CHEMICAL COMPOUNDS

- Dalton's theory does not mention this, but there is more than one way for atoms to come together to make chemical compounds!

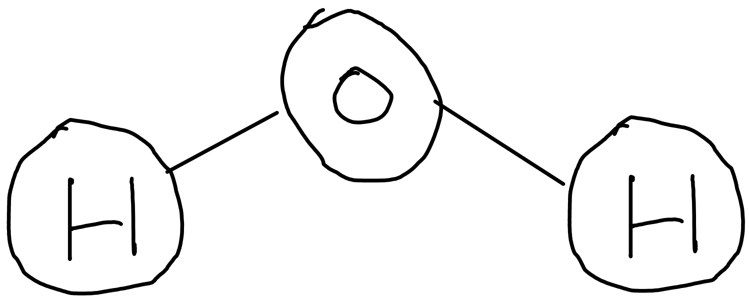
- There are TWO common kinds of chemical compound, classified based on how the atoms in the compound are held together:

1. MOLECULAR COMPOUNDS

2. IONIC COMPOUNDS

MOLECULAR COMPOUNDS

- form when atoms SHARE outer electrons with each other. This results in a set of connected atoms called a MOLECULE



Stick figure of a water (H_2O) molecule

- usually form between nonmetals and other nonmetals or between nonmetals and metalloids

Examples:

H_2O	CO_2	CCl_4
CO	N_2O_5	PCl_5

CANDLE WAX is made up of molecular compounds

- some solid at room temperature. These solids tend to have low melting points.

PCl_5 is a solid, mp = 180 °C

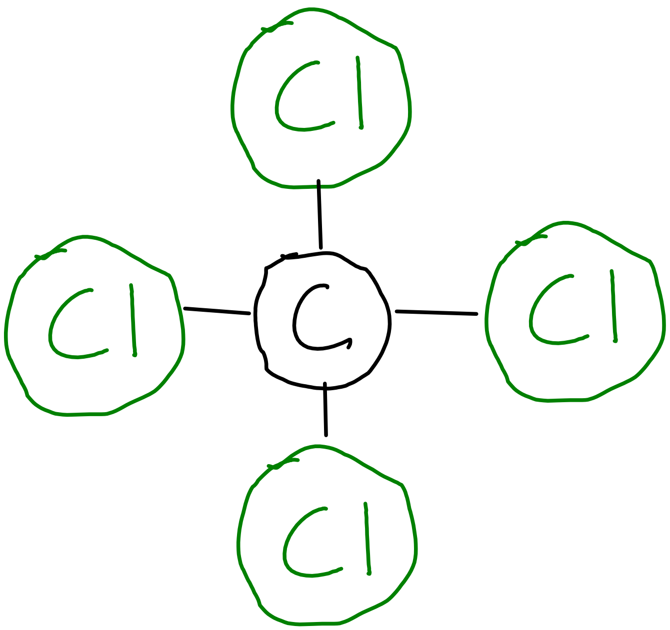
- many are liquids or gases at room temperature

H_2O, CCl_4 : liquids CO, CO_2, N_2O_5 : gases

MOLECULAR FORMULAS

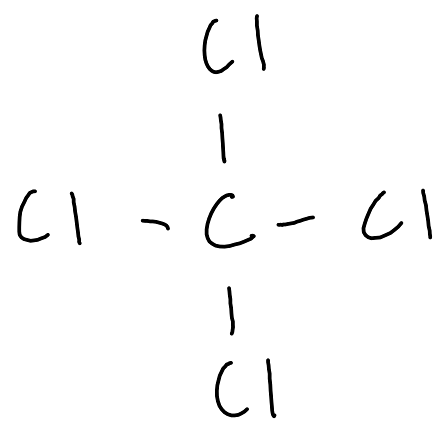
- formula of a molecular compound represents the EXACT NUMBER OF ATOMS OF EACH ELEMENT in a single molecule of the compound

Example: Each molecule of CCl_4 contains exactly one carbon atom and four chlorine atoms



CCl_4

"ball and stick" model



Structural formula: shows how atoms are connected in a molecule

IONIC COMPOUNDS

- formed when atoms TRANSFER ELECTRONS between each other forming charged atoms, called IONS.

