Ch. 6 Notes - FORMATION OF COMPOUNDS

NOTE: Vocabulary terms are in **boldface and underlined**. Supporting details are in *italics.*

I. Valence Electron Review

A. **Valence electrons**—the *electrons in the highest energy level* of at atom

1) tells *how many are available for bonding*

2) tells *how many e- will be gained or lost in forming ions*

B. Review electron dot diagrams (Lewis structures) - our method:

"right, left, up, down, top all the way around – counterclockwise"

GROUP #:	VALENCE # out of 8:	USUALLY, WHEN FORMING IONS:
Group IA (1)	1	loses 1
Group IIA (2)	2	loses 2
Group IIIA (13)	3	loses 3
Group IVA (14)	4	can lose, gain, or share
Group VA (15)	5	gains 3
Group VIA (16)	6	gains 2
Group VIIA (17)	7	gains 1
Group VIIIA (18)	8	does not form ions

II. Ion Formation

A. *atomic neutrality: atoms are neutral (net charge of zero) # protons = # electrons*

B. **ion**—*a charged atom(s) or a charged group of atoms*

1) formed by gain or loss of electrons

2) **cation**— *a positive ion formed by losing electrons*

3) **anion**— *a negative ion formed by gaining electrons*

a) *common ending is —IDE* (chloride, bromide, iodide...)

b) *ions of Group VIIA*, the halogens, are called *halide ions*

CP AN **Cations Positive, Anions Negative** "Cat People Are Nice"

YOU CAN'T LOSE OR GAIN PROTONS TO FORM AN ION !

4) an ion has different properties than its element (Na atom vs. Na^+ ion)

5) **isoelectronic**—*having the same number of electrons*

*** The reason why an atom loses or gains electrons is to be isoelectronic with the closest Noble Gas.

C. ionic **charges** (**oxidation states**, **oxidation numbers**) of the groups

Charge Chant Song:

" +1, +2, +3, mixed, -3, -2, -1, 0 …
+2 in the middle, unless they tell you otherwise"

(Note – you can write charges with the sign before or after the number. In textbooks, you will not see the number 1 used with a charge. Only + or - will be shown for 1+ or 1-.)

Group number:	IA	IIA	IIIA	IVA	VA*	VIA*	VIIA*	VIIIA
	1	2	13	14	15	16	17	18
Main ionic charge:	1+	2+	3+	M	3-	2-	1-	none

M most of the Group IVA don't usually form ions; when they do, there are mixed charges possible

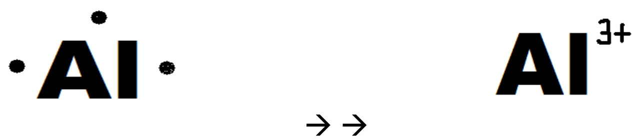
* when applicable

D. **<u>Octet Rule</u>**

1) *reactivity of atoms is based on achieving a complete octet (8/8)=* s^2p^6
2) *atoms in compounds tend to have a stable* **<u>Noble Gas configuration</u>**
3) exception – **<u>pseudo-Noble gas configuration</u>**: $s^2p^6d^{10}$ (see next section)

E. examples of ions

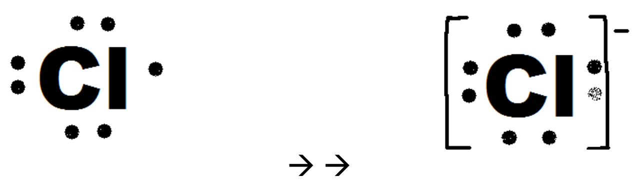
EXAMPLE 1) Aluminum loses three electrons when its ion is formed. Show what happens with "before and after" electron dot diagrams. The aluminum ion is isoelectronic with which Noble gas?



13 p^+ 13 e^- (3 valence)	13 p^+ 10 e^- (loses three to empty the original valence) isoelectronic with Ne

---

EXAMPLE 2) Chlorine gains one electron when its ion is formed. Show what happens with "before and after" electron dot diagrams. The chloride ion is isoelectronic with which Noble gas?



