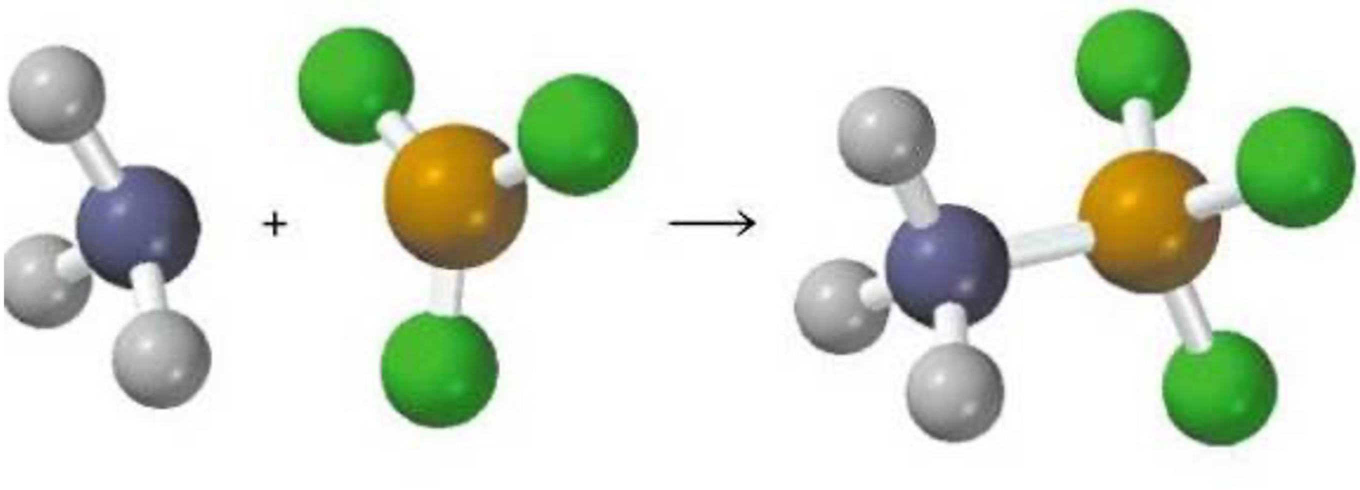
Chapter Five

Ionic & Covalent Compounds



Types of Compounds

Compound: 2 or more elements chemically combined

Ionic:

- Cation + Anion
- Form from transfer of electrons
- Often metal + nonmetal
  - Elements that are very "different"
  - Opposite sides of Periodic Table
- Ex. NaCl (sodium chloride)
- Contain specific ratios of ions but no specific number of ions

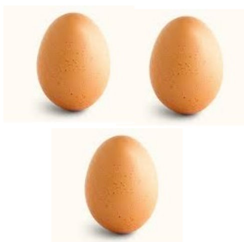
Covalent:

- Form by sharing electrons
- Contain atoms, not ions
- Often nonmetal + nonmetal
  - Elements that are "similar"
  - Same side of Periodic Table
  - Hydrogen is a nonmetal
- Ex. CO_2 (carbon dioxide)
- <u>Molecules</u> contain specific numbers of atoms.

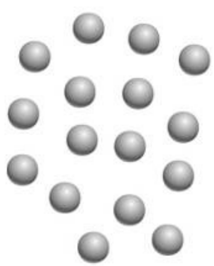
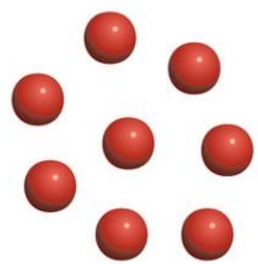
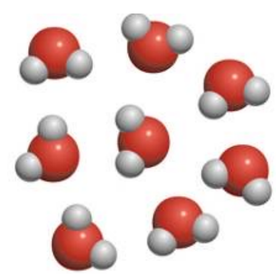
Law of Definite Proportions

A compound will always have same chemical composition

- Each product is formed from definite proportions of reactants

 +  → 

3 eggs | 2 cups flour | 1 cake

 +  → 

16 Hydrogen atoms | 8 Oxygen atoms | 8 Water molecules

Water is ALWAYS H_2O

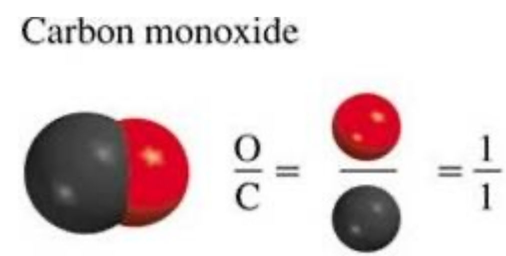
- Same mass proportions & atomic ratios of elements present

Law of Multiple Proportions

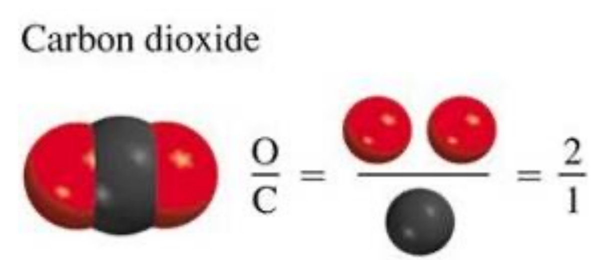
If the same two elements can combine to form more than one compound:

- The masses of one element combine with a fixed mass of the second element.
- The combination is in a ratio of **small whole numbers.**

Open face sandwich
1 bread + 1 filling
1:1 ratio



Regular sandwich
2 bread + 1 filling
2:1 ratio

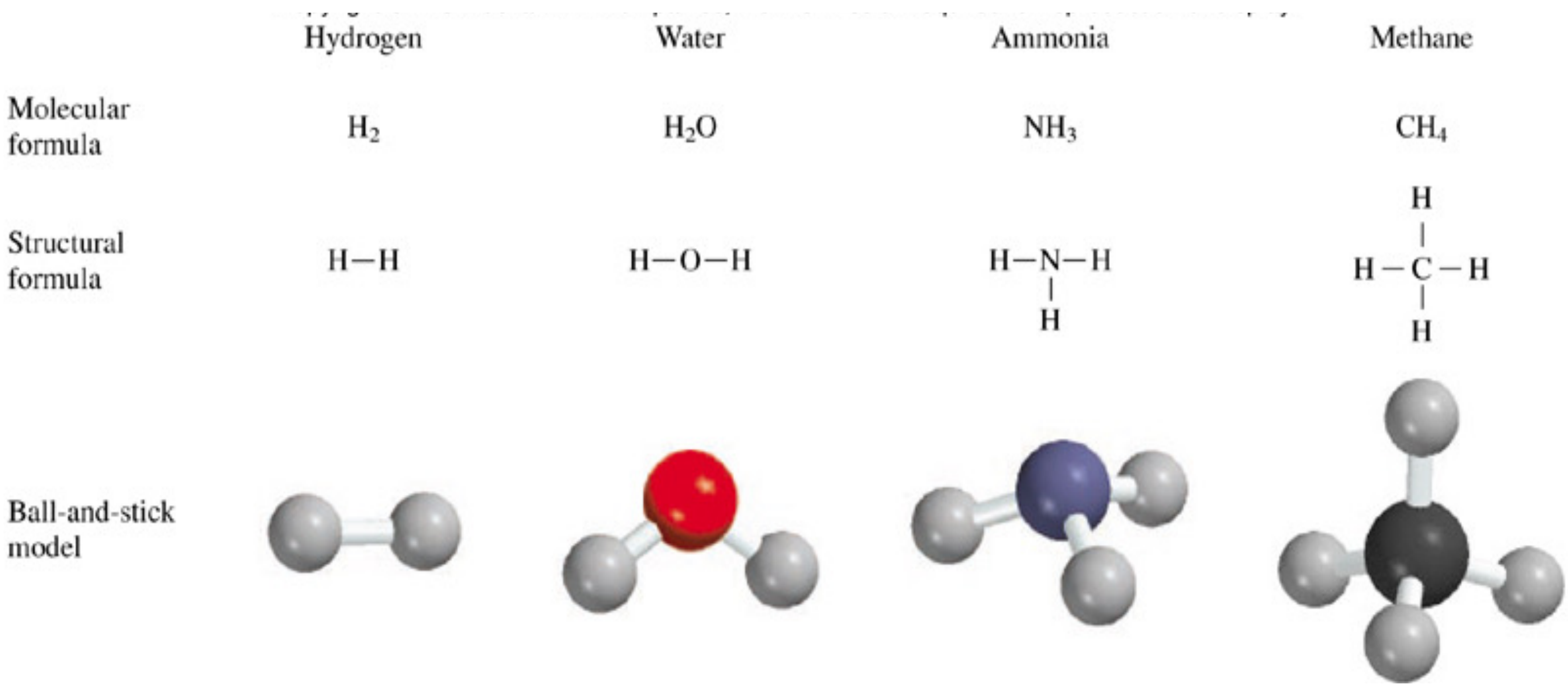


Compounds are formed when atoms of different elements unite in fixed proportions

Chemical Formulas

Represent chemical composition (atomic ratios)

- **Empirical**: Ratio of atoms (NH_2 instead of N_2H_4)
  - Can use for ionic or covalent compounds
- **Molecular**: Actual # of atoms (N_2H_4)
  - Only use for covalent compounds. Molecule = covalent
- **Structural**: Shows how atoms are connected in <u>molecules</u>