Two kinds of ions:

cation

(1) CATIONS: formed when an atom LOSES one or more electrons.

- overall, a cation has a POSITIVE charge, because it has more protons in the nucleus than electrons in the electron cloud

- usually formed by METALS, but occasionally hydrogen will also form a cation

(2) ANIONS: formed when an atom GAINS one or more electrons

- overall, an anion has a NEGATIVE charge, because it has more electrons in the electron cloud than protons in the nucleus

- usually formed by NONMETALS

IONIC COMPOUNDS

- USUALLY form from metals combining with nonmetals, or from metals combining with metalloids

Examples: $NaCl$ $MgCl_2$ $NaOH$

$Ca(OH)_2$ Na_2CO_3

Fe_2O_3 FeO

- almost always solid at room temperature, and usually have relatively high melting points

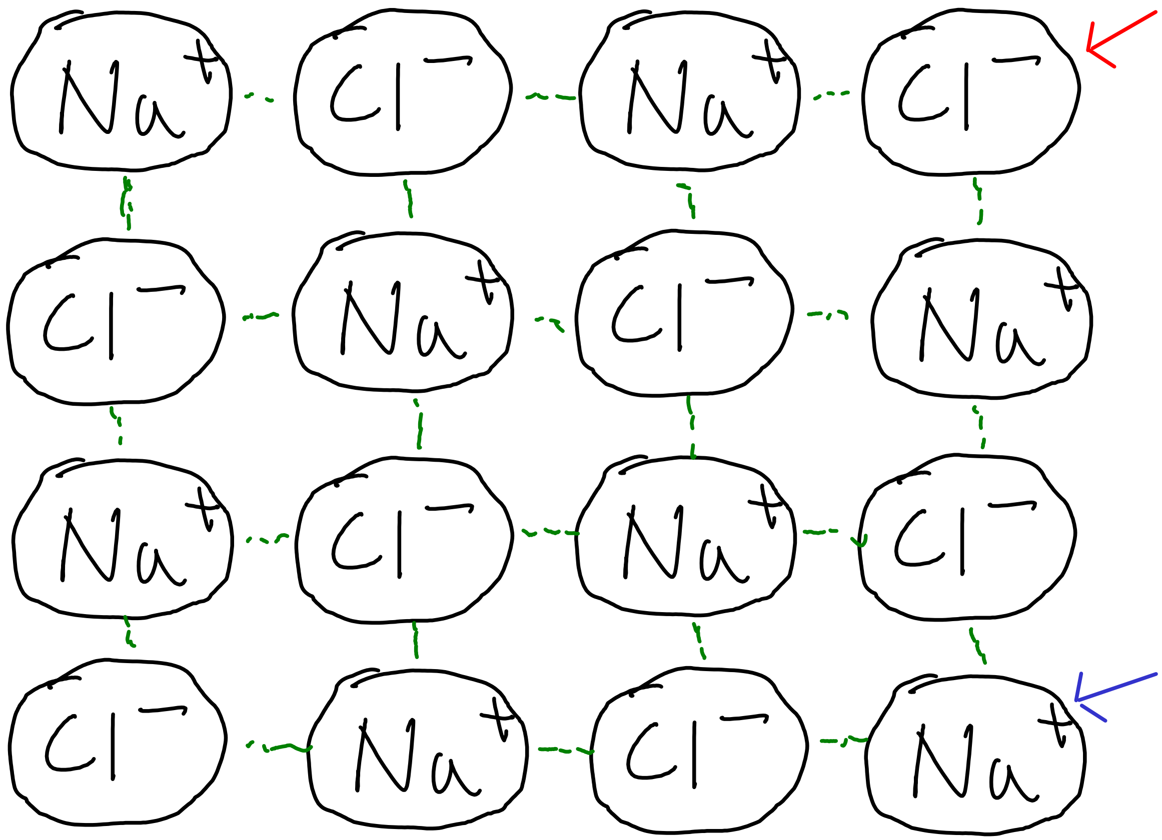
All of the above are solids at room temperature. NaCl has a melting point of 801°C.

