grains in steel

Metallic Salts—Ionic Bonding

- **Octet Rule** — atoms prefer to have a filled valence shell containing 8 electrons (except He)
- To obtain an octet atoms **lose**, **gain** or **share electrons**
- Ionic bonds result when one element loses electrons and the other element gains electrons

Ionic Bond

- **Cations** and **anions** are formed and held together by strong (+) and (-) charges



Ionic Bonding

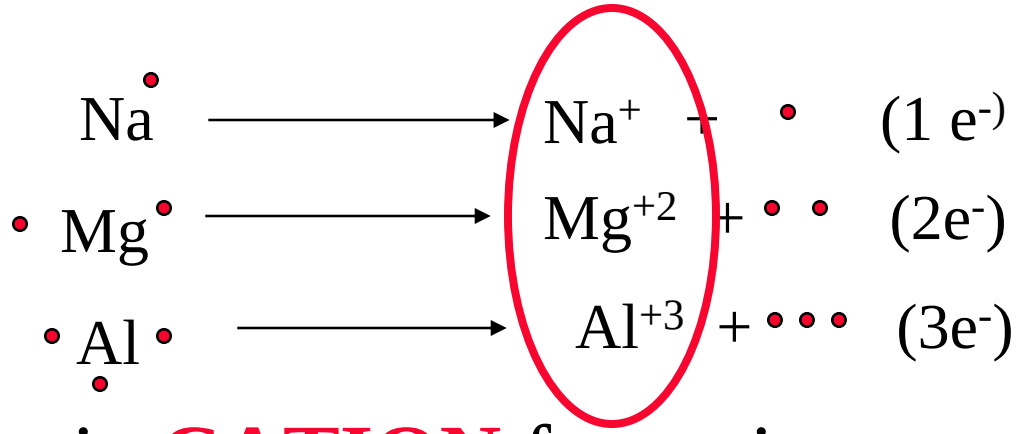
- Results in **IONIC COMPOUNDS**
- Basic unit formed is called a **FORMULA**
- Ionic compounds formed between

  Metals - Groups I, II, III

  Nonmetals - Groups V, VI, VII

Formation of **Positive Ions**

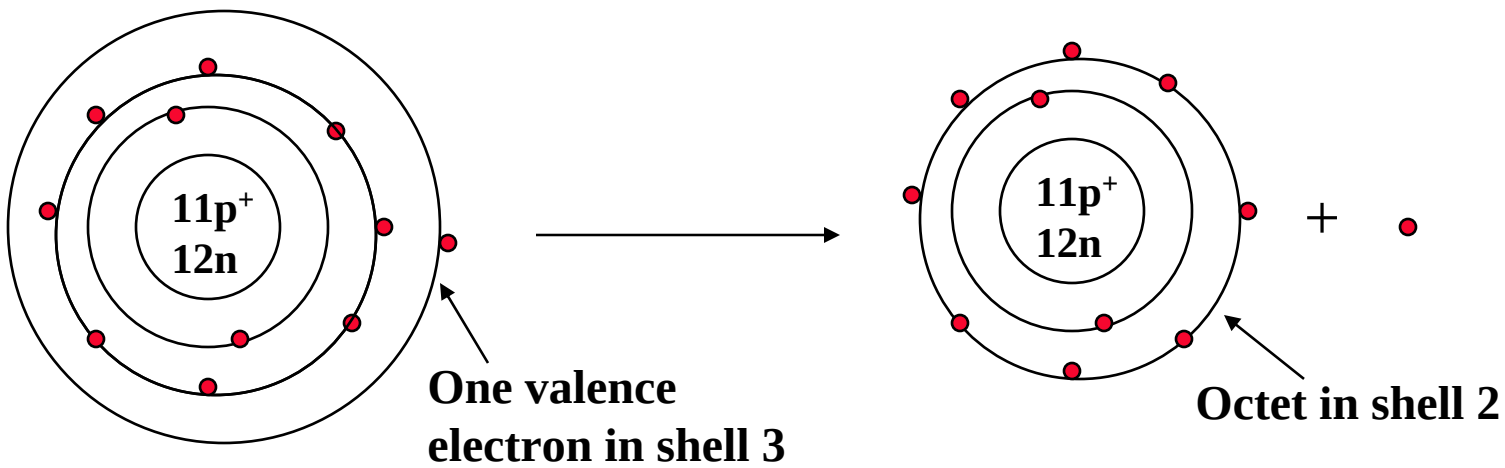
- Metal elements in Groups 1, 2 and 3A can easily lose 1, 2 or 3 valence electrons to obtain an "octet"