Chemical Formulas

Symbols tell you what elements are present

$$\mathbf{Fe(CO_3)_2}$$

Subscripts tell you how many atoms/ions of each element are present

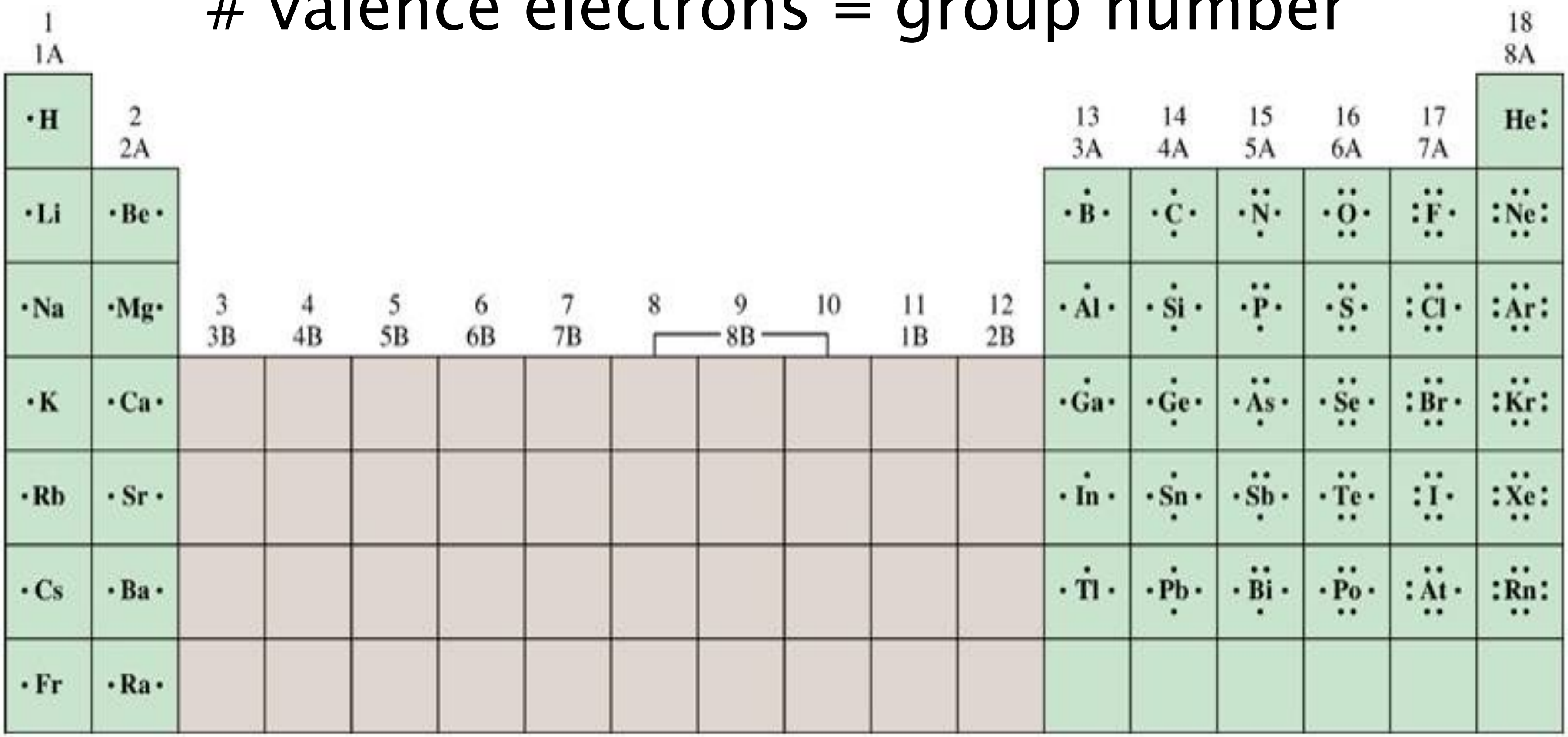
Parentheses show that a subscript belongs to a group of elements, not a single element (distribute the 2 to oxygen & carbon)

Lewis Dot Symbols

Consists of atomic symbol surrounded by 1 dot for each valence electron in the atom

Only used for main group elements

valence electrons = group number



Drawing Lewis Dot Symbols

Mg

S

Cl

Ar

Formulas & Names of Ionic Compounds

Sodium chloride

Ionic Bonding

Electrons are transferred from one atom to another forming charged atoms called **ions**

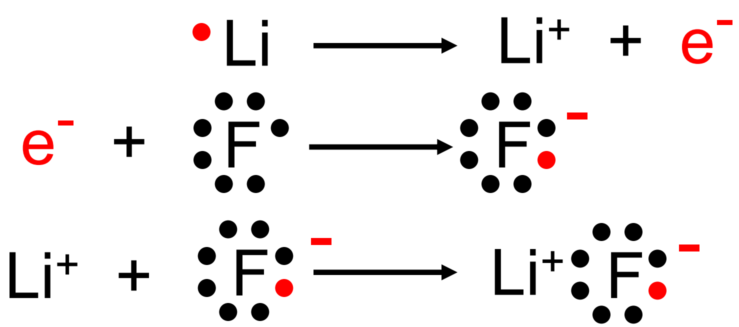
- Metal atoms: Lose electrons to form positive **cations**
- Nonmetal atoms: Gain electrons to form negative **anions**

Electrostatic force (+ & – attraction) bonds ions into an ionic compound (ionic bond)

- Form an ionic salt with repeating structure: NaCl, LiF

Ionic Bonds follow the octet rule

- Atoms lose or gain valence e– to make an octet (8e–)
- 8 valence e– = Noble gas configuration



$1s^2 2s^1 \rightarrow 1s^2$

$1s^2 2s^2 2p^5 \rightarrow 1s^2 2s^2 2p^6$

Ionic Compounds (salts)