- as solids, do not conduct electricity. If dissolved in water (some do not dissolve significantly in water), will form a solution that conducts electricity.

IONIC COMPOUNDS

- ionic compounds are held together by ELECTROSTATIC INTERACTIONS

(in other words, the attraction between oppositely charged ions!)



Each chloride ion is strongly attracted to ALL of the sodium ions surrounding it!

Each sodium ion is strongly attracted to ALL of the chlorine atoms surrounding it!

There are no "molecules" in ionic compounds - in the sense that you can't point to a discrete unit of atoms that are connected to only each other

IONIC FORMULAS

- since there are no "molecules", an ionic formula cannot describe how many and what kinds of atoms are in a molecule!

- all ionic compounds are observed to be (overall) electrically neutral, so the IONS they contain must be present in such a way that the charges BALANCE EACH OTHER

    - an ionic formula gives the SMALLEST WHOLE NUMBER RATIO OF CATION TO ANION in the ionic compound

Na^{+} Cl^{-} make $NaCl$ (1:1 ratio)

Ca^{2+} Cl^{-} make $CaCl_2$ (1:2 ratio)

Na^{+} N^{3-} make Na_3N (3:1 ratio)

Fe^{3+} O^{2-} make Fe_2O_3 (2:3 ratio)

WRITING AN IONIC FORMULA

- if you know the ions that make up a compound, all you need to do is find the smallest ratio of cation to anion the compound needs to have an overall charge of zero

Example: Mg^{2+}, P^{3-} ... what is formula?

Mg^{2+}

P^{3-} ← more − than +, so add more Mg^{2+}

← more + than −, so add P^{3-}

Mg^{2+} ← more − than +, so add Mg^{2+}

Mg_3P_2 In the final formula, don't write the charges on the ions!

* Remember, ionic compounds are written with the SMALLEST whole-number ratio!

Ionic formulas are ALWAYS written with the cation first, and the anion second!

Cross method: Mg^{2+} P^{3-} Mg_3P_2

More examples:

Ca^{2+} F^-

$$\begin{array}{l} Ca^{2+}\ F^- \\ \phantom{Ca^{2+}}\ F^- \\ \hline CaF_2 \end{array}$$

Ti^{4+} O^{2-}

~~Ti_2O_4~~ $\rightarrow$

$$\begin{array}{l} Ti^{4+}\ O^{2-} \\ \phantom{Ti^{4+}}\ O^{2-} \\ \hline TiO_2 \end{array}$$

K^+ N^{3-}

$$\begin{array}{l} K^+\ N^{3-} \\ K^+ \\ K^+ \\ \hline K_3N \end{array}$$

You can also use the "cross method", as described in your textbook, to write formulas. Use caution, as the "cross method" will sometimes give you the wrong formula! It would give you the wrong answer for this one!

PREDICTING CHARGES

- how do you figure out the charge that an element might take when it becomes an ion?

- for many main group elements, you cah predict the charge using the periodic table!

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
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									

*"inner" transition metals go here

Elements in group VIIIA - the "noble gases" - do not form ions!

Many OTHER main-group elements form either anions or cations that have the same overall number of electrons as the NEAREST (in terms of atomic number) noble gas!