- Results in **CATION** formation
- Called an **OXIDATION** reaction (**OIL**)

Formation of **Cations**

$Na^{\bullet} \longrightarrow Na^{+} + \bullet \quad (1\ e^{-})$

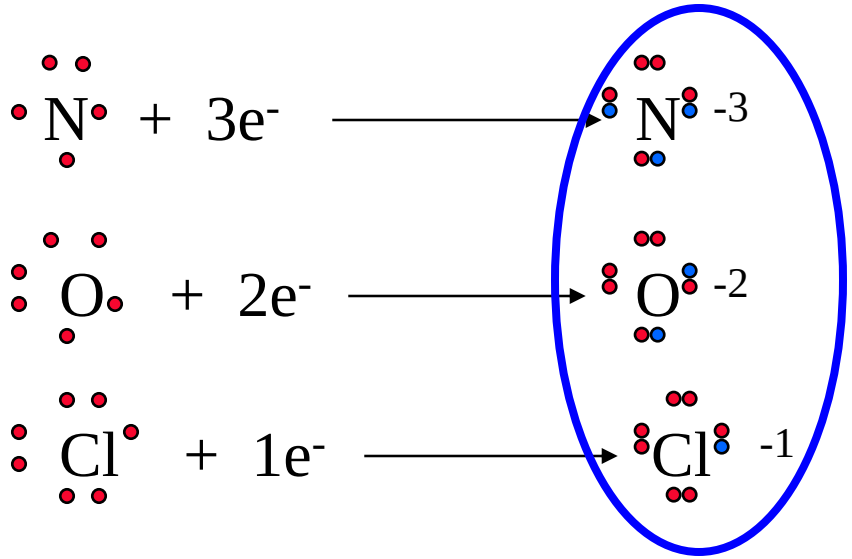


11 +
<u>11 -</u>
0 charge

11 +
<u>10 -</u>
+1 charge

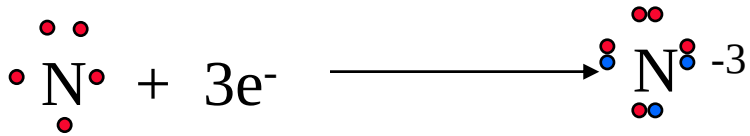
Formation of **Negative Ions**

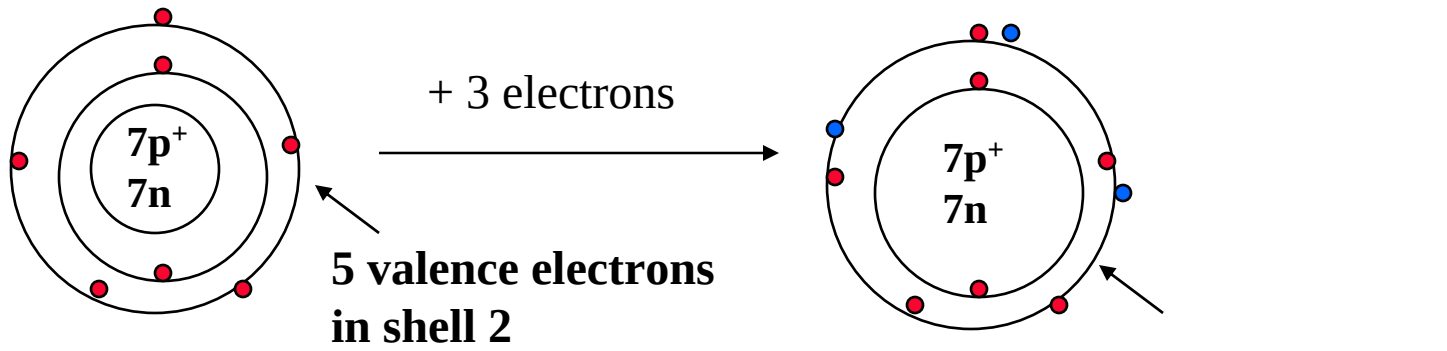
- Nonmetal elements in groups VA, VIA, and VIIA can easily gain 1, 2, or 3 electrons to obtain an "octet"



- result in **ANION** formation - REDUCTION (RIG)