17 p+ 17 e- (7 valence)	17 p+ 18 e- (gains one to fill the valence) isoelectronic with Ar

---

III. Electron Configurations for Ions

A. Ions become **<u>isoelectronic</u>** with the Noble Gases.

1) **<u>cation</u>** examples (s^2p^6)

*** Cations lose electrons to become isoelectronic with the previous Noble Gas. ***

EXAMPLE 3) Na has one valence e^-. It forms a 1+ ion, exposing its filled n = 2 shell.

	Na	→	Na^+	+	e^-
Complete config.:	$1s^2 2s^2 2p^6 \underline{3s^1}$		$1s^2 \underline{2s^2 2p^6} 3s^0$		the 3s electron
Valence config.:	$3s^1$		$2s^2 2p^6$		

The sodium ion has the electron configuration of neon (10 e-), but it still has a nucleus with 11 protons, keeping it sodium.

EXAMPLE 4) Al has three valence e^-. It forms a 3+ ion, exposing its filled n = 2 shell.

	Al	→	Al^{3+}	+	$3e^-$
Complete config.:	$1s^2\ 2s^2\ 2p^6\ \underline{3s^2\ 3p^1}$		$1s^2 \underline{2s^2 2p^6} 3s^0 3p^0$		3s and 3p electrons
Valence config.:	$3s^2 3p^1$		$2s^2 2p^6$		

The aluminum ion has the electron configuration of neon (10 e-), but it still has a nucleus with 13 protons, keeping it aluminum.

2) **anion** examples (s^2p^6)

*** Anions become isoelectronic with the Noble Gas at the end of their row. ***

EXAMPLE 5) Cl has seven valence electrons. When it forms a -1 ion, it is isoelectronic with argon. Show how the electron configuration changes from atom to ion.

	Cl	+	e^-	→	Cl^-
Complete config.:	$1s^2 2s^2 2p^6 \underline{3s^2 3p^5}$		shared or stolen e^-		$1s^2 2s^2 2p^6 \underline{3s^2 3p^6}$
Valence config.:	$3s^2 3p^5$				$3s^2 3p^6$

The chloride ion has the electron configuration of argon (18 e-), but it still has a nucleus with 17 protons, keeping it an ion of Cl.

EXAMPLE 6) S has six valence electrons. It forms a -2 ion and has the electron configuration of argon. Show how the electron configuration changes from atom to ion.

	S	+	2 e^-	→	S^{2-}
Complete config.:	$1s^2 2s^2 2p^6 \underline{3s^2 3p^4}$		shared or stolen e^-		$1s^2 2s^2 2p^6 \underline{3s^2 3p^6}$
Valence config.:	$3s^2 3p^4$				$3s^2 3p^6$

The sulfide ion has the electron configuration of argon (18 e-), but it still has a nucleus with 16 protons, keeping it an ion of S.

B. **Pseudo-Noble gas configuration** = $s^2p^6d^{10}$
   1) found in ions such as Zn^{2+} and Ga^{3+}
   2) found a metal that already has transition (d) electrons forms a cation
   3) this is an exception to normal s^2p^6 Noble Gas configuration

EXAMPLE 7) Show how zinc forms an ion by achieving a Pseudo-Noble Gas Configuration.

	Zn	→	Zn^{2+}	+	2 e^-
Complete:	$1s^2 2s^2 2p^6 3s^2 3p^6 \underline{4s^2} 3d^{10}$		$1s^2 2s^2 2p^6 \underline{3s^2 3p^6} 4s^0 \underline{3d^{10}}$		the 4s electrons
Valence config.:	$4s^2$		$3s^2 3p^6 3d^{10}$		

C. Ways to achieve a stable outer energy level
   1) *transferring of electrons* = **ionic bond**
   2) *sharing of electrons* = **covalent bond**

IV. Formation of **Ionic Compounds** *(electron transfer)*

A. **ionic bond**—*a chemical attraction between positive ions (cation) and a negative ion (anion)*
   1) cation is the metal
   2) anion is the nonmetal

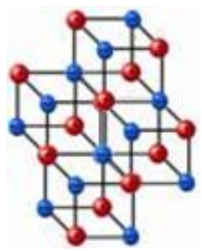
B. *total of positive charges = total of negative charges*

C. **Noble Gas configurations** of both ions are achieved

D. *electronegativity differences are large*
   1) the cation is not electronegative ("not greedy" or electropositive) and will let its electron(s) be taken
   2) the anion is more electronegative ("greedy") and will take the electron(s)