PREDICTING CHARGE

You can reliably determine the charge using our method for Groups IA, IIA, IIIB, Aluminum, and the Group VA, VIA, and VIIA NONMETALS

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
H																	He
Li	Be											B	C	N	O	F	10 Ne
Na	Mg											Al	Si	P	S	Cl	18 Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	36 Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	54 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									

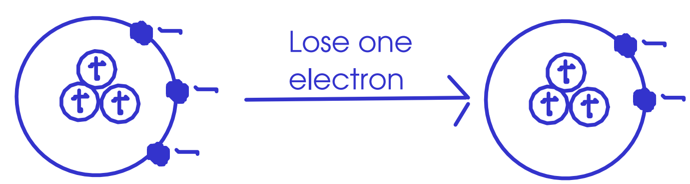
*"inner" transition metals go here

Aluminum (Al): At atomic number 13, it is three electrons away from neon (Ne), and 5 electrons away from argon (Ar). Prediction: Aluminum will lose three electrons to form the cation Al^{3+}

Bromine (Br): At atomic number 35, bromine is one electron away from krypton (Kr). Prediction: Bromine will gain one electron to form the anion Br^{-}

Strontium (Sr): At atomic number 38, strontium is two electrons away from krypton. Prediction: Strontium will lose two electrons to form the cation Sr^{2+}

Lithium (Li) ion would have a charge of +1:
+3-2 = +1



EXAMPLES

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
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									

*"inner" transition metals go here

Find the formulas of:

(1) an ionic compound containing Al and Br

(2) an ionic compound containing Mg and O

(3) an ionic compound containing S and K

Al^{3+} Br^{-}

Mg^{2+} O^{2-}

S^{2-} K^{+}

Find the formula of:

* an ionic compound containing Al and Br

Al^{3+} Br^{-} Br^{-} Br^{-} → $AlBr_3$

Find the formula of:

* an ionic compound containing Mg and O

Mg^{2+} O^{2-}

MgO

Find the formula of:

