# *Chemistry 3A*

# Introductory General Chemistry

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# This Slide Set: Book Chapter 4

- Matter: Properties and Changes Affecting It
- Compounds
- Molecules As Polyatomic Forms of The Elements
- Ionic Compounds
- Chemistry Nomenclature: Naming of Compounds

# Matter: Properties and Changes Affecting It

***Physical Property***

a characteristic of a substance that can be observed or measured without changing the identity of the substance

| | |
|---|---|
| Color | Electrical conductivity |
| Hardness | Density |
| Malleability (ability to be hammered) | Melting point |
| Solubility | Boiling point |

# Matter: Properties and Changes Affecting It

***Chemical Property***

potential to undergo some chemical change or reaction by virtue of its composition

- Metals like Zn (zinc) reacting with acid
- Forming oxides in reacting with oxygen
- This involves substance changing into another substance

# Physical (State) Changes

**States** of matter are **solid**, **liquid**, **gas**

Changes in the **states** of matters are:

- Vaporization

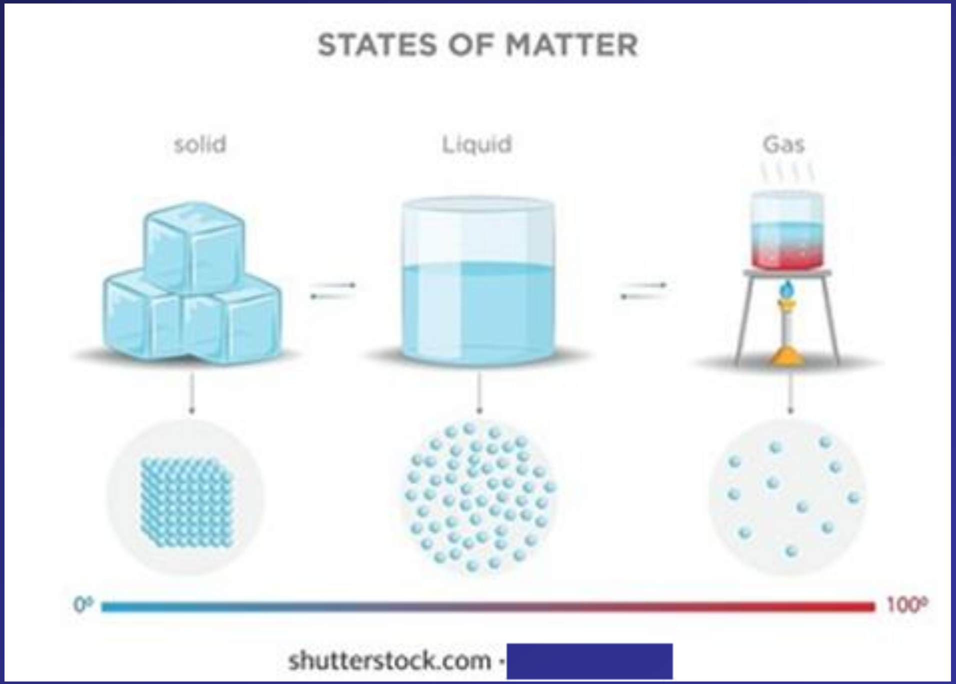
  *Liquid to gas*

- Freezing

  *Liquid to solid*

- Condensation

  *Gas to liquid*



# Chemical Changes

Figure 4.1.2.2: Burning of wax to generate water and carbon dioxide is a chemical reaction. (CC-SA-BY-3.0; Andrikkos )

# Making Use of Physical Properties

*Distillation*

Separating/purifying compounds based on boiling point

*Precipitation*

Separating/purifying compounds based on solubility

- Some stay in solution,
- Others come out of solution

*Filtration*

Separating compounds

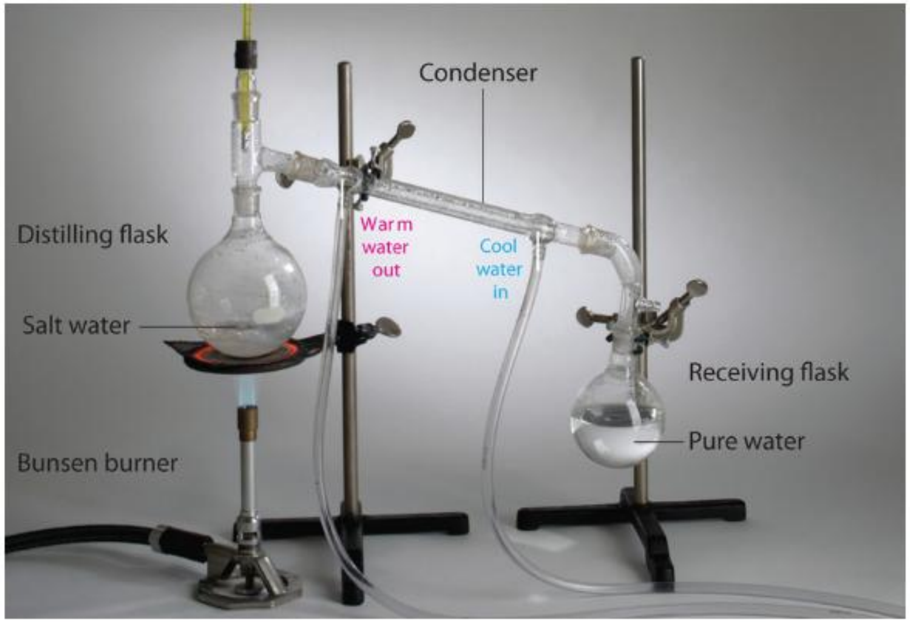



Figure 4.1.2.3: *The Distillation of a Solution of Table Salt in Water. The solution of salt in water is heated in the distilling flask until it boils. The resulting vapor is enriched in the more volatile component (water), which condenses to a liquid in the cold condenser and is then collected in the receiving flask.*

Parts of a distillation setup: Bunsen burner, salt water in distilling flask, condenser with cool water in and warm water out, pure water in receiving flask