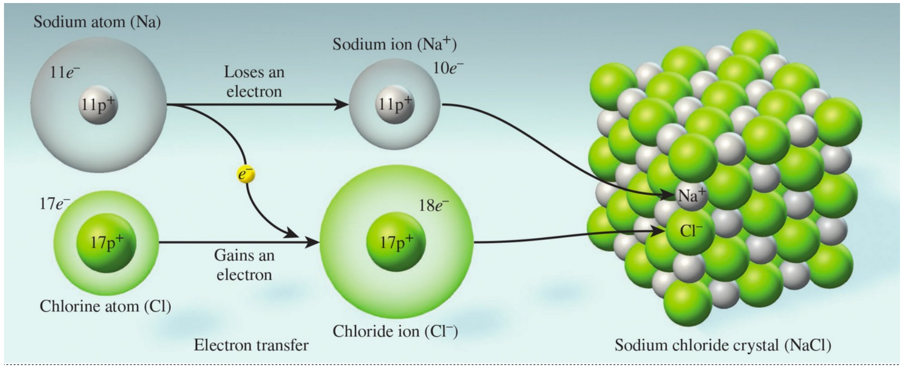
Cations & Anions bind together to form crystals

The net charge on the compound is 0

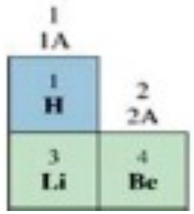
- Positive & negative charges are balanced: number of positive charges = number of negative charges
- Not always a 1:1 ratio of ions – depends on charge

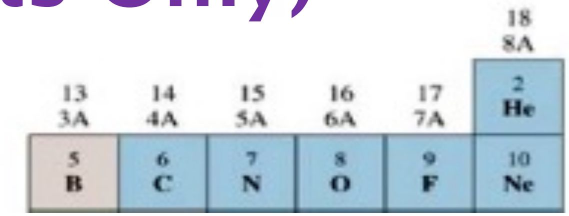
Large network of ions

- Not distinct individual units
- Positive charge of cation attracts all nearby anions
- Negative charge of anion attracts all nearby cations
- Energy required to convert an ionic solid into ions in the gas phase is known as lattice energy



Using the Periodic Table to Predict Ionic Charge (**Main Group Elements Only)**





Goal: Get 8 valence electrons (“full”)

- electrons in “outermost” energy level
- ”A” column number tells number of valence electrons
- Noble gases (column 8A/18) already have 8 – generally no charge
- Can gain or lose electrons to get 8 – generally do what is easier
- Electrons are negative → gain electrons = negative charge!

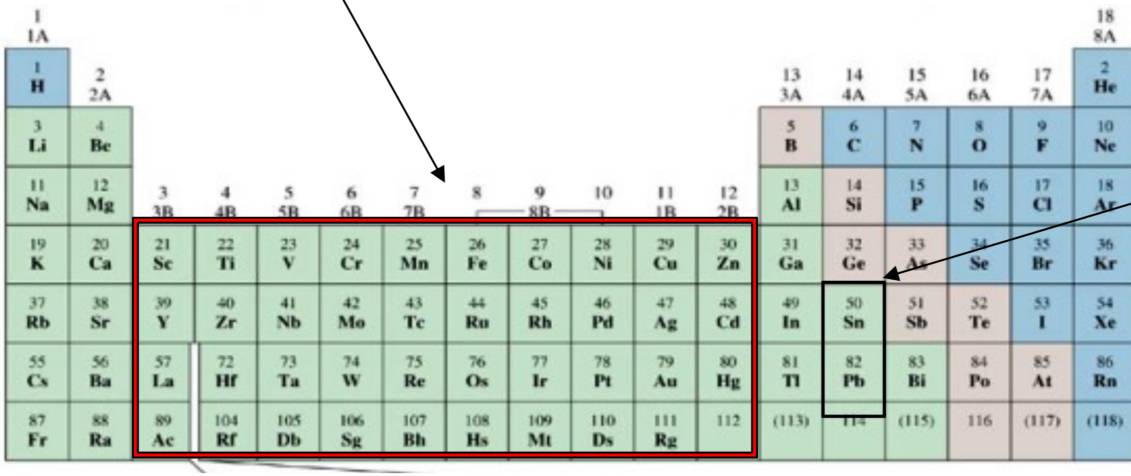
The correct charge is <u>usually</u> the smallest number

Left Side (metals): K^{1+} or K^{-7} Mg^{2+} or Mg^{6-}

Right Side (nonmetals): O^{6+} or O^{2-} F^{7+}, or F^{1-}

Ionic Bonding:
Ca & Cl

Charges on Transition & Other Multi-charge Metals



Sn & Pb are the “others” that you will see most often

- Become cations
- Charge cannot always be predicted by column
- Often have more than one charge (also possible for some main group elements)
  - Designated with a Roman Numeral
  - Iron (III) = Fe^{3+}; Iron (II) = Fe^{2+}
  - Roman numerals required in names of ionic compounds if cation can have more than one charge
    - Iron (III) oxide
    - Copper (II) chloride

Polyatomic Ions

- Charged molecules
- Lose or gain electrons as a group
- Charge is spread over 2 or more atoms

Memorize the following polyatomic ions!

Ammonium	NH_4^+	Hydronium	H_3O^+
Phosphate	PO_4^{3-}	Acetate	CH_3COO^-
Hydroxide	OH^-	Nitrate	NO_3^-
Cyanide	CN^-	Sulfate	SO_4^{2-}
Permanganate	MnO_4^-	Chlorate	ClO_3^-
Carbonate	CO_3^{2-}	Perchlorate	ClO_4^-

Formula of an Ionic Compound must give an overall charge of zero!