* an ionic compound containing S and K

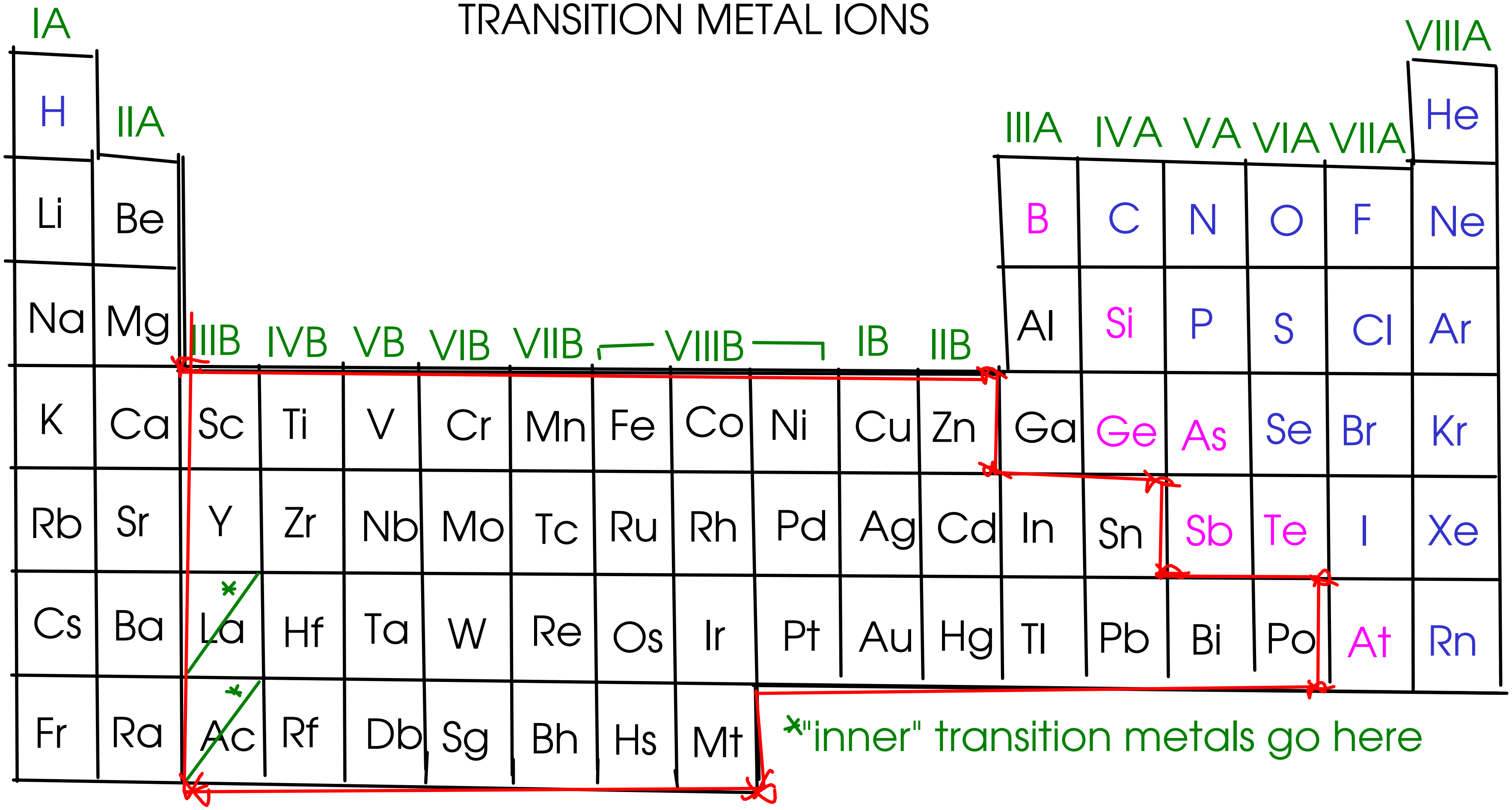
S^{2-} K^{+} K^{+}

K_2S

~~SK_2~~

Remember: Cations come first in ionic formulas.

TRANSITION METAL IONS



The transition metals always form CATIONS!

However, many transition metals are capable of forming SEVERAL DIFFERENT CATIONS!

Example: Iron (Fe) forms two cations, depending on the situation: Fe^{2+} or Fe^{3+}

TRANSITION METAL CATIONS

- So how do you know which cation you're dealing with? For now, you'll have to be told

- Either the chemical formula of an ionic compound or the name of an ionic compound can tell you what charge is on the transition metal cation.

Examples:

Fe_3N_2

Fe^{2+} N^{3-}

Fe^{2+} N^{3-}

Fe^{2+}

+6 -6

* We call this form of iron ion "iron(II)"! (pronounced "iron two")

FeN

Fe^{3+} N^{3-}

+3 -3

* We call this form of iron ion "iron(III)".

POLYATOMIC IONS

- Some MOLECULES can gain or lose electrons to form CATIONS or ANIONS. These are called POLYATOMIC IONS

- Polyatomic ions form ionic compounds in the same way that single-element ions do.

Example: CO_3^{2-} : CARBONATE ION

Al^{3+} $\quad CO_3^{2-}$

Al^{3+} $\quad CO_3^{2-}$

CO_3^{2-}

$Al_2(CO_3)_3$

*Compare to Al_2O_3

* Use parenthesis when an ionic compound's formula contains more than one of a polyatomic ion.

See the web site or page 63 - table 2.5 - for a list of common polyatomic ions!

NAMES OF IONS

- To properly discuss ions and ionic compounds, we have to know how to name them!

CATIONS

3 kinds:

(1) Main group cations (metals that take only one charge when forming ions)

- The element's name is the same as the ion's name!

Mg^{2+} : "magnesium ion"

(2) Transition metal cations (from metals that can form several cations)

- The CHARGE of the cation must be given. Use a ROMAN NUMERAL after the element name to indicate charge!

Fe^{2+} : "iron(II) ion" Cu^{+} : "copper(I) ion"

Fe^{3+} : "Iron(III) ion"

(3) Polyatomic cations

- Memorize list.