Formation of **Anions**

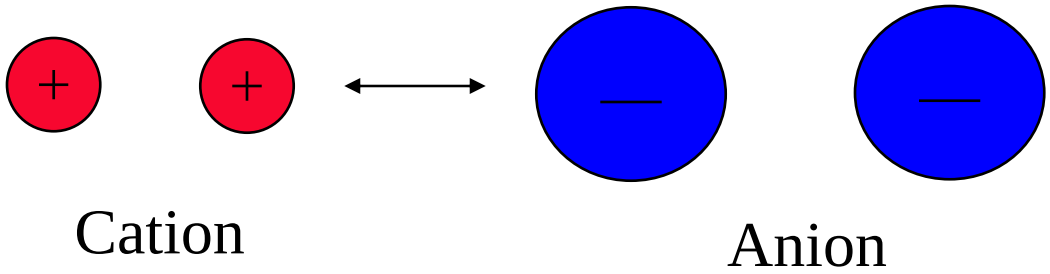




7 +
7 -
0 charge

7 +
10 -
-3 charge

Ionic Bonds — Ionic Compounds



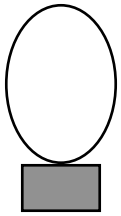
Electrostatic attraction = ionic bond

Ionic compounds

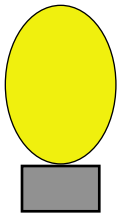
- crystalline solids with high mp
- usually water soluble
- electrolytes (conduct electricity)

Do Ions Really Exist?

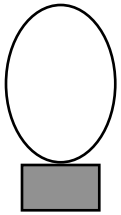
pure H_2O =



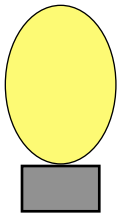
H_2O + NaCl =

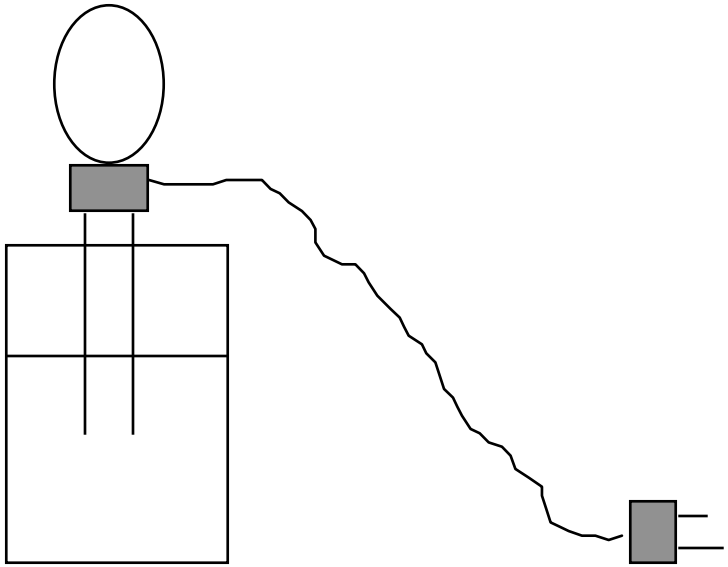


H_2O + Sugar =



Tap water =





Conductivity tester

Binary Compounds

- composed of **only 2 different elements**
- **may be ionic or covalent compounds**

IONICS = a metallic element is usually present

COVALENTS = contain only nonmetallic elements

Ionic or Covalent?

- HCl
- NaCl
- PCl_5
- $Cu(OH)_2$
- NH_3
- CH_3COOH
- Ag_2S

Metal + Nonmetal = Ionic

Binary Ionic Compounds

- **Writing correct names from formulas**

1. Metal ions gets its element name and is put first
2. Nonmetal ion is named second and the ending of its name is changed to **—IDE**

NaCl	Sodium chlor**IDE**
$CaCl_2$	Calcium chlor**IDE**
$AlCl_3$	Aluminum chlor**IDE**

Binary Covalent Compounds

- **Writing correct names from formulas**

1. First element gets its elemental name
2. The ending of the name of the second element is changed to **—IDE**
3. If ***numerical subscripts*** are present
   - use **prefixes** to indicate how many atoms are present

HCl	Hydrogen chlor**IDE**
H_2S	**Di**hydrogen sulf**IDE**
CCl_4	Carbon **tetra**chlor**IDE**

Comparing Ionics & Covalents

- Binary Ionics (metallic element)

NaCl	Sodium chlor**IDE**
$CaCl_2$	Calcium chlor**IDE**
$AlCl_3$	Aluminum chlor**IDE**

- Binary Covalents (no metallic elements)