Al & O

Ca & Br

Na & CO_3

Ca & NO_3

Pb^{4+} & O

Names of Ions and Ionic Compounds

Naming Ions:

For cations: add the word ION after element name

Na = sodium

- In col 1, so loses 1 e^-
- Na^+ =

Al = aluminum

- In col 13, so loses 3 e^-
- Al^{3+} =

For anions: change the element name ending to –ide first

Cl = chlorine

- In col 17, so gains 1e^-
- Cl^- =

O = oxygen

- In col 16, so gains 2 e^-
- O^{2-} =

Naming Ionic Compounds (ie salts):

- Write the name of the cation followed by the name of the anion.
- If the cation can have more than one charge, include a Roman Numeral representing the charge after the name of the cation.

Na & Cl

Net Charge: (+1) + (-1) = 0
Chemical Formula is NaCl

Na = sodium
Cl = chloride
Name = Sodium chloride

Al & O

Net Charge: 2(+3) + 3(-2) = 0
Chemical Formula is Al_2O_3

Al = aluminum
O = oxide
Name = Aluminum oxide

Fe & S

Fe = iron -> 2 possible charges, +2 & +3
S = Sulfide -> charge is -2

If Iron is +2
Net Charge: (+2)+(-2) = 0
Chemical Formula is FeS
Name = Iron (II) sulfide

If Iron is +3
Net Charge: 2(+3)+3(-2) = 0
Chemical Formula is Fe_2S_3
Name = Iron (III) sulfide

Naming Ionic Compounds

1.) K_2O

2.) CaF_2

3.) KF

4.) $Ca(NO_3)_2$

5.) K_3PO_4

If the formula contains a cation that can have more than one charge, you need to determine the charge based on the anion & include it as a Roman Numeral.

6.) $PbCl_2$

7.) Fe_2O_3

Formulas & Names of Covalent Compounds

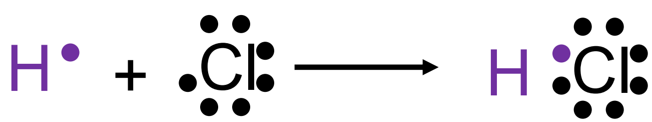
CO_2 = Carbon Dioxide

Covalent Bonding

Electrons are shared between atoms, forming a covalent bond

- Elements are similar so they are not able to fully pull electrons away from each other
- Atoms remain uncharged, but “gain” additional valence electrons to have an octet
- Number of shared electrons can vary depending on the number needed for each atom to gain an octet

Often results in formation of individual units called molecules



= Molecule of HCl

- Sometimes large networks similar to ionic crystals can be formed – diamonds are one example

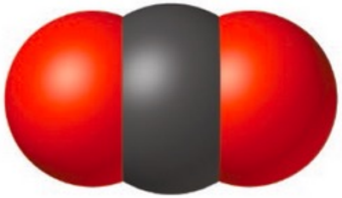
Molecular Compounds

Molecules contain specific numbers of atoms

- The number and type of each atom is shown in the molecular formula
- Diatomic molecules – 2 atoms
  - Homonuclear – same element
    not a compound (just an element)

  - Heteronuclear – different elements
    a **compound**

- Polyatomic molecules – more than 2 atoms



Names of Binary Molecules (2 Elements, Covalent)

Names and formulas have 2 parts, 1 for each element:

Dinitrogen tetroxide -------------------- N_2O_4

1st word is 1st element name --------- N = Nitrogen

2nd word is 2nd element name
→ **change ending to "–ide"** ---------- O = Oxygen → Oxide

Formula: Subscripts = # of atoms ------ N_2O_4

Name: Prefix = # of atoms --------------- Dinitrogen tetroxide

Do not include a prefix for the first element if there is only one atom

Ex: CO_2 = Carbon dioxide (not monocarbon dioxide)
CO = Carbon monoxide

Need to know prefixes up to 10

TABLE 5.5	Greek Prefixes		
Prefix	**Meaning**	**Prefix**	**Meaning**
Mono-	1	Hexa-	6
Di-	2	Hepta-	7
Tri-	3	Octa-	8
Tetra-	4	Nona-	9
Penta-	5	Deca-	10

Note that the o or a at the end of the prefix is often dropped when the element begins with a vowel.

- Monoxide, not monooxide
- Tetroxide, not tetraoxide

Names & Formulas of Binary Molecules

1.) N_2O

2.) SCl_3

3.) P_2O_5

4.) nitrogen dioxide

5.) dinitrogen tetrasulfide

Acids and Bases

Acid

- Arrhenius: Compound ionizes in H_2O to form H^+ & anions
  - Name by changing anion –ide ending to –ic acid
  - Add hydro to acids with HX formula (X=halogen; col.17)

    ex: HCl = Hydrochloric acid
- Bronsted acids: H^+ grabs H_2O to form H_3O^+ in water

Base

- Arrhenius: Compound ionizes in H_2O to form OH^- & cations
  - Name as salts: All hydroxide salts are considered bases
- Bronsted base: Pulls H+ from H_2O so NH_3 is a base:

$$H_2O + NH_3 \Rightarrow OH^- + NH_4^+ \Rightarrow NH_4OH$$

Neutralization

- Reaction between acid & base – form water & a salt

$H^+ + OH^- \Rightarrow H_2O$ and cation + anion ⇨ salt

$HCl + NaOH \Rightarrow H_2O + NaCl\ (aq)$

Common acids and bases

Be able to recognize & associate formula with name

Acids

Hydrochloric Acid:	HCl	Carbonic Acid:	H_2CO_3
Sulfuric Acid:	H_2SO_4	Nitric Acid:	HNO_3
Chloric Acid:	$HClO_3$	Phosphoric Acid:	H_3PO_4
Perchloric acid:	$HClO_4$	Acetic Acid:	CH_3COOH