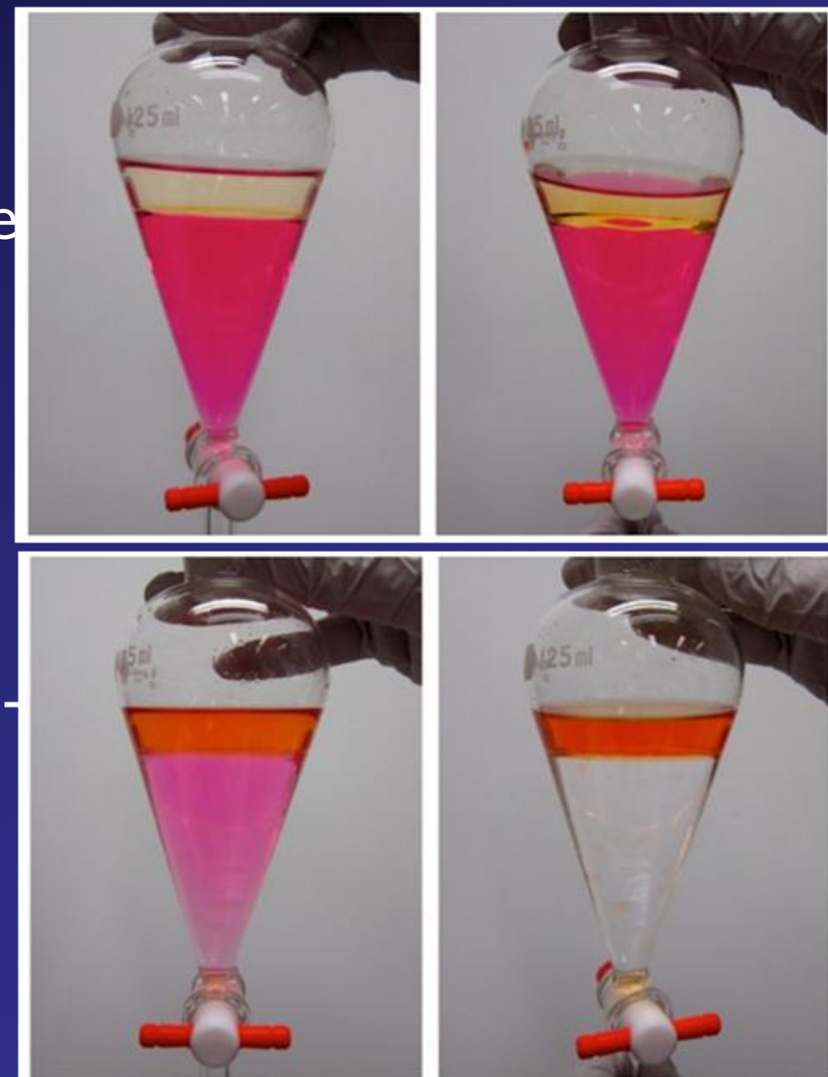
# Making Use of Physical Properties

*Solvent Extraction*

Separating/purifying compounds based on preference ("partition") for organic vs aqueous solvents

*Chromatography*

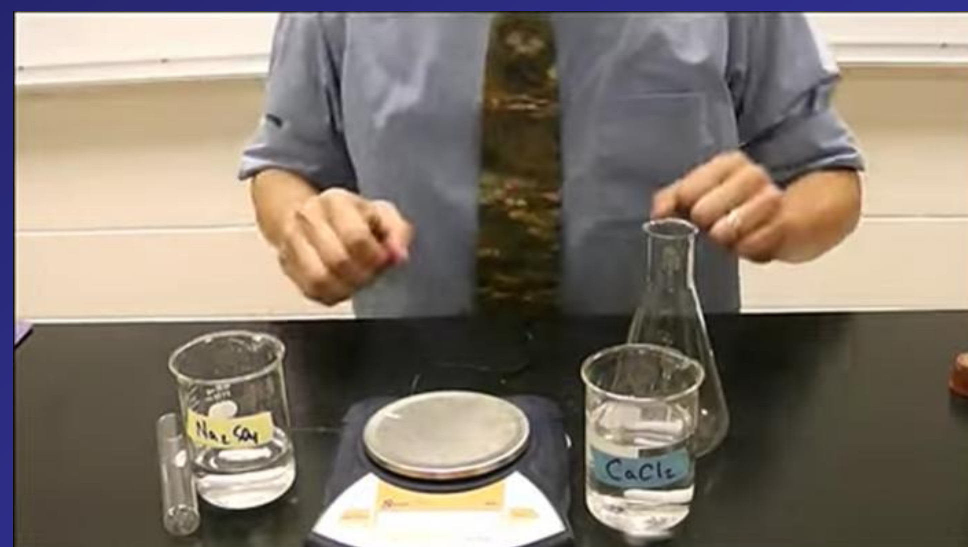
Separating/purifying compounds based on same principle as solvent extraction but with flowing (mobile) vs non-flowing (stationary) phases



# LAW of Conservation of Mass

- 1789 French chemist Lavoisier
- Matter cannot be created or destroyed
- Chemical reaction: mass of reactants and mass of products identical

$$\underbrace{2\,H_2 + O_2}_{\textit{reactants}} \longrightarrow \underbrace{2\,H_2O}_{\textit{products}}$$



https://www.youtube.com/watch?v=Wwmsy4huZQ0

Components are **not evenly distributed**
•You can often **see or separate** the parts

# Mixtures

*Homogeneous*

- one in which the composition is **uniform throughout**. You can't see the individual components, and every sample taken from the mixture will have the same properties
- Appears as a single phase (solid, liquid, or gas)
- Evenly distributed particles
- Cannot distinguish components by eye

*Heterogeneous*

- has a **non-uniform composition**
- The different parts of the mixture are **visibly distinct**, and samples taken from different areas may have different properties
- Multiple phases may be present
- Components are not evenly distributed
- You can often see or separate the parts

# Compounds

A **compound** is a substance that contains two or more elements chemically combined in a fixed proportion

- $CH_4$ (methane)
- One carbon atom
- Four hydrogen atoms

- Unlike mixtures, cannot be separated by physical means
- Can be "decomposed" by chemical changes
  $CH_4\ (g) + 2\ O_2\ (g) \rightarrow CO_2\ (g) + 2\ H_2O\ (g)$

# Compounds: Chemical Formula

A **chemical formula** is a way of presenting information about the relative chemical proportions of atoms that constitute a particular compound or molecule

- $H_2O$
- $H_2SO_4$
- $Ca_3(PO_4)_2$

# Compounds: Molecular Formula

A **molecular formula** is a chemical formula gives number of atoms of each of the elements present in one molecule of a specific compound

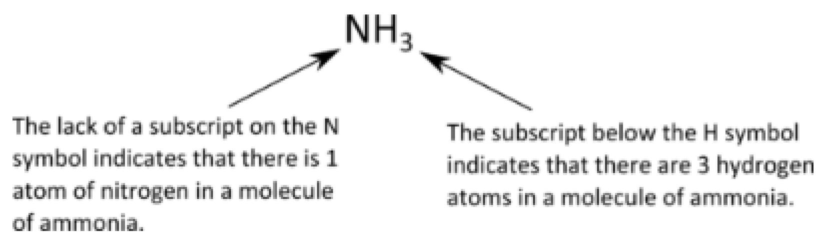



Figure 4.3.1.1: The molecular formula for ammonia. NH3. There is one atom of nitrogen and 3 atoms of hydrogen in a molecule of ammonia.

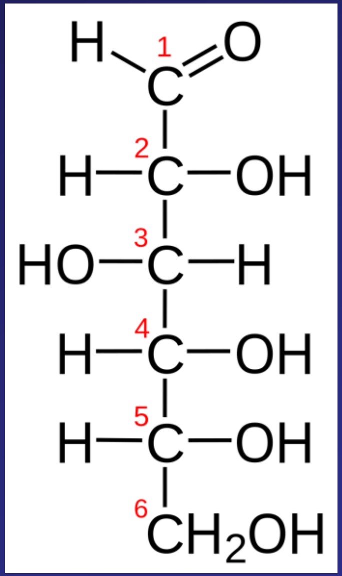
- It is composed of element symbols for the atoms and subscripts to indicate count of the atoms. If there is only one atom in the compound, a subscripted “1” is omitted

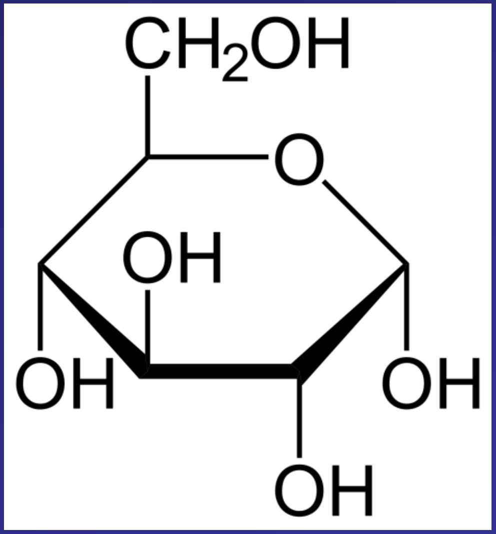
# Compounds: Empirical Formula

An **empirical formula** is a chemical formula that shows the elements in a compound in their lowest whole-number ratio

