Chapter 2b
Atoms, Molecules, and Ions

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