Bases

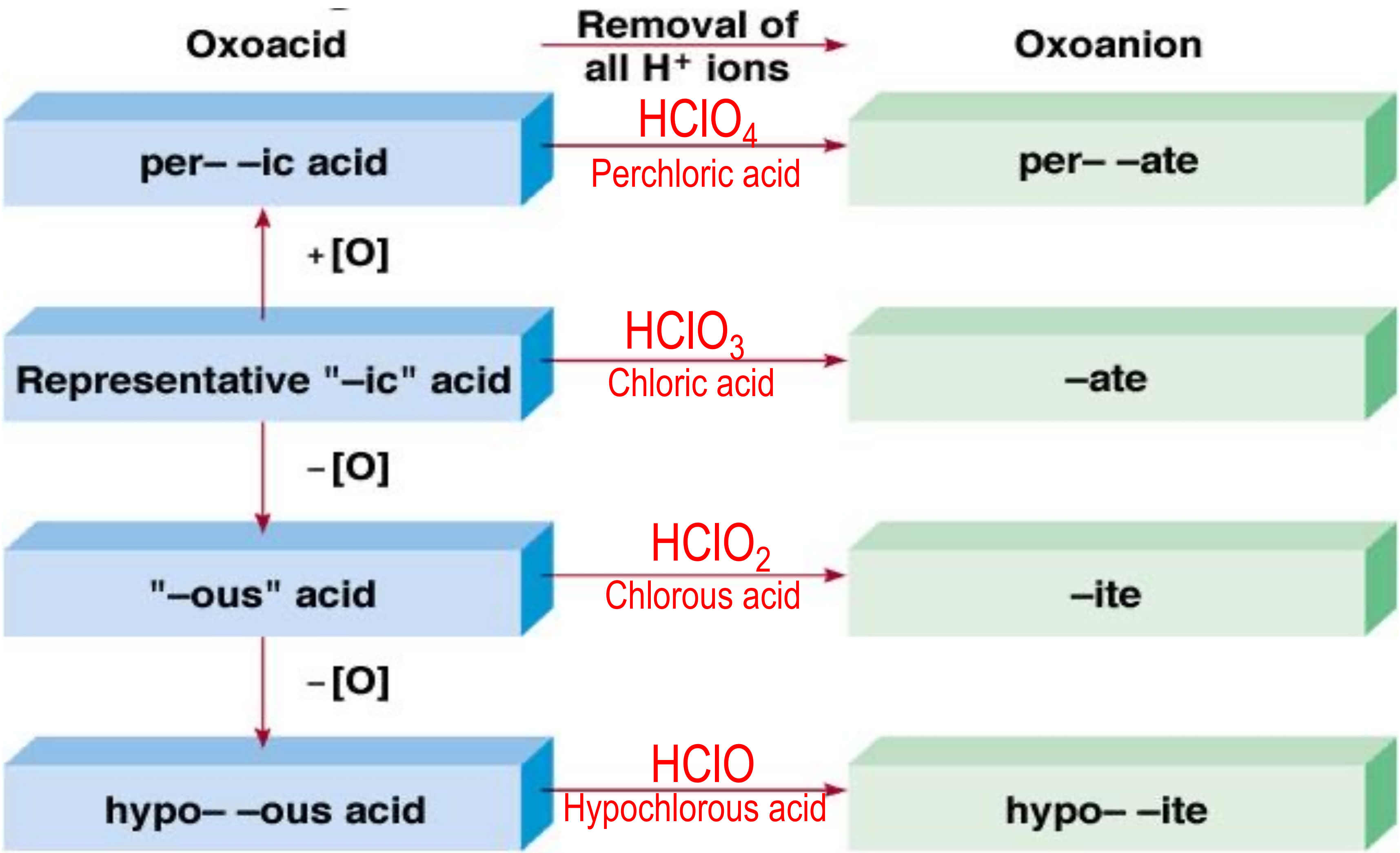
Sodium hydroxide: $NaOH$

Potassium hydroxide: KOH

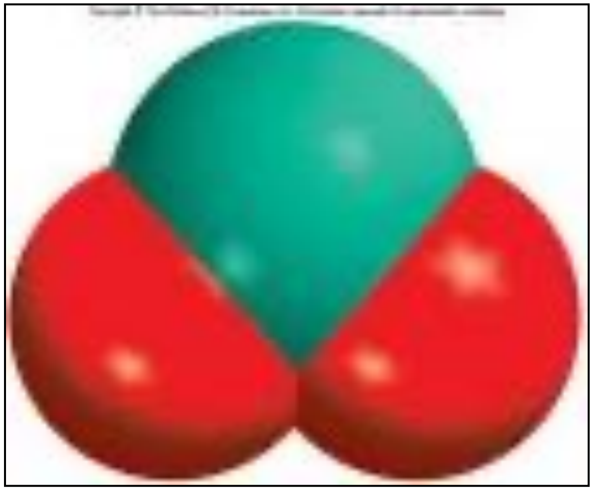
Ammonium hydroxide: NH_4OH (ammonia, NH_3, in H_2O)