HCl	Hydrogen chlor**IDE**
H_2S	**Di**hydrogen sulf**IDE**
CCl_4	Carbon **tetra**chlor**IDE**

Binary Ionic Compounds

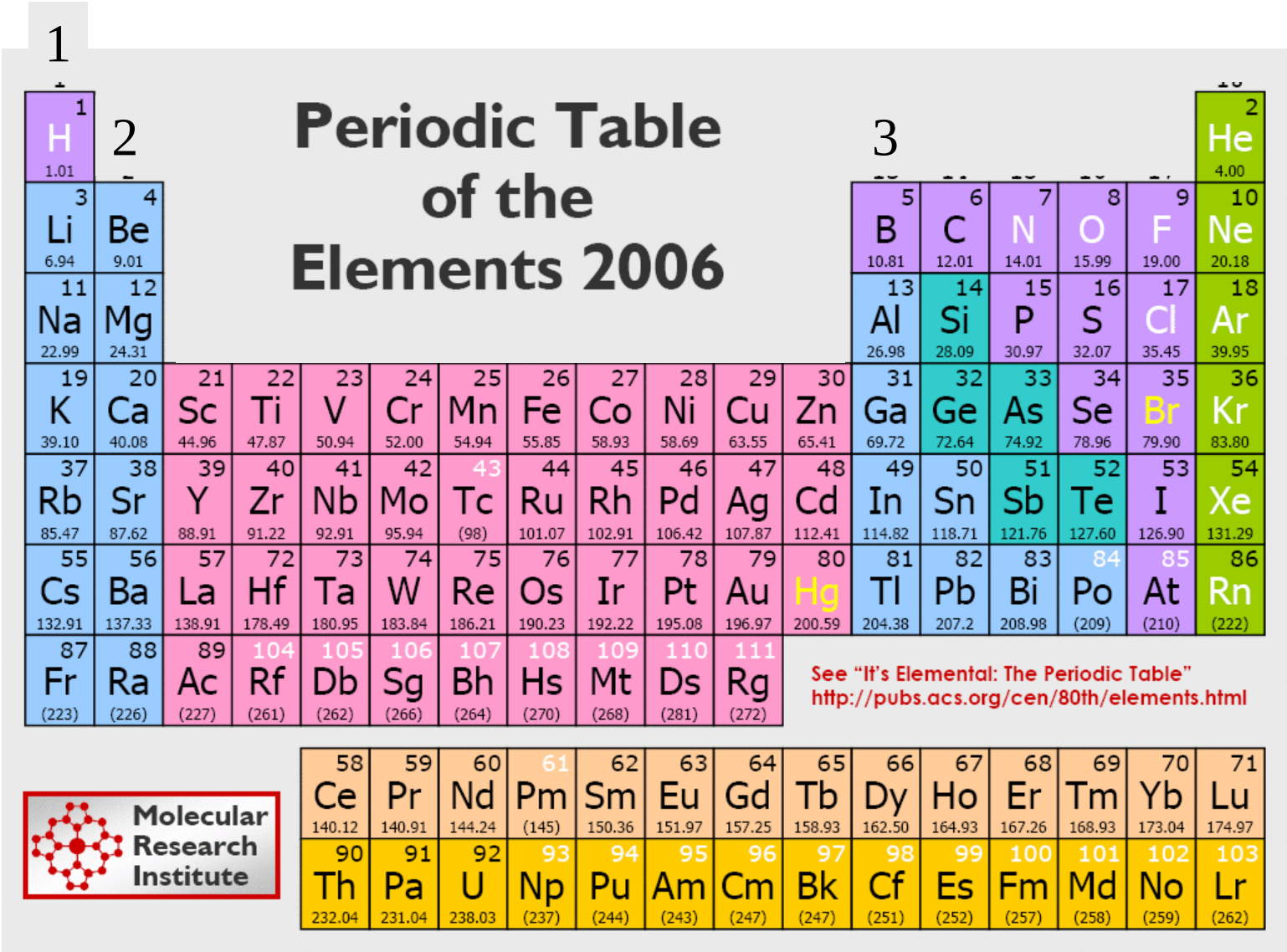
- **Writing correct formulas**
  1. Metal symbol written first
  2. Nonmetal symbol second
  3. Appropriate subscripts so that amount of (+) equals amount of (-)