Glucose has a molecular formula of $C_6H_{12}O_6$

But glucose has an **empirical formula** of $CH_2O$



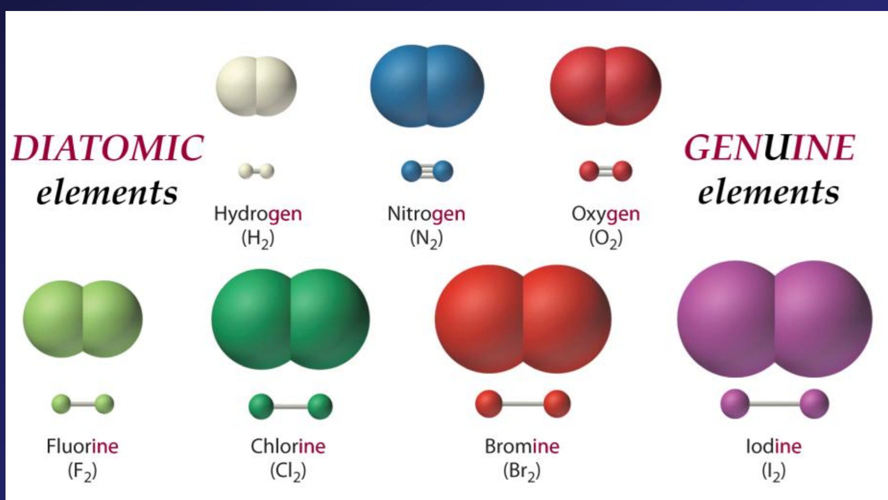

Why? Because when chemists first start to analyze & characterize an unknown compound, they find glucose has **1 part carbon**, **1 part oxygen**, **2 parts hydrogen**

**NOTE THIS**: in some cases the empirical formula and molecular formula are the same!!

# Atomic Elements, Molecular Elements

- Elements that exist as their individual atoms in nature are called **atomic elements**
- Some elements do not exist in nature as individual atoms, but bonded with each other. These are **molecular elements**

Molecular elements can form often **diatomic molecules** or **polyatomic molecules**



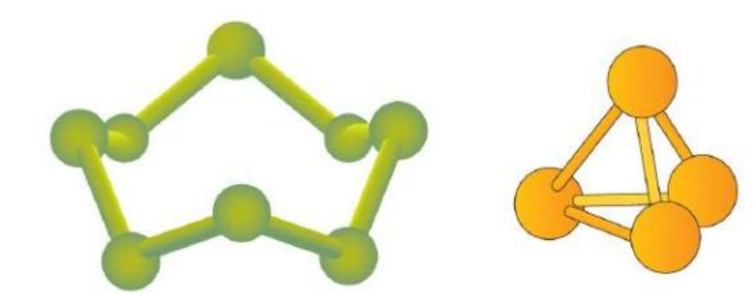
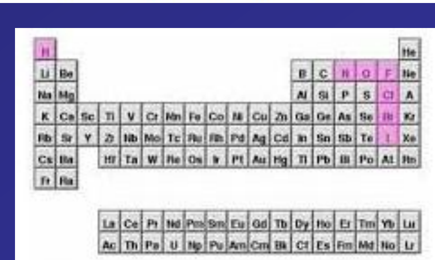



Figure 4.4.1: Molecular Art of $S_8$ and $P_4$ Molecules. If each green ball represents a sulfur atom, then the diagram on the left represents an $S_8$ molecule. The molecule on the right shows that one form of elemental phosphorus exists, as a four-atom molecule.



$H_2$ → Hydrogen
$N_2$ → Nitrogen
$F_2$ → Fluorine
$O_2$ → Oxygen
$I_2$ → Iodine
$Cl_2$ → Chlorine
$Br_2$ → Bromine

→

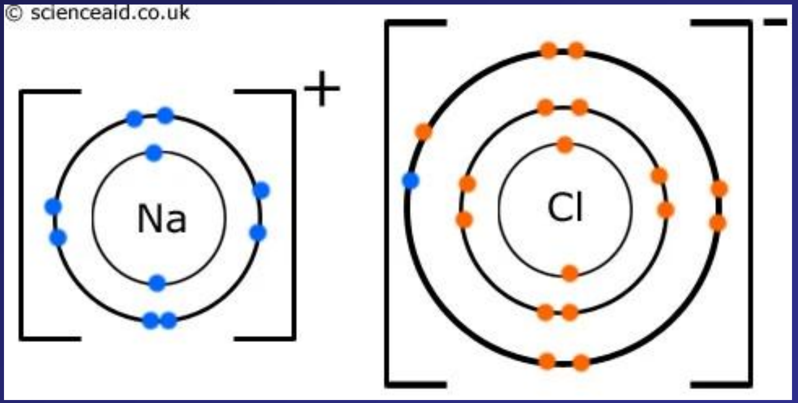
Have
No
Fear
Of
Ice
Cold
Beer

# Formula Unit

- "The formula unit is the basic unit of ionic compounds"
- Also: "in chemistry, a **formula unit** is the smallest unit of a non-molecular substance, such as an ionic compound, covalent network solid, or metal
- Something that does form a discrete molecule, something not forming a molecular compound
- $NaCl$, $CaF_2$, $ZnBr_2$ are the three formula units of these ionic compounds

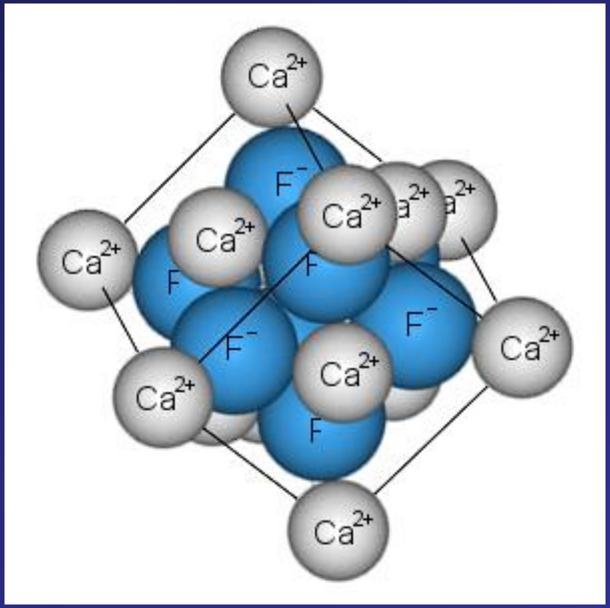
# Ionic Compounds

Ionic compounds form when atoms BOND with each other based on one atom have a positive charge and the other having a negative charge




A sodium (Na) atom easily gives up the ONE electron (all for energetic stability) which is its ONE valence shell electron to a chlorine (Cl) atom which has SEVEN valence shell electrons and wants a more stable complete valence shell of EIGHT electrons. The electron transfer creates an IONIC bond and Na and Cl will form an ionic compound as a result

# Ionic Compounds




Generally metal elements will form ionic compounds with nonmetal elements in the correct ratios

Metals will give up electrons and nonmetals as a rule to form these ionic compounds
(with lots of exceptions to the rule)

# Ionic Compounds

- Ionic compounds will dissolve in water to form individual ions that move about
- When they form crystal solids, they exist in a lattice with an ordered structure in the correct ratio of atoms of the formula unit in the solid state
- The ratio of atoms in the formula unit should have a zero net charge