E. **<u>formula unit</u>**— the *lowest whole-number ratio of ions* in an ionic compound
   1) do not use the term "molecule" to describe an ionic compound
   2) ionic compounds occur in *repeating units in their crystals*

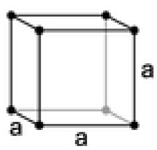
F. *crystalline solids*—a structure containing *3-D repeating patterns* of formula units



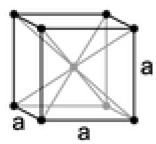
   1) crystals are arranged in a *positive-negative alternating setup*:

Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-
Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+
Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-
Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+
Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-
Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+	Cl-	Na+

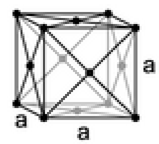
   2) examples of crystal shapes: SC, BCC, FCC, HCP



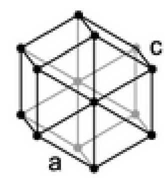
simple cubic



body-centered cubic (BCC)



face-centered cubic (FCC)



hexagonal close-packed (HCP)

   3) setup is called a **<u>crystal lattice</u>** which is hard and brittle
   4) **<u>lattice energy</u>**
      a) *the strength needed to separate 1 mole of ions from the crystal lattice*
      b) smaller ions have greater lattice energy
      c) common unit = kJ/mol

G. **<u>salt</u>**—*any ionic compound*, not just sodium chloride

H. *electrolytic solution –an aqueous solution which conducts a current because it contains ions (**<u>electrolytes</u>**)* (more later)

V. Cations and Anions in ionic compounds

A. formation of **<u>cations</u>**
   1) the **<u>octet rule</u>** applies
   2) example

EXAMPLE 8) Francium has one valence electron (87 total e^-). It is easier for it to lose the valence electron than it is to gain seven more to complete the "shell." It forms a 1+ ion, exposing a previously filled shell.

$$Fr \rightarrow Fr^+ + e^-$$

The francium ion is isoelectronic with radon (86 e^-), but it still has a nucleus with 87 protons, keeping it an ion of Fr instead of changing it into an atom of Rn.

B. formation of **<u>anions</u>**
   1) the **<u>octet rule</u>** applies
   2) *common ending is —IDE* (chloride, sulfide, oxide...)
   3) example

EXAMPLE 9) Selenium has six valence electrons (34 total e^-). It only needs two more to achieve a complete octet. It forms a 2- ion and has the configuration of krypton (36 e^-).

$$Se + 2e^- \rightarrow Se^{2-}$$

The selenide ion is isoelectronic with krypton (36 e-), but it still has a nucleus with 34 protons, keeping it an ion of Se instead of changing it into an atom of Kr.

VI. Electron Dot Diagrams for Ionic Compounds

A. make sure the compound is composed of metals and nonmetals

B. draw the dot diagrams of the cations and anions, using different colors if possible or open circles and closed circles for electrons from the different ions

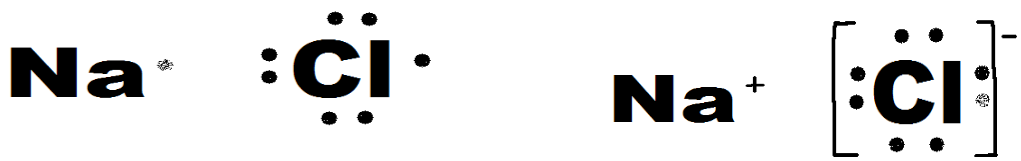
(Remember all electrons are alike, but show which ones came from which ions in the transfer.)

C. all ions should be stable

1) all cation dot diagrams show no dots
2) all anion dot diagrams show a complete octet
3) all charges will balance out to zero