$$Na^{+1} + Cl^{-1} \longrightarrow NaCl$$

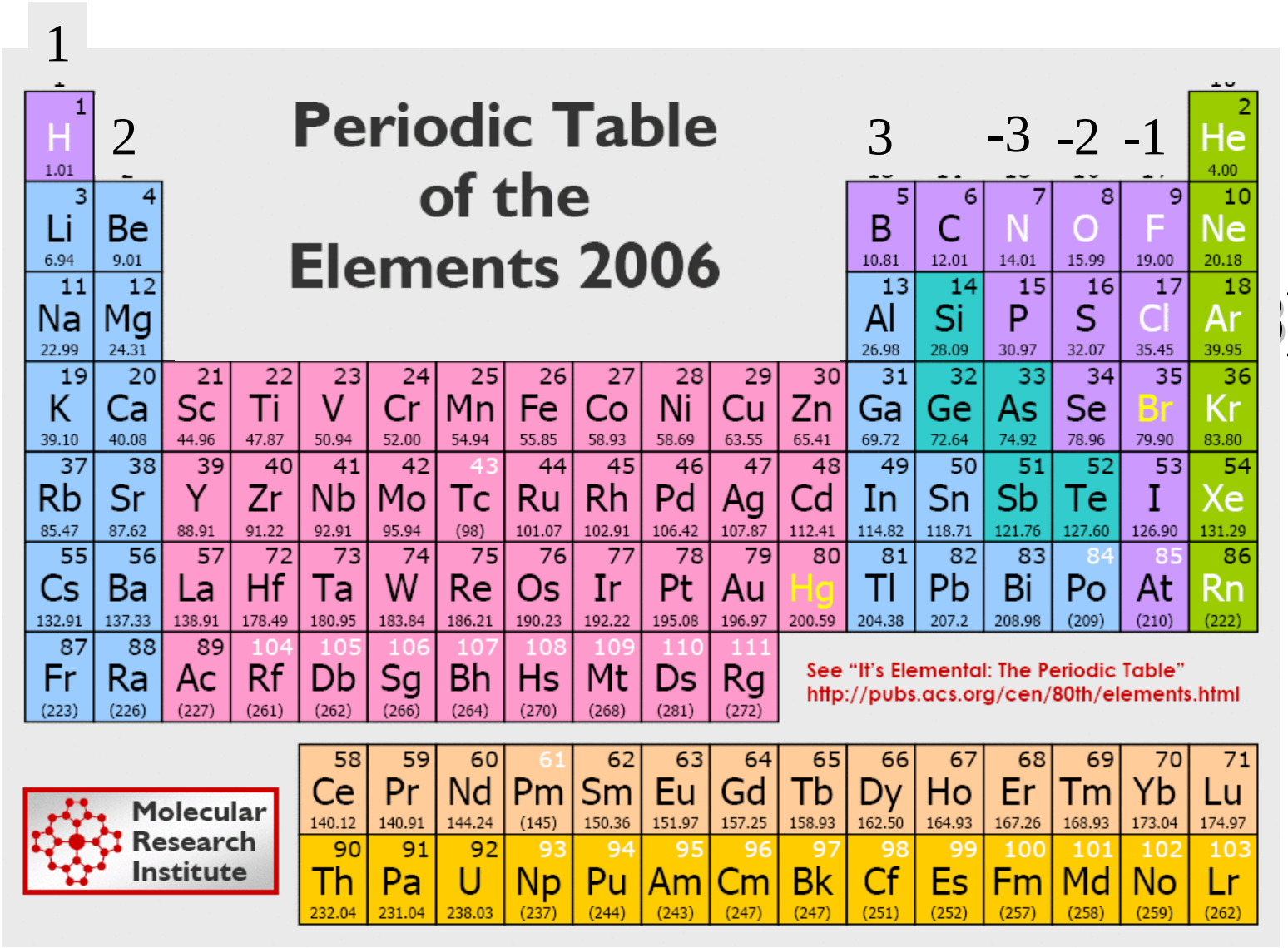
$$Ca^{+2} + Cl^{-1} \longrightarrow CaCl_2$$

$$Al^{+3} + Cl^{-1} \longrightarrow AlCl_3$$

Finding Charges for **Cations**



Finding Charges for **Anions**



Ions of Transition Metals

- can form several different charged ions
- important ones to know

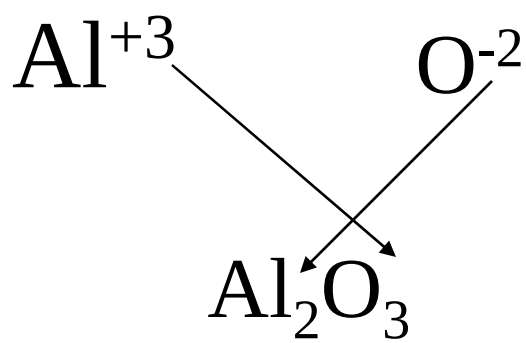
Fe	Fe^{+2} and Fe^{+3}
Cu	Cu^{+1} and Cu^{+2}
Sn	Sn^{+2} and Sn^{+4}