Aluminum nitride

aluminum ion has 3+ charge: $Al^{3+}$

nitride ion has a 3- charge: $N^{3-}$

One $Al^{3+}$ combines with one $N^{3-}$ $\rightarrow$ $Al_1N_1$

Final formula: **AlN** (leave out 1s if in subscript)

# Cations and Anions

- We talked about this is a previous lecture
- cations “move to” the cathode
- anions “move to” the anode
- Cations are positively charged ions

$Na^+$, $K^+$, $Ca^{2+}$, $Li^+$

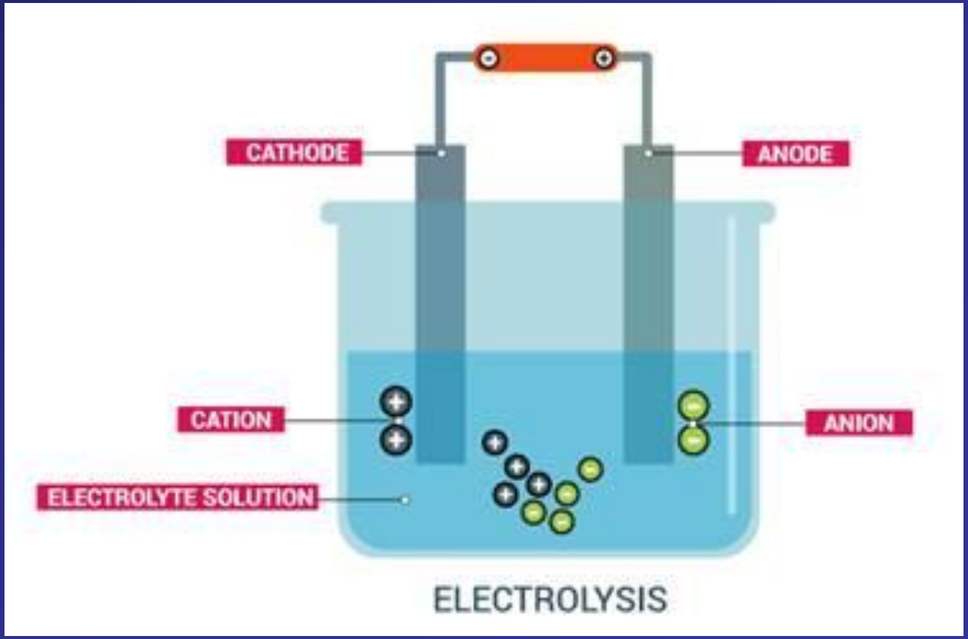
- Anions are negatively charged ions

$Cl^-$, $Br^-$, $OH^-$

- Cathode is negatively charged pole
- Anode is positively charged pole

$$\mathrm{Na} \rightarrow \mathrm{Na}^+ + \mathrm{e}^-$$

$$\mathrm{e}^- + \mathrm{Cl} \longrightarrow \mathrm{Cl}^-$$



# Stock System

- Part of the naming system for compounds

| Formula | Old naming | Stock System | Ion |
|---|---|---|---|
| $CuCl$ | cuprous chloride | copper(I) chloride | $Cu^{+}$ |
| $CuCl_2$ | cupric chloride | copper(II) chloride | $Cu^{2+}$ |
| $FeCl_2$ | ferrous chloride | iron(II) chloride | $Fe^{2+}$ |
| $FeCl_3$ | ferric chloride | iron(III) chloride | $Fe^{3+}$ |

# Criss-Cross Method

- If you are trying to figure out number of atoms in a formula unit or molecule where the cations and anions have different charge magnitudes, this method helps
- Formulas for ionic compounds regarded as empirical formulas: use lowest ratio

lead (IV) oxide

| | |
|---|---|
| What is cation and anion? | $Pb^{4+}$, $O^{2-}$ |
| Exchange charge magnitudes to be subscripts on other atoms | $Pb_2O_4$ |
| Find "greatest common divisor" → 2 | $PbO_2$ |

# Criss-Cross Method (more)

## calcium oxide

| | |
|---|---|
| What is cation and anion? | $Ca^{2+}$, $O^{2-}$ |
| Exchange charge magnitudes to be subscripts on other atoms | $Ca_2O_2$ |
| Find "greatest common divisor" → 2 | $CaO$ |

## copper(I) sulfide

| | |
|---|---|
| What is cation and anion? | $Cu^{+}$, $S^{2-}$ |
| Exchange charge magnitudes to be subscripts on other atoms | $Cu_2S_1$ |
| Nothing to divide | $Cu_2S$ |

# Polyatomic Ions

- In previous slides, we saw cations/anions as single elements
- Here the anion is polyatomic. The method still applies. Note how parentheses are placed around the polyatomic (an)ion to treat it as an ionic group

- calcium nitrate

| | |
|---|---|
| What is cation and anion? | $Ca^{2+}$, $NO_3^-$ |
| Exchange charge magnitudes to be subscripts on other atoms | $Ca_1(NO_3)_2$ |
| Nothing to divide | $Ca(NO_3)_2$ |

# Polyatomic Ions

- potassium sulfate

| | |
|---|---|
| What is cation and anion? | $K^+$, $SO_4^{2-}$ |
| Exchange charge magnitudes to be subscripts on other atoms | $K_2(SO_4)_1$ |
| Nothing to divide | $K_2SO_4$ |

- In the calcium nitrate, we have TWO nitrates, so we had to use parentheses in final formula to show the group and add the subscript 2
- If there is only 1 polyatomic ion group, we don't need parentheses

# Predicting Cation or Anion

- Table group and number of electrons in valence shell are connected: Group 1 – 1 valence electron, Group 2 – 2 valence electrons, and so on
- This helps you predict whether an atom wants to get rid of acquire electrons!

*Groups 3-12 have variable charge, except those shown below*

| 1 | 2 | 3–10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|
| $H^+$ | | | | | | | | | | |
| $Li^+$ | $Be^{2+}$ | | | | $B^{3+}$ | | $N^{3-}$ | $O^{2-}$ | $F^-$ | |
| $Na^+$ | $Mg^{2+}$ | | | | $Al^{3+}$ | | $P^{3-}$ | $S^{2-}$ | $Cl^-$ | |
| $K^+$ | $Ca^{2+}$ | | | $Zn^{2+}$ | $Ga^{3+}$ | | $As^{3-}$ | $Se^{2-}$ | $Br^-$ | |
| $Rb^+$ | $Sr^{2+}$ | | $Ag^+$ | $Cd^{2+}$ | $In^{3+}$ | | | $Te^{2-}$ | $I^-$ | |

Figure 4.5.1.3: Predicting Ionic Charges. The charge that an atom acquires when it becomes an ion is related to the structure of the periodic table. Within a group (family) of elements, atoms form ions of a certain charge.