D. examples

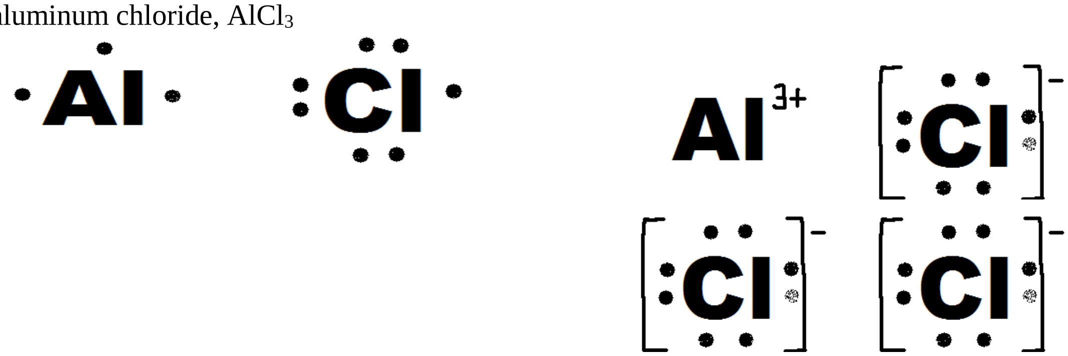
E10) sodium chloride, NaCl



sodium atom chlorine atom →→ sodium ion chloride ion

CATION CHARGE TOTAL = 1+
ANION CHARGE TOTAL = 1-
NET CHARGE = 0

E11) aluminum chloride, $AlCl_3$



aluminum atom chlorine atom →→ aluminum ion chloride ions

(three Cl^- are needed to balance the charges)

CATION CHARGE TOTAL = 3+
ANION CHARGE TOTAL = 3 x (1-) = 3-
NET CHARGE = 0

VII. Compounds in general

A. **<u>compound</u>** (“cmpd.”)—*a substance formed from more than one element*

B. **<u>molecule</u>**—*a group of atoms with no net charge*

C. two general types of compounds

1) **<u>molecular compound</u>**—*composed of atoms*
   - usually liquids or gases at room temp.
   - usually have a low melting point (m.p.) and boiling point (b.p.)
   - *composed of nonmetals*… like CO_2

2) **<u>ionic compounds</u>**—*composed of positive/negative ions*
   - usually crystalline solids at room temp.
   - usually have a high melting point (m.p.) and boiling point (b.p.)
   - *composed of metals and nonmetals*… like NaCl

D. Comparison of properties of ionic and molecular compounds

	Molecular compounds	**Ionic compounds**
Particles	Molecules	Formula units (salts) made of ions
Elements	Nonmetals	Metals & nonmetals
Conductivity	Low “nonelectrolytes”	High (when molten or in aqueous solution) “electrolytes”
State at room temp.	Solid, liquid, or gas	Solid
Type of Bond	Polar or nonpolar covalent	Ionic

E. **<u>chemical formula</u>**

1) symbols representing the composition of the smallest unit of a substance

2) *shows which elements are present and how many there are*

   H_2SO_4 = hydrogen, sulfur, oxygen = 7 atoms total

3) **<u>molecular formula</u>**—symbols representing the composition of a *molecular compound*

4) **<u>formula unit</u>**— the lowest whole-number ratio of ions in an *ionic compound*
   a. It is improper to use the term “molecule” to describe an ionic compound.
   b. Ionic compounds occur in repeating units in crystal lattices

5) number codes
   a. **<u>subscript</u>**—a number written slightly *below* the symbol Br_2
   b. **<u>superscript</u>**—a number written slightly *above* the symbol Sr^{2+}

(In chem., a superscript is not called an exponent. Nothing is being multiplied.)

VIII. Ionic Compounds

A. *metals form cations (+)* *nonmetals form anions (--)*

B. ******* You must know the **one-charge transition metal ions: Ag^+, Cd^{2+}, Zn^{2+}** ***

C. *“MIDDLE METALS”* = multiple charges on the transition metals and others) –
if an atom can form more than one charge as an ion, you must say which one it is.

**** ALL “middle metals” except Ag, Cd, and Zn must have Roman numerals with their ion names.****

1) Stock system uses number clues – most common way

$FeBr_3$ = iron(III) bromide   SnS = tin(II) sulfide – subscripts were reduced

2) Classical (Latin root) system

LOWER CHARGED ION: suffix "–OUS"   *Cu^+ = cuprous ion*
HIGHER CHARGED ION: suffix "–IC"   *Cu^{2+} = cupric ion*