Ag = +1

Cr, Co, Ni, Zn, Cd, Hg, Pb = +2

The “Cross-over” Method

- Quick way to write formulas for ionic compounds



- The value of the charge on one ion becomes the subscript for other ion

Obtaining Metals from Ores

Never occur "Free"

Lithium
Potassium
Barium
Strontium
Calcium
Sodium
Magnesium
Beryllium
Aluminum
Manganese
Zinc
Chromium

Rarely found "Free"

Iron
Cadmium
Cobalt
Nickel
Tin
Lead
HYDROGEN
Antimony
Bismuth
Arsenic

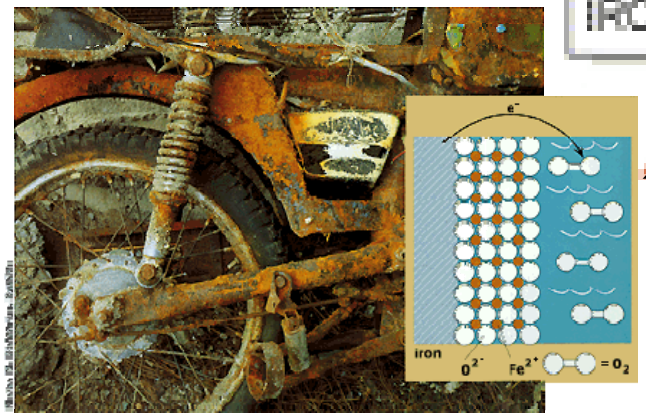
Often found "Free"

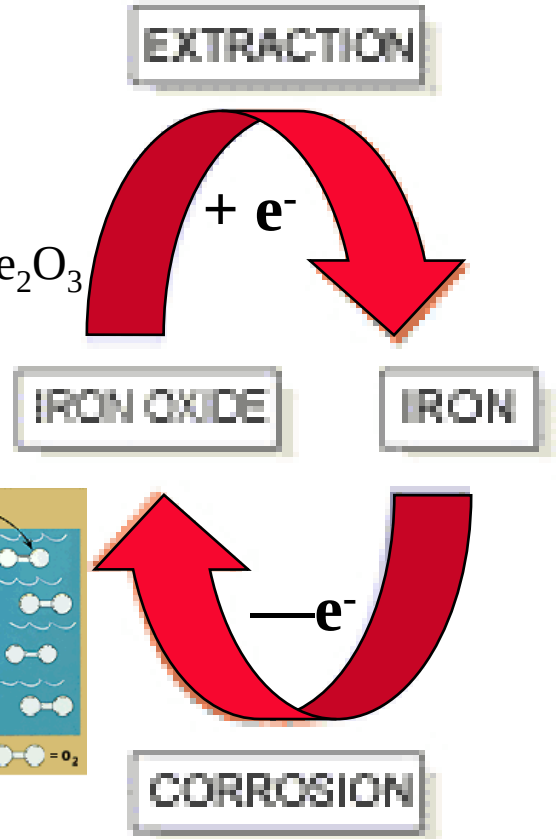
Copper
Mercury
Silver
Platinum
Gold

The *Redox* Cycle

Hematite (iron ore) = Fe_2O_3

Rust = Fe_2O_3





Reduction(RIG)

Oxidation(OIL)

Spontaneous Redox Reaction

$$Cu + AgNO_3 \longrightarrow ???$$

Copper metal Silver nitrate

Copper metal disappears and silver metal appears.

$$Cu + 2Ag^{+1} \longrightarrow Cu^{+2} + 2Ag$$

$+2\ e^-$

$-2\ e^-$

Copper metal loses electrons to form copper cations (oxidation).

Silver ions gain electrons to form silver metal (reduction).

Obtaining Metals from Ores

- Iron occurs most frequently as Fe_2O_3 and not as "native iron"
- Ores are "oxidized metals"
- Fe^{+3} is "oxidized iron" — it has...

lost electrons

gained oxygen

$$4\,Fe + 3\,O_2 \longrightarrow 2\,Fe_2O_3$$

Oxidation-Reduction Reactions

- To obtain iron metal the Fe must be forced to ...