# Ionic or Not Ionic?

- Is the cation a metal and anion a nonmetal?
  - Likely ionic
- Are all the atoms in the molecule/compound nonmetallic elements?
  - Likely not ionic
- Is there a polyatomic group that you recognize as ionic?
  - Ammonium ($NH_4^+$) cation
  - Nitrate ($NO_3^-$) anion
  - This automatically makes this type of compound ionic

# Ionic or Not Ionic?

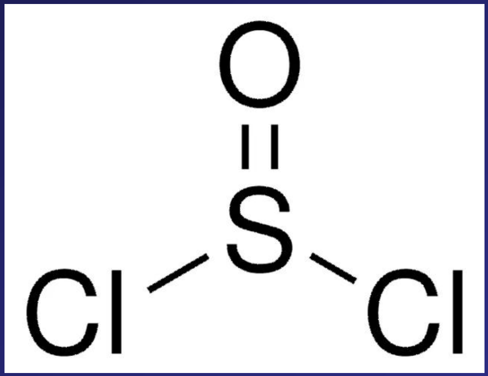
Identify each compound as ionic or not ionic.

a. $N_2O$

b. $FeCl_3$

c. $(NH_4)_3PO_4$

d. $SOCl_2$




- A) nitrogen (N) and oxygen (O) atoms nonmetals:
  *not ionic*
  B) iron (Fe) = metal, chlorine (Cl) = nonmetal:
  *ionic*
- C) ammonium ($NH_4$) = recognized polyatomic cation, phosphate = recognized polyatomic anion
  *ionic*
- D) S, O, and Cl are all non-metals, and no recognized polyatomic ions seen *not ionic*

Thionyl chloride (structure above) is used in organic chemistry to chlorinate compounds

# Polyatomic vs Molecular Ion

***Extra stuff: no need to memorize***

- When atoms are bonded together, that looks like a molecule, right?
- But chemists have a certain terminology here when it comes to polyatomic vs molecular ions
- Methane ($CH_4$) is normally not an ionized molecule. But it can be if one uses high energy to knock an electron out. This is an unstable ion formation
- In polyatomic ions, these are ionized as part of a stable state, and they remained ionized

# Naming Tips/Mnemonics

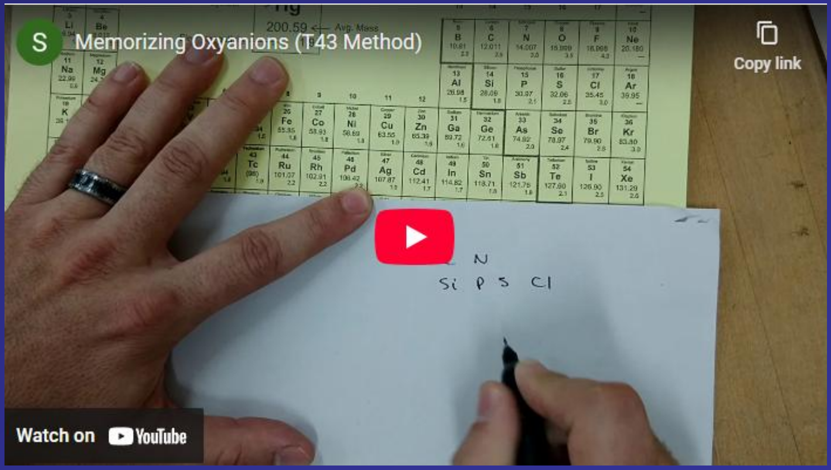
### Mnemonic Tip for Naming

Think of it like a ladder of oxygen content:

- **Hypo-** = lowest
- **-ite** = low
- **-ate** = high
- **Per-** = highest

And for acids:

- **-ous acid** = from -ite
- **-ic acid** = from -ate

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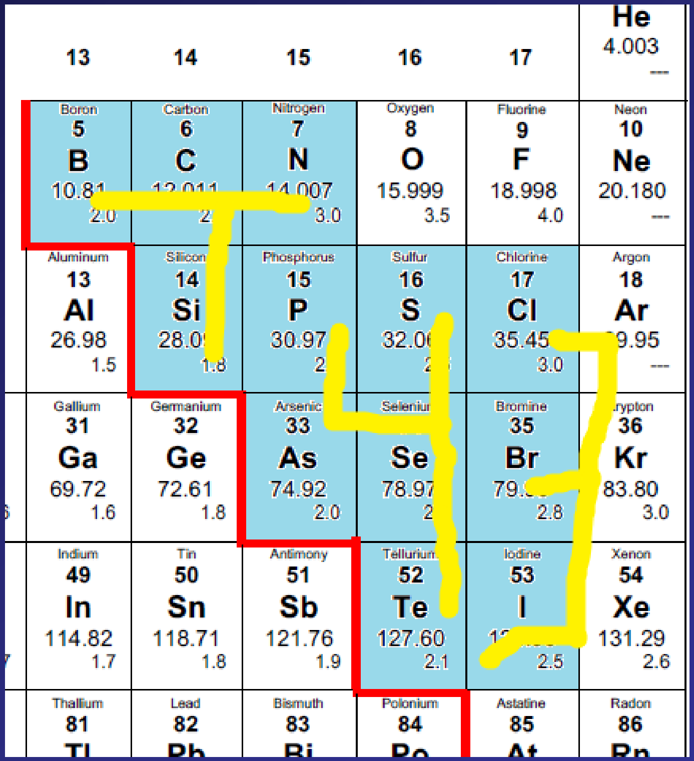
# T43 Method

- T: B, C, N, Si
- 4: P, S, As, Se, Te
- 3: Cl, Br, I




Oxygens:

4: $PO_4$, $SO_4$, $AsO_4$, $SeO_4$, $TeO_4$

3: $ClO_3$, $BrO_3$, $IO_3$

T: $BO_3$, $CO_3$, $NO_3$, $SiO_3$

Charged:

3-> (-1): $ClO_3^-$, $BrO_3^-$, $IO_3^-$

4-> (-2): $PO_4^{2-}$, $SO_4^{2-}$, $AsO_4^{2-}$, $SeO_4^{2-}$, $TeO_4^{2-}$

T: $BO_3^{3-}$, $CO_3^{2-}$, $SiO_3^{2-}$, $NO_3^{1-}$

(start from N [1-], then C and Si [both 2-], then B [3-])

# Chemistry Nomenclature: Naming of Compounds

- Some history
  Lavoisier (1787) publishes
  "New Chemical Nomenclature"
- Now done by IUPAC
  International Union of Pure and Applied Chemists
  The Red Book
- https://iupac.org/what-we-do/books/redbook/

# Chemistry Nomenclature: Naming of Compounds

*Ionic compounds*

- Type I cations: charge does not vary

directly use element name

$Na^{+}$ → "sodium"
$Al^{3+}$ → "aluminum"

# Chemistry Nomenclature: Naming of Compounds

*Binary ionic compounds*

Combine Type I monoatomic cation name with monoatomic anion

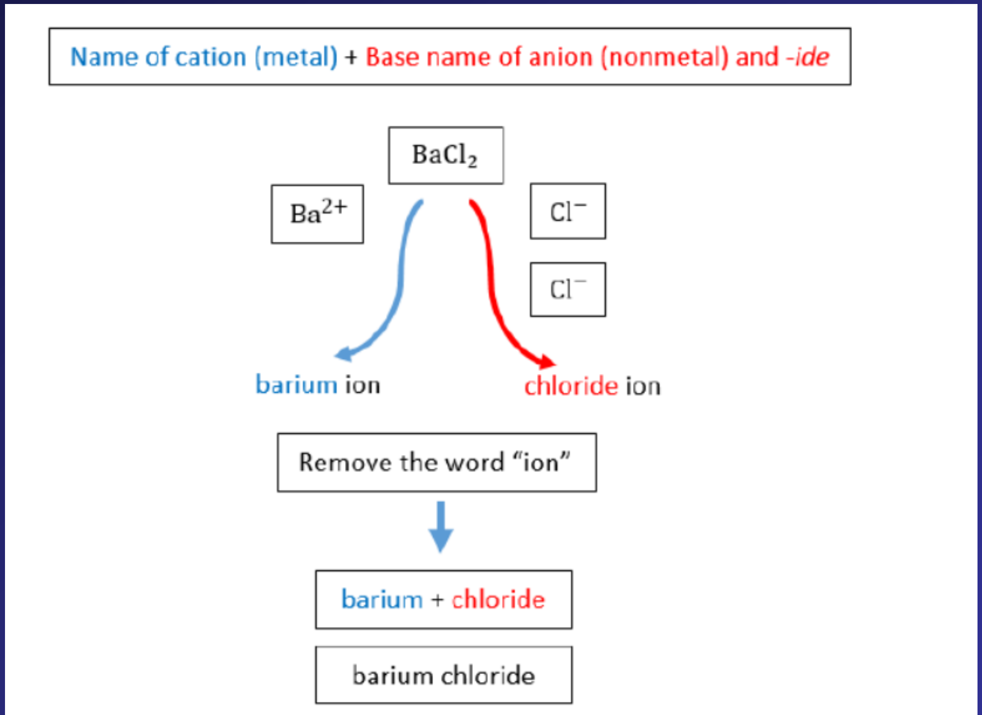



Figure 4.6.1.1: Naming $BaCl_2$
Naming formula: Name of metal cation + base name of nonmetal anion + suffix -ide. BaCl2 is named as barium chloride.