ION FORMULA	STOCK NAME	(CLASSICAL NAME)
Cu^+	copper(I) ion	cuprous ion
Cu^{2+}	copper(II) ion	cupric ion
Fe^{2+}	iron(II) ion	ferrous ion
Fe^{3+}	iron(III) ion	ferric ion
Pb^{2+}	lead(II) ion	plumbous ion
Pb^{4+}	lead(IV) ion	plumbic ion
Sn^{2+}	tin(II) ion	stannous ion
Sn^{4+}	tin(IV) ion	stannic ion

D. Tin and lead…

*** You must know that tin (Sn) and lead (Pb) need Roman numerals with their ion names. ***

IX. Binary compounds: binary ionic (this chapter) and binary molecular (next chapter)

A. **binary compound**—*composed of two elements*

B. **binary ionic compound**—("BI")—*metal cation / nonmetal anion combination*

1) compound composed of **monatomic** (*one symbol*) ions
2) crisscross formula method is used
3) name the cation first, then the anion (-*IDE* ending)
4) use Roman numerals if/when needed for the cation
5) examples:

$CaBr_2$ = calcium bromide   KI = potassium iodide $FeCl_3$ = iron(III) chloride

C. *"crisscross" formula method for ionic compounds (charge balancing)*

1) *write the symbols of the two ions next to each other*
2) *write the charges as superscripts*
3) *balance the formula by crisscrossing the numbers (net charge = 0)*
4) *the numbers are now subscripts, telling you how many of each symbol is in the formula*
5) *if the charges are the same, they cancel out*
6) *if the charges are multiples of each other, reduce them*

EXAMPLE 12: calcium nitride

$Ca^{2+} N^{3-}$

$Ca^{2+} N^{3-}$ (crisscross)

Ca_3N_2

EXAMPLE 13: aluminum chloride

$Al^{3+} Cl^{1-}$

$Al^{3+} Cl^{1-}$ (crisscross)

Al_1Cl_3

$AlCl_3$

X. Polyatomic ions

A. **polyatomic ion**—*a group of charged atoms*

B. most end in *–ATE* or *–ITE*

C. To avoid confusion, you may keep the parentheses around the polyatomic ion if there is only one polyatomic ion in the formula, but be aware that teachers and textbooks do not do this. Na(OH) = NaOH

POLYATOMIC IONS

Chemistry 1 Honors students must memorize these 27 ions.
Chemistry 1 students must memorize 20 ions (delete the seven marked with ***).

+1 CHARGE:

ammonium $(NH_4)^+$

-1 CHARGE:

acetate
$(C_2H_3O_2)^-$ or $(CH_3COO)^-$
bicarbonate or
hydrogen carbonate $(HCO_3)^-$
*** bisulfate or
hydrogen sulfate $(HSO_4)^-$
*** bromate $(BrO_3)^-$
chlorate $(ClO_3)^-$
chlorite $(ClO_2)^-$
cyanide $(CN)^-$
hydroxide $(OH)^-$
hypochlorite $(ClO)^-$
nitrate $(NO_3)^-$
nitrite $(NO_2)^-$
perchlorate $(ClO_4)^-$

MORE -1 CHARGE

permanganate $(MnO_4)^-$
*** thiocyanate $(SCN)^-$

-2 CHARGE:

carbonate $(CO_3)^{-2}$
*** carbonite $(CO_2)^{-2}$
chromate $(CrO_4)^{-2}$
dichromate $(Cr_2O_7)^{-2}$
*** oxalate $(C_2O_4)^{-2}$
silicate $(SiO_3)^{-2}$ or $(SiO_4)^-$
sulfate $(SO_4)^{-2}$
sulfite $(SO_3)^{-2}$
*** thiosulfate $(S_2O_3)^{-2}$

-3 CHARGE:

*** arsenate $(AsO_4)^{-3}$
phosphate $(PO_4)^{-3}$
phosphite $(PO_3)^{-3}$

OTHER IONS YOU MAY SEE: hydride H^- , peroxide $(O_2)^{-2}$, hydronium $(H_3O)^+$

XI. Ternary Compounds

A. **ternary compound**—compound made up of *three different elements*

B. **ternary ionic compound**—("TI")— *metal cation / nonmetal anion combination of three symbols, involving polyatomic ions. Also called* ***polyatomic ion compounds.***