Hematite (iron ore) = Fe_2O_3

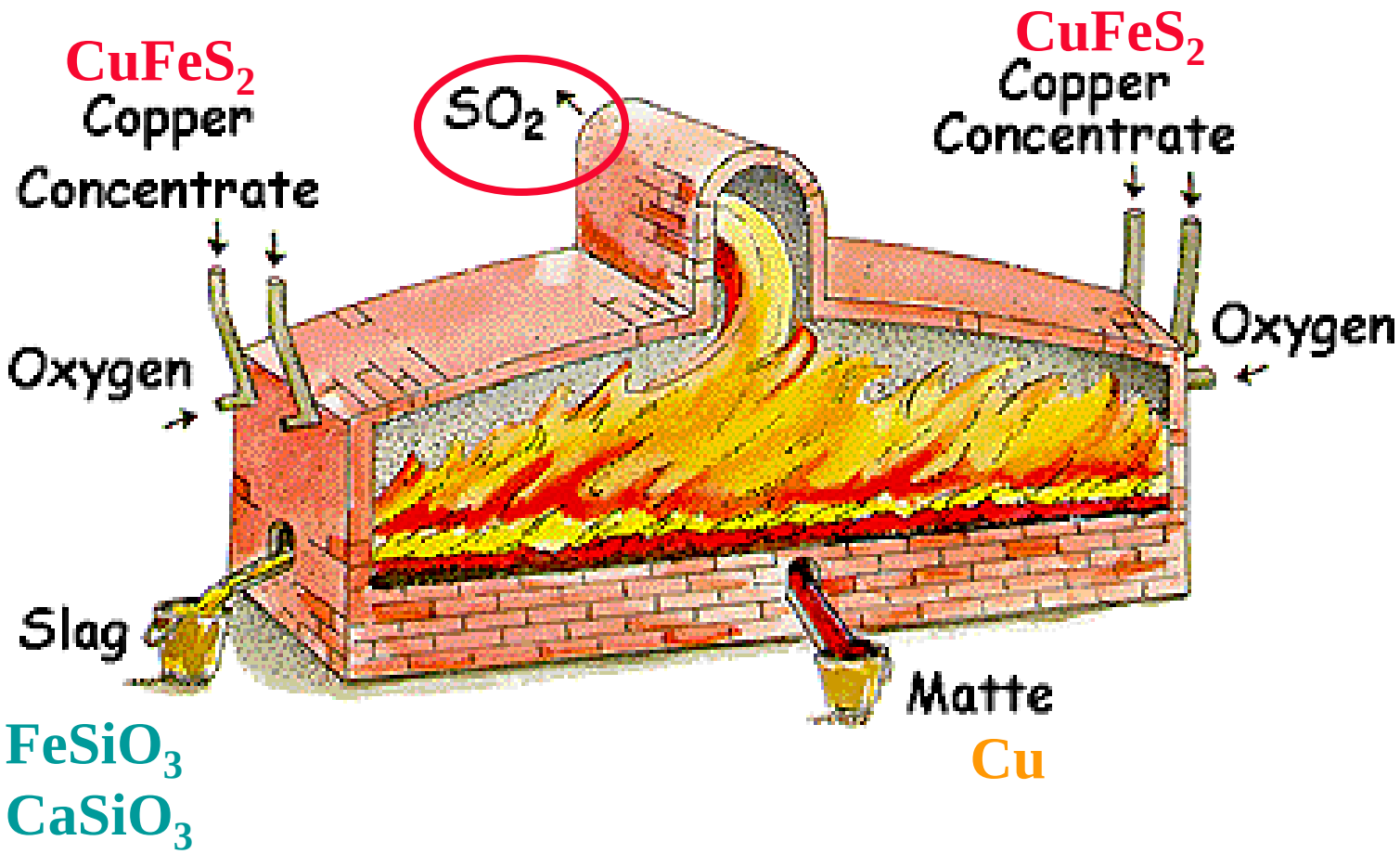
gain electrons

lose oxygen

$$Fe_2O_3 + 3CO \longrightarrow 2\,Fe + 3\,CO_2$$

iron compound → **free iron**

Copper from Chalcopyrite



Redox and Metallurgy

- **Refining** of metals — supplying electrons to produce "reduced metals"

  iron from Fe_2O_3 (hematite)

  aluminum from Al_2O_3 (bauxite)

  copper from CuS, Cu_2O, $CuFeS_2$

- **Electrolysis** and **Electroplating**

  use of electricity to produce oxidation-reduction reactions with metals

Chemical Equations

Reactants **Products**

$$4\,Fe + 3O_2 \longrightarrow 2\,Fe_2O_3$$

Coefficient **Subscript** **Coefficient**

- Formulas for all elements and compounds involved in the reaction
- How many atoms or molecules of things are present at beginning and at the end
- Total number and types of atoms must be equal on left and right of arrow (balanced)