# Chemistry Nomenclature: Naming of Compounds

*Ionic compounds*

Type II cations: charge of element will vary use the Stock system

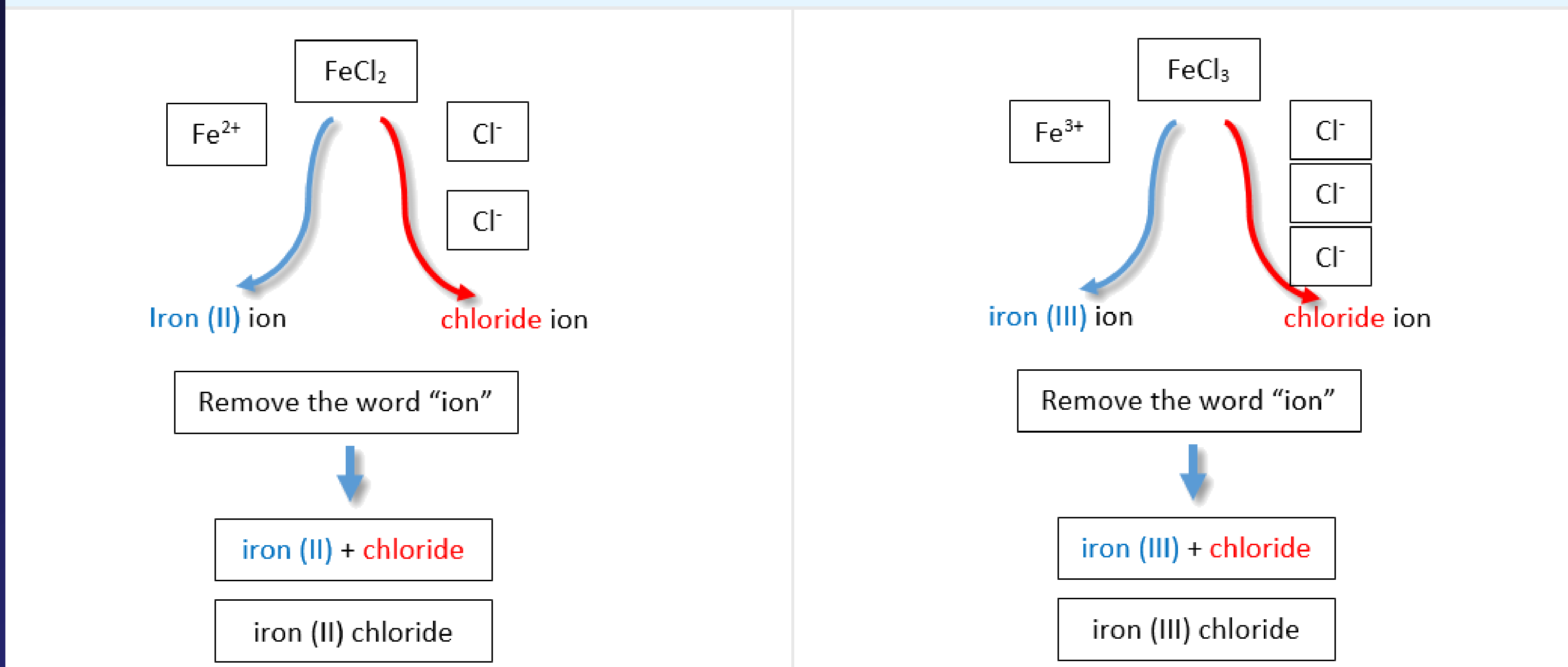
| Element | Charge | Name |
|---|---|---|
| iron | 2+ | iron(II) ion |
| | 3+ | iron(III) ion |
| copper | 1+ | copper(I) ion |
| | 2+ | copper(II) ion |
| tin | 2+ | tin(II) ion |
| | 4+ | tin(IV) ion |
| lead | 2+ | lead(II) ion |
| | 4+ | lead(IV) ion |
| chromium | 2+ | chromium(II) ion |
| | 3+ | chromium(III) ion |
| gold | 1+ | gold(I) ion |
| | 3+ | gold(III) ion |

# Chemistry Nomenclature: Naming of Compounds

- Combine Type II cation name using Stock roman numerals with the anion name

Table 4.6.1.3: Naming the $FeCl_2$ and $FeCl_3$ Compounds in the Modern/Stock System.

**Name of cation (metal) + (Roman Numeral in parenthesis) + Base name of anion (nonmetal) and *-ide***



# Chemistry Nomenclature: Naming of Compounds

## *Ionic compounds*

### Monoatomic Anions

Table 4.6.1.2: Some Monatomic Anions

| Ion | Name |
|---|---|
| $F^-$ | fluoride ion |
| $Cl^-$ | chloride ion |
| $Br^-$ | bromide ion |
| $I^-$ | iodide ion |
| $O^{2-}$ | oxide ion |
| $S^{2-}$ | sulfide ion |
| $P^{3-}$ | phosphide ion |
| $N^{3-}$ | nitride ion |