NH_4^{+} : "ammonium ion"

ANIONS

2 kinds

1 Main-group nonmetals

- Use the STEM NAME of the element, then add "-ide" suffix

N^{3-} : "nitride" ion

P^{3-} : "phosphide ion"

S^{2-}: sulfide ion

O^{2-} : "oxide ion"

F^{-} : "fluoride ion"

2. Polyatomic ions

- Memorize list.(see web site)

$C_2H_3O_2^{-}$: "acetate ion"

SO_4^{2-} : "sulfate ion"

NO_3^{-} : "nitrate ion"

SO_3^{2-} "sulfite ion"

NO_2^{-} : "nitrite ion"

* Polyatomic ions ending in "-ate" and "-ite" suffixes always contain oxygen! "-ate" ions have more oxygen atoms than their "-ite" counterparts.

NAMING IONIC COMPOUNDS

- The name of the compound is based on the name of the ions in the compound
- Cation first, anion second

Examples:

$Mg(OH)_2$

magnesium hydroxide

Fe_2O_3

Fe^{3+} O^{2-}
Fe^{3+} O^{2-}
O^{2-}

$+6$ -6

iron(III) oxide

Na_2S

sodium sulfide

CuO

Cu^{2+} O^{2-}

$+2$ -2

copper(II) oxide

$BeBr_2$

beryllium bromide

Cu_2O

Cu^{+} O^{2-}
Cu^{+}

$+2$ -2

copper(I) oxide

Remember to include the Roman numeral for CHARGE in the name of transition metal compounds!

Page 63 (9th edition): Chart of polyatomic ions

NAMING IONIC COMPOUNDS

$(NH_4)_2S$

ammonium sulfide

$FeCO_3$

Fe^{2+} CO_3^{2-}

iron(II) carbonate

TiS_2

Ti^{4+} S^{2-}

S^{2-}

$+4$ -4

titanium(IV) sulfide

$Ba_3(PO_4)_2$

barium phosphate

Spelling matters!

Ba_3P_2

barium phosphide

DETERMINING THE FORMULA OF AN IONIC COMPOUND FROM THE NAME

- The name of an ionic compound is made of the names of the CATION and ANION in the compound.

- To get the FORMULA, you must figure out the SMALLEST RATIO of cation to anion that makes the charges balance out

---

Examples:

iron(III) carbonate

Fe^{3+} CO_3^{2-}
Fe^{3+} CO_3^{2-}
CO_3^{2-}

$Fe_2(CO_3)_3$

potassium sulfide

K^+ S^{2-}
K^+

K_2S

calcium bromide

Ca^{2+} Br^-
Br^-

$CaBr_2$

DETERMINING IONIC FORMULAS

sodium sulfate

Na^{+} SO_4^{2-}

Na^{+}

Na_2SO_4

strontium oxide

Sr^{2+} O^{2-}

SrO

tin(II) phosphate

Sn^{2+} PO_4^{3-}

Sn^{2+} PO_4^{3-}

Sn^{2+}

$Sn_3(PO_4)_2$

chromium(III) nitrate

Cr^{3+} NO_3^{-}

NO_3^{-}

NO_3^{-}

$Cr(NO_3)_3$

barium hydroxide

Ba^{2+} OH^{-}

OH^{-}

$Ba(OH)_2$

~~$BaOH_2$~~

Don't forget the parenthesis when you have more than one hydroxide ion!

titanium(IV) chloride

Ti^{4+} Cl^{-}

Cl^{-}

Cl^{-}

Cl^{-}

$TiCl_4$

HYDRATES

- many ionic compounds are formed by crystallizing the compound from water. Sometimes, this causes water molecules to become part of the crystal structure.

- This water is present in a definite ratio to the ions in the compound. Can be removed by heating, but will NOT evaporate if the compound is left standing.

ex: $CuSO_4 \cdot 5H_2O$

water molecules per formula unit of compound

dot indicates that the water is weakly bound to the ionic compound

- many DESSICANTS are hydrates that have had their water molecules driven off. They will slowly reabsorb water from the air (and keep the environment in a dessicator at a low humidity)

- Hydrates are named using the name of the ionic compound, and a Greek prefix in front of the word "hydrate" to indicate how many water molecules are associated

Cu^{2+} SO_4^{2-}

Why "copper(II)"?

copper (II) sulfate pentahydrate