1) *crisscross* formula method is used
- *write the symbols of the two ions next to each other*
- *be careful to keep the parentheses around the polyatomic ion*
- *write the charges as superscripts*
- *balance the formula by crisscrossing the numbers (net charge = 0)*

- *the numbers are now subscripts, telling you how many of each symbol is in the formula*
- *if the charges are the same, they cancel out*
- *if the charges are multiples of each other, reduce them*

EXAMPLE 14: strontium nitrate

Sr^{2+} and $(NO_3)^{1-}$

$Sr^{2+}(NO_3)^{1-}$

$Sr^{2+}(NO_3)^{1-}$

$Sr_1(NO_3)_2$

$Sr(NO_3)_2$

EXAMPLE 15: aluminum sulfate

Al^{3+} and $(SO_4)^{2-}$

$Al^{3+}(SO_4)^{2-}$

$Al^{3+}(SO_4)^{2-}$

$Al_2(SO_4)_3$

2) name the cation first, then the anion
3) use Roman numerals if/when needed for the cation

C. examples

E16: sodium sulfate — Na_2SO_4

E17: potassium permanganate — $KMnO_4$

E18: iron(III) hydroxide — $Fe(OH)_3$

XII. Hydrates (preview, from chapter 9)

A. **water of hydration**—*water molecules chemically integrated into a crystalline structure*

B. **hydrate**—*a compound with water in its structure*

1) *general formula:* *[compound]* $\cdot H_2O$
2) *naming: [compound name] (prefix)hydrate*

MONO-,	DI-,	TRI-,	TETRA-,	PENTA-,	HEXA-,	HEPTA-,	OCTA-,	NONA-,	DECA-
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

$CuSO_4 \cdot 5H_2O$ copper(II) sulfate pentahydrate

C. **anhydrous**—*a hydrate without its water of hydration*

$Na_2SO_4 \cdot 2H_2O \rightarrow Na_2SO_4 + 2H_2O$

sodium sulfate dihydrate → anhydrous sodium sulfate + water

D. **efflorescence**—the release of water by a hydrate (heating not needed)

E. **hygroscopic**—*removing water from the atmosphere*

F. **deliquescence**

1) absorbing excess water from the atmosphere to form a liquid substance
2) this is an extreme hygroscopic condition

G. **desiccant**

1) a *drying agent* which is hygroscopic
2) examples: Damp Rid; packets of silica powder in shoe boxes

XIII. Metals

A. electrons and electricity: metallic bonds

1) **metallic bonds**—*sharing of delocalized electrons between metal cations, allowing current to flow*
   - a) **delocalized electrons**— *shared electrons* not in one place; mobile
   - b) delocalized electrons are free to move throughout the piece of metal
   - c) **electron sea model**– *metal cations are surrounded by "community" shared electrons*

2) *conductivity*—electron flow

delocalized (shared) electrons

B. examples of crystal patterns in metals

1) BCC: Li, Na, K, Rb, Cs, Ba, Ra, V, Cr, Mn, Fe, Nb, Mo, Ta, W, Pd, Pt, Eu
2) FCC: Ca, Sr, Ni, Cu, Al, Au, Ag, Ge, Pb, Rn, Ir, Ce, Ac, Th, Yb
3) HCP: Be, Mg, Sc, Ti, Y, Zr, Zn, Lu, Hf, Co, Tc, Ru, Re, Os, Cd, Tl, La, Pr, Nd, Gd, Tb, Dy, Er, Tm, Am, Cm

C. characteristics of metals

1) *ductility (ductile)—able to be pulled into thin wires*
2) *malleability (malleable)—able to be hammered into sheets*
3) *conductivity—ability for delocalized electrons to move (electricity)*
4) *thermal conductivity—transfer of heat*
5) shiny and lustrous
6) durable and strong

D. alloys

1) **alloy**—*physical blending of metals*
2) additional properties may be seen beyond those of the original metals
3) types, formed by "doping the crystal" – dopants are usually added in small concentrations (<1000 ppm)
   - a) substitutional – changes in the crystal lattice from substituting a different ion for the one originally there
   - b) interstitial – small holes in the crystal are filled with different atoms
4) examples
   - a) brass = Cu, Zn
   - b) bronze = Cu, Zn, Sn
   - c) stainless steel = Fe, Cr, Ni
   - d) 10K gold = Au, Ag, Cu