# Chemistry Nomenclature: Naming of Compounds

- Combine polyatomic cation names with polyatomic anion names

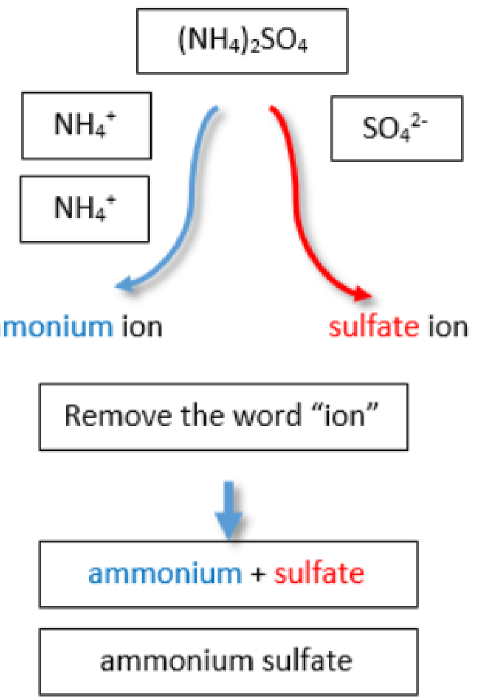



Figure 4.6.1.2: Naming Ionic Compounds with Polyatomic Ions

# Chemistry Nomenclature: Naming of Compounds

- Flowchart

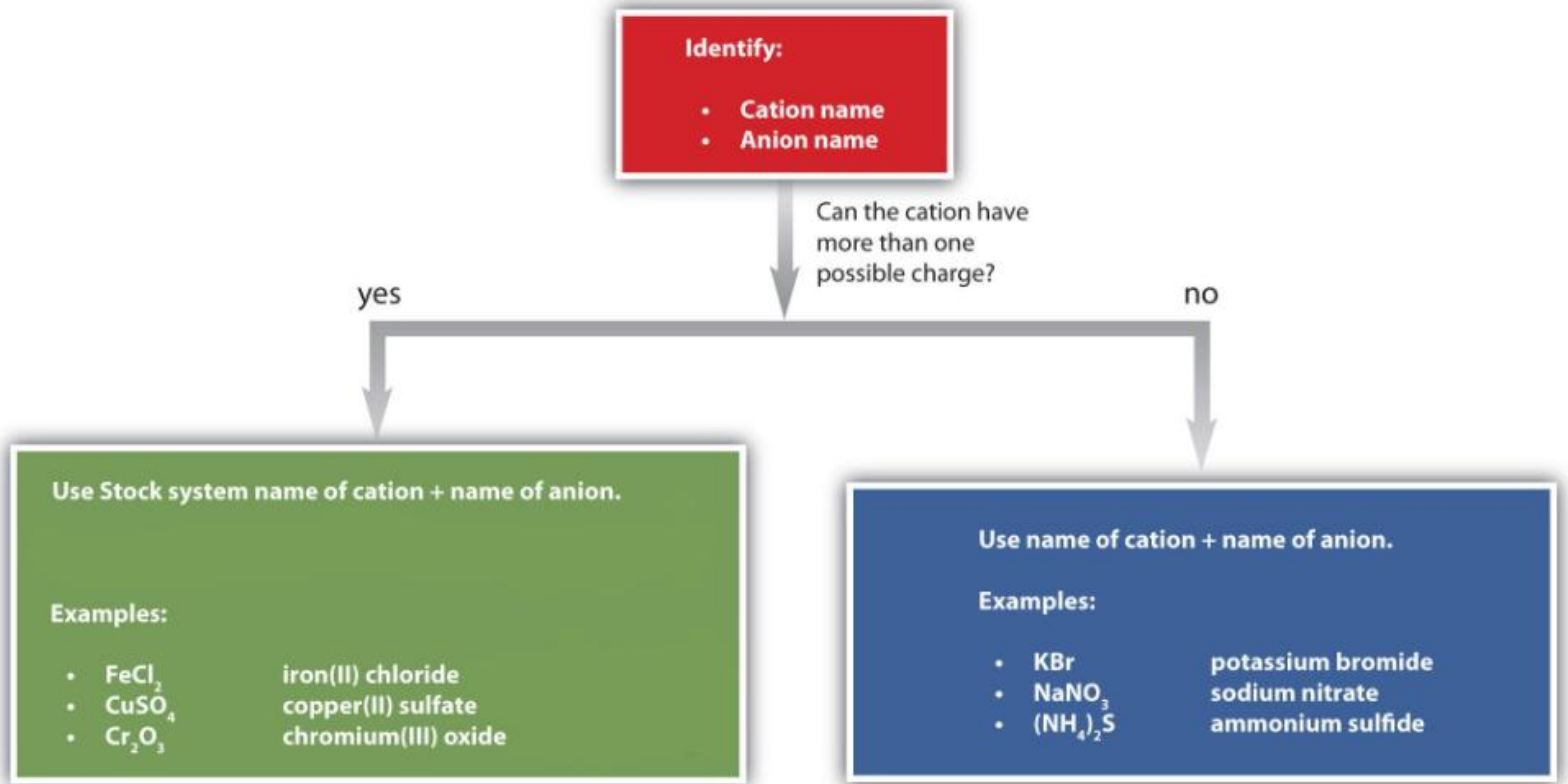



Figure 4.6.1.3: A Guide to Naming Simple Ionic Compounds.

# Chemistry Nomenclature: Naming of Compounds

- Zn = zinc, Br = bromine → bromide
  - Zn has only one ion ($Zn^{2+}$)

  "zinc bromide"
- Al = aluminum, O = oxygen → oxide
  - Al has only one ion ($Al^{3+}$)

  "aluminum oxide"
- $NH_4^+$ = ammonium, $PO_4$ = phosphate
  - Only one charge state for each

  "ammonium phosphate" (not "triammonium phosphate")
- Au = gold, F = fluorine → fluoride
  - Gold has multiple charge states

  "gold(III) fluoride"
- Ag = silver, F = fluorine → fluoride
  - Ag has only one ion ($Ag^+$)

  "silver fluoride"

a. $ZnBr_2$

b. $Al_2O_3$

c. $(NH_4)_3PO_4$

d. $AuF_3$

e. $AgF$

# Polyatomic Ions

- Ions not necessarily a charge on a single atom of an element
- They can be a group of atoms bonded together that form natural (stable) ions

| Selected Common Polyatomic Ions | | | | | |
|---|---|---|---|---|---|
| **Formula** | **Name** | **Formula** | **Name** | **Formula** | **Name** |
| $H_3O^+$ | hydronium | $NH_4^+$ | ammonium | $Hg_2^{2+}$ | mercury(I) |
| $OH^-$ | hydroxide | $CN^-$ | cyanide | $O_2^{2-}$ | peroxide |
| $MnO_4^-$ | permanganate | $CrO_4^{2-}$ | chromate | $Cr_2O_7^{2-}$ | dichromate |
| $C_2O_4^{2-}$ | oxalate | $C_2H_3O_2^-$ or $CH_3COO^-$ | | acetate | |

# Polyatomic Ions

| Oxyanions Ending in “-ate” | | | | |
|---|---|---|---|---|
| borate, $BO_3^{3-}$ | carbonate, $CO_3^{2-}$ | nitrate, $NO_3^-$ | | |
| | silicate, $SiO_3^{2-}$ | phosphate, $PO_4^{3-}$ | sulfate, $SO_4^{2-}$ | chlorate, $ClO_3^-$ |
| | | arsenate, $AsO_4^{3-}$ | selenate, $SeO_4^{2-}$ | bromate, $BrO_3^-$ |
| | | | tellurate, $TeO_4^{2-}$ | iodate, $IO_3^-$ |

# Naming Oxyanions

- Without the $H^+$ (H+ makes an acid an acid)

**Oxyanions (without $H^+$)**

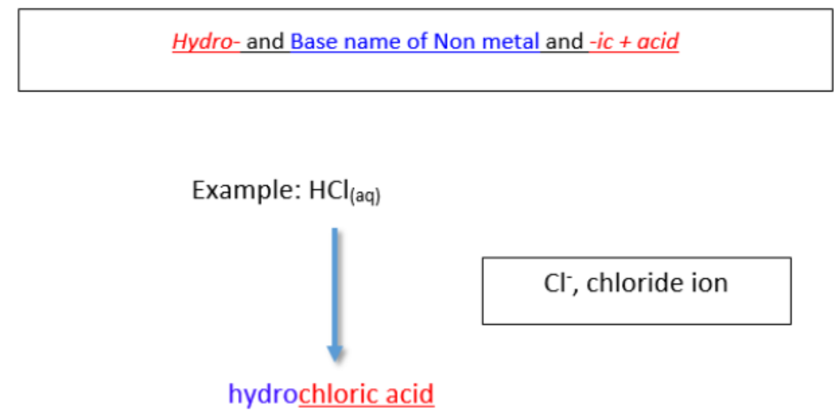
The naming pattern depends on the number of oxygen atoms:

| Oxygen Count | Prefix/Suffix | Example (Cl-based) |
|---|---|---|
| 1 fewer than -ite | **hypo-...-ite** | hypochlorite ($ClO^-$) |
| Base level | **-ite** | chlorite ($ClO_2^-$) |
| 1 more than -ite | **-ate** | chlorate ($ClO_3^-$) |
| 1 more than -ate | **per-...-ate** | perchlorate ($ClO_4^-$) |

| Naming Rules for Oxyanions (keep charges the same as -ate): | | Examples |
|---|---|---|
| per- | one more oxygen (than -ate) | perchlorate, $ClO_4^-$ |
| -ite | one less oxygen (than -ate) | chlorite, $ClO_2^-$ |
| hypo- | one less oxygen (than -ite) | hypochlorite, $ClO^-$ |
| thio- | replace one oxygen with one sulfur | thiosulfate, $S_2O_3^{2-}$ |