Lithium hydroxide: $LiOH$

Naming Oxoacids and their Anions: Reference Only



Molar Mass & Mass Percent Calculations



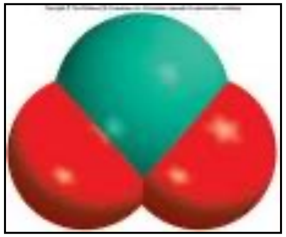
SO_2: 64.0648g/mol

49.9476% oxygen
50.0524% sulfur

Molar Mass

The mass of one mole of a substance

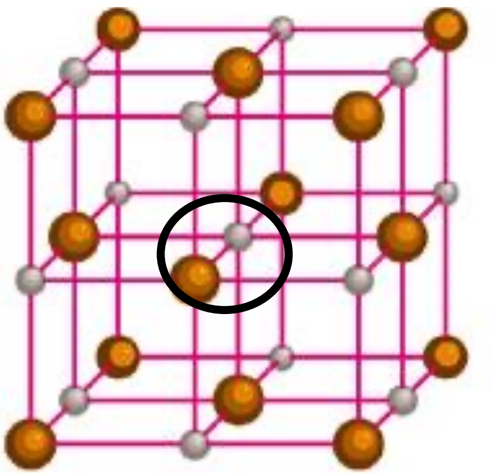
- Units of g/mol



SO_2 - molecule

To calculate for a compound:

- Find atomic mass of each element
  → located on Periodic table (often below symbol)
- Multiply atomic mass of element by subscript, then add all elements together.
- Molecular mass: mass of molecule
  → include every atom
- Formula mass: mass of ions in a salt
  → use smallest ratio



NaCl – ionic compound

Examples:

1 mol Na = 22.99 g/mol

1 mol SO_2 = 64.07g/mol

1 mole NaCl = 58.44g/mol

Calculating Molar Mass for Compounds

1.) NaCl

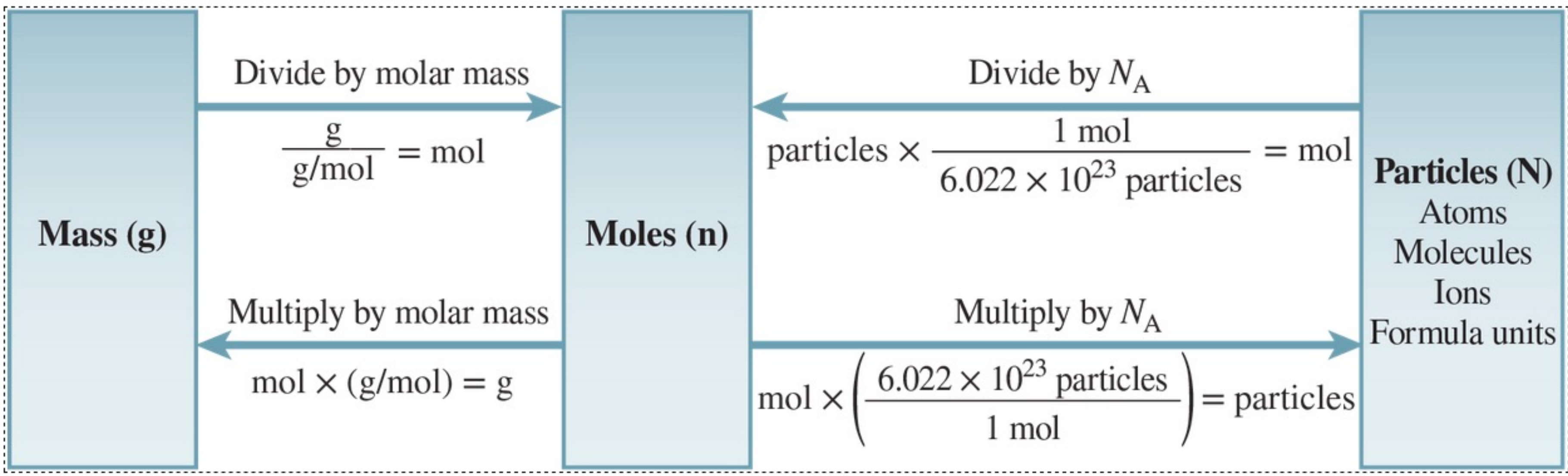
2.) SO_2

3.) $Pb(NO_3)_2$

Mole-based Calculations (Mass/Mole/Particle Conversions)

Molar Mass (*M*): grams/mol – from Periodic Table!

Avogadro's Number N_a: 6.022×10^{23} particles/mol



Same as for elements,
but with molar mass of **compounds**

moles → mass
What is the mass, in grams, of 0.557 mol K_2O? (52.5 g)

mass → # moles
How many moles are there in 25.64 g of K_2O? (0.2722 mol)

moles → # particles

How many molecules are in 2.6 moles of CO_2? (1.6 x 10^{24} molecules)

moles → # particles

How many oxygen atoms are in 4.57 moles of SO_3? (8.26x10^{24} atoms O)

moles → # particles

How many ions are in 2.6 moles of NaCl? (3.1 x 10^{24} ions;
1.6x10^{24} Na^+ ions & 1.6x10^{24} Cl^- ions)

Combined!