Balanced Chemical Equations

- Matter cannot be created or destroyed!
- Total number and types of atoms must be the same on both sides of the arrows
- The arrangement and combinations of atoms are different on each side of the arrow

$$\mathbf{Fe_2O_3 + 3CO \longrightarrow 2\,Fe + 3\,CO_2}$$

Balancing Simple Equations

$$H_2 + O_2 \longrightarrow H_2O$$

Count up atoms on each side of arrow.

H	**2**	**H**	**2**
O	**2**	**O**	**1**

Balance unbalanced elements by placing small whole number coefficients in front of formulas. Recount.

$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

H	**4**	**H**	**4**
O	**2**	**O**	**2**

Balancing Simple Equations

$$Al + Cl_2 \longrightarrow AlCl_3$$

Al	**1**	**Al**	**1**
Cl	**2**	**Cl**	**3**

$$Al + 3Cl_2 \longrightarrow 2\ AlCl_3$$

Cl	**6**	**Cl**	**6**
Al	**1**	**Al**	**2**

$$2Al + 3Cl_2 \longrightarrow 2\ AlCl_3$$

Al	**2**	**Al**	**2**
Cl	**6**	**Cl**	**6**

Are these equations balanced?

$$N_2 + O_2 \longrightarrow NO$$

$$2\ HgO \longrightarrow Hg + O_2$$

$$Al + Cl_2 \longrightarrow AlCl_3$$

$$2\ Cu_2O + O_2 \longrightarrow 4\ CuO$$

Large-Scale Reactions

- Impossible to measure out atoms and molecules.
- Chemists use **MOLES** instead of molecules

moles help us relate

Number of atoms, molecules, ions, electrons	Grams of elements or compounds
↑	↑
Hard to see or count	Easy to see and measure

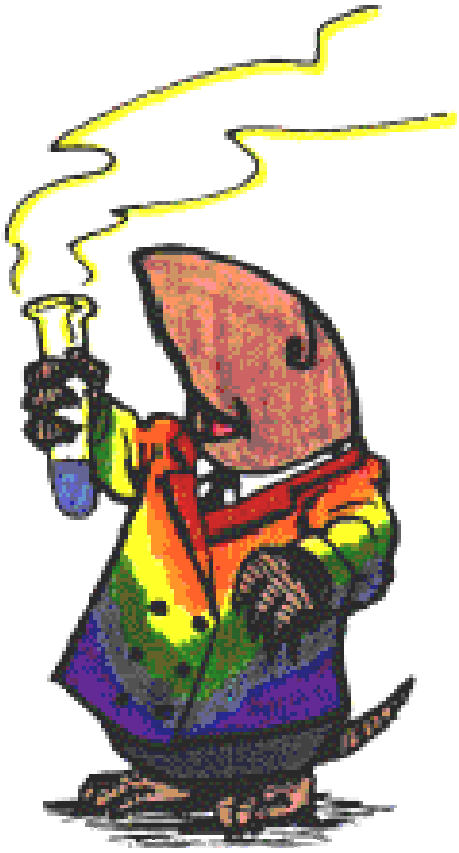
Molar Quantities in Equations

$$Fe_2O_3 + 3CO \longrightarrow 2\,Fe + 3\,CO_2$$

1 mole of iron(III) oxide
plus
3 moles of carbon monoxide
produce
2 moles of elemental iron
and
3 moles of carbon dioxide

What is a Mole?

- 1 mole = 6.02×10^{23} things
- The “things” can be
  - Atoms
  - Molecules
  - Ions
  - Electrons



Practically a mole is...

- 1 mole of an element = atomic weight of the element in grams
- 1 mole of a compound = sum of atomic weights of all elements in the compound in grams

$12\ g\ C = 6.02 \times 10^{23}$ atoms of carbon

$18\ g\ H_2O = 6.02 \times 10^{23}$ molecules of water