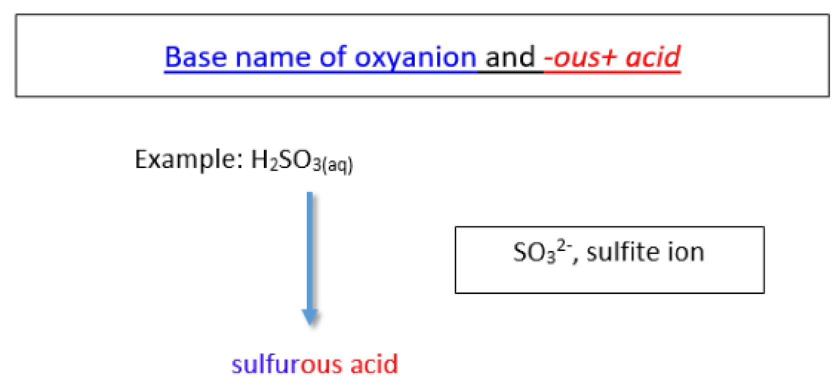
# Acid Naming

- We will learn more about acids later and the importance of the proton (the hydrogen atom without its electron) in making acids




Formula for naming acids: Hydro- and Base name of nonmetal and -ic + acid. Example: HCl is hydrochloric acid.

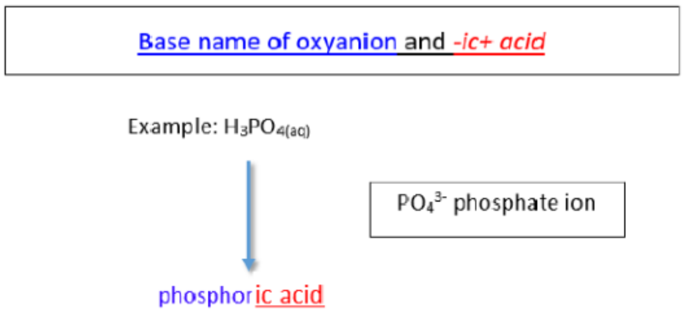
But learn the names NOW. Testing will be later



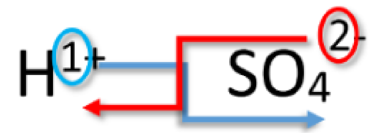

Formula for naming oxyanions with -ite ending: Base name of oxyanion and -ous + acid. Example: H2SO3 is sulfurous acid.

# Acid Naming

We will come back to this in learning about acids and bases, and you being tested on this.




Formula for naming oxyanions with -ate ending: Base name of oxyanion and -ic + acid. Example: H3PO4 is phosphoric acid.




H2SO4: H has +1 charge and SO4 has -2 charge, so there must be 2 H+ and 1 SO4 for the charges to balance out.

Formula: $H_2SO_4$

***Figure* 4.6.3.2:** *Crisscross approach to writing formula for sulfuric acid.*

# Naming Oxyacids

**Oxyacids (with $H^+$)**

When hydrogen is added to form the acid, the name changes:

| Oxyanion | Acid Name |
|---|---|
| hypochlorite ($ClO^-$) | **hypochlorous acid** |
| chlorite ($ClO_2^-$) | **chlorous acid** |
| chlorate ($ClO_3^-$) | **chloric acid** |
| perchlorate ($ClO_4^-$) | **perchloric acid** |

The suffix **-ous** corresponds to **-ite**, and **-ic** corresponds to **-ate**.

| **Naming Rules for Adding Hydrogens to Oxyanion** (the charges change): | | **Examples** |
|---|---|---|
| 0 $H^+$ | Normal anion name | phosphate, $PO_4^{3-}$ |
| 1 $H^+$ | Add hydrogen as prefix (charge reduced by 1) | hydrogenphosphate, $HPO_4^{2-}$ |
| 2 $H^+$ | Add dihydrogen as prefix (charge reduced by 1) | dihydrogenphosphate, $H_2PO_4^-$ |

# Molecular Compound Naming

- Molecular compounds are inorganic compounds that take form of discrete **molecules**
  - The bonds are shared between atoms (not ionic)
  - Shared bonds are covalent bonds

  - In carbon dioxide, the bond between the central carbon and two oxygen atoms on either side are shared (no "ionic character")

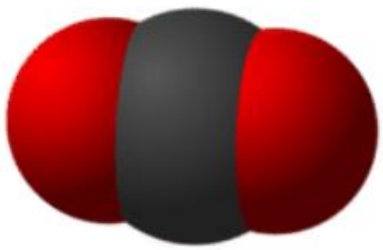


Figure 4.6.2.1: Carbon dioxide molecules consist of a central carbon atom bonded to 2 oxygen atoms.

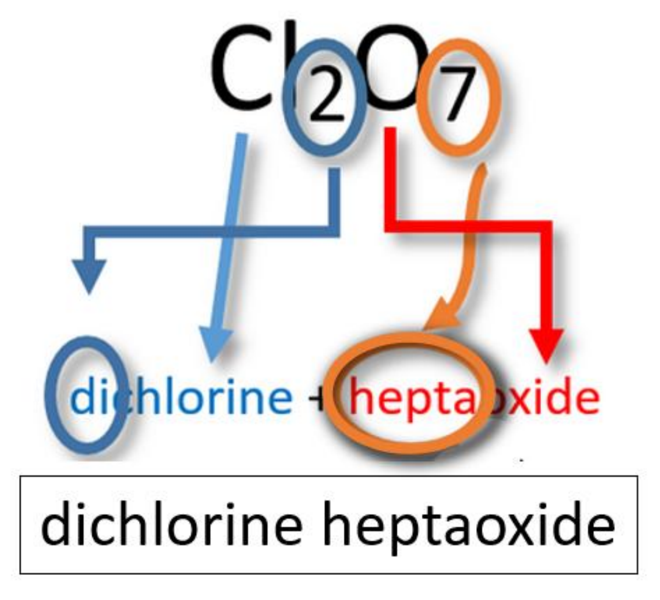
# Molecular Compound Naming

- Binary Molecular Compounds
- 1st element: name of element
- 2nd element: stem of element name + **-ide**
- Prefixes: apply numerical prefixes to both elements

Table 4.6.2.1: Numerical Prefixes for Naming Binary Covalent Compounds

| Number of Atoms in Compound | Prefix on the Name of the Element |
|---|---|
| 1 | mono-* |
| 2 | di- |
| 3 | tri- |
| 4 | tetra- |
| 5 | penta- |
| 6 | hexa- |
| 7 | hepta- |
| 8 | octa- |
| 9 | nona- |
| 10 | deca- |

*May be omitted for the first element's name.



# Molecular Compound Naming

## Common Name Compounds

A systematic name not really used

- $H_2O$: water
- $NH_3$: ammonia
- $CH_4$: methane
- $H_2O_2$: hydrogen peroxide

# Tying It Together