How many atoms are there in 2.578 g of SO_2
(MM = 64.065 g/mol)?

Mass → Moles → Molecules → Atoms

A: 7.270×10^{22} atoms

Percent Composition of Compounds by Mass (Mass % Compostion)

- General idea for percentages is "part / total"
- For mass %: mass of each element in the compound divided by the total mass of the compound
- Units should be the same for both values (usually g)

To Determine the Mass % of a Compound:

- Assume 1 mole of compound.
  - ❖ This will make subscripts = # moles of each element
- Calculate molar mass of compound.
- Calculate mass of each element based on subscripts.
- For each element, divide mass by molar mass of compound

Mass % Compostion

3 pieces Pepperoni (Pe) – 10. g per piece
2 pieces Cheese (Ch) – 9.0 g per piece
5 pieces Veggie (Ve) – 12 g per piece

$Pe_3Ch_2Ve_5$

Total: 10 slices, 108 g

Percent by slice:

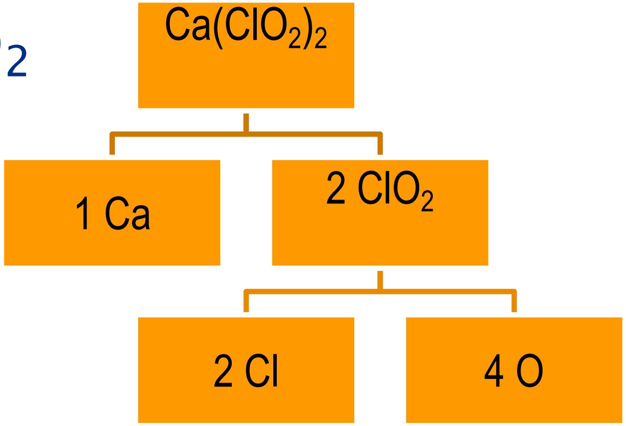
Pe: (3/10)*100 = 30%
Ch: (2/10)*100 = 20%
Ve: (5/10)*100 = 50%

Percent by mass:

Pe: (30./108)*100 = 27%
Ch: (18/108)*100 = 17%
Ve: (60./108)*100 = 56%

Mass % Composition of Calcium Chlorite, $Ca(ClO_2)_2$

Step 1: Find the molar mass of $Ca(ClO_2)_2$



Step 2: Divide each elemental mass by the molar mass of $Ca(ClO_2)_2$ (Total should equal approximately 100%)

Empirical Formulas from Mass % Composition

What is the empirical formula for a compound with a mass composition of 2.2% H, 26.7% C, and 71.1% O?

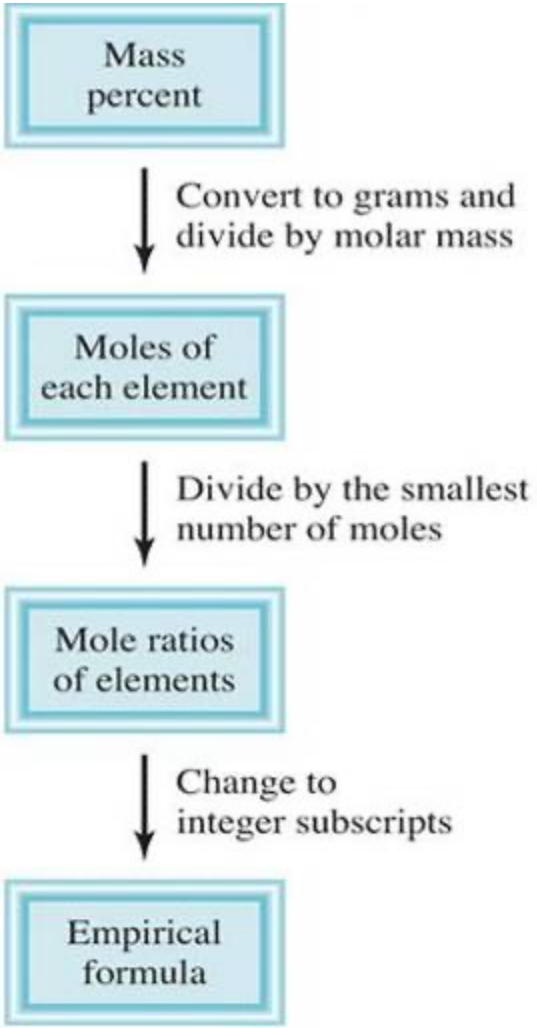
Assume 100g, then can change % of each element to grams:

Convert grams of each element to moles:

Divide by smallest # of moles

Use integers for subscripts

$H_1C_1O_2 = HCO_2$ (empirical formula)



What If You Don't get Whole Numbers?

Multiply Results from Empirical Formula by the smallest possible value to get whole numbers:

C = 1.5

O = 1

H = 3

Formula = $C_3H_6O_2$

Molecular Formula from Mass % Composition

What is the molecular formula for a compound with a mass composition of 2.2% H, 26.7% C, and 71.1% O, **and a molar mass of 135.053g/mol**?

Follow steps to get empirical formula:

From previous slide: HCO_2

Calculate formula mass from empirical formula:

Divide molar mass by formula mass:

Multiply subscripts by value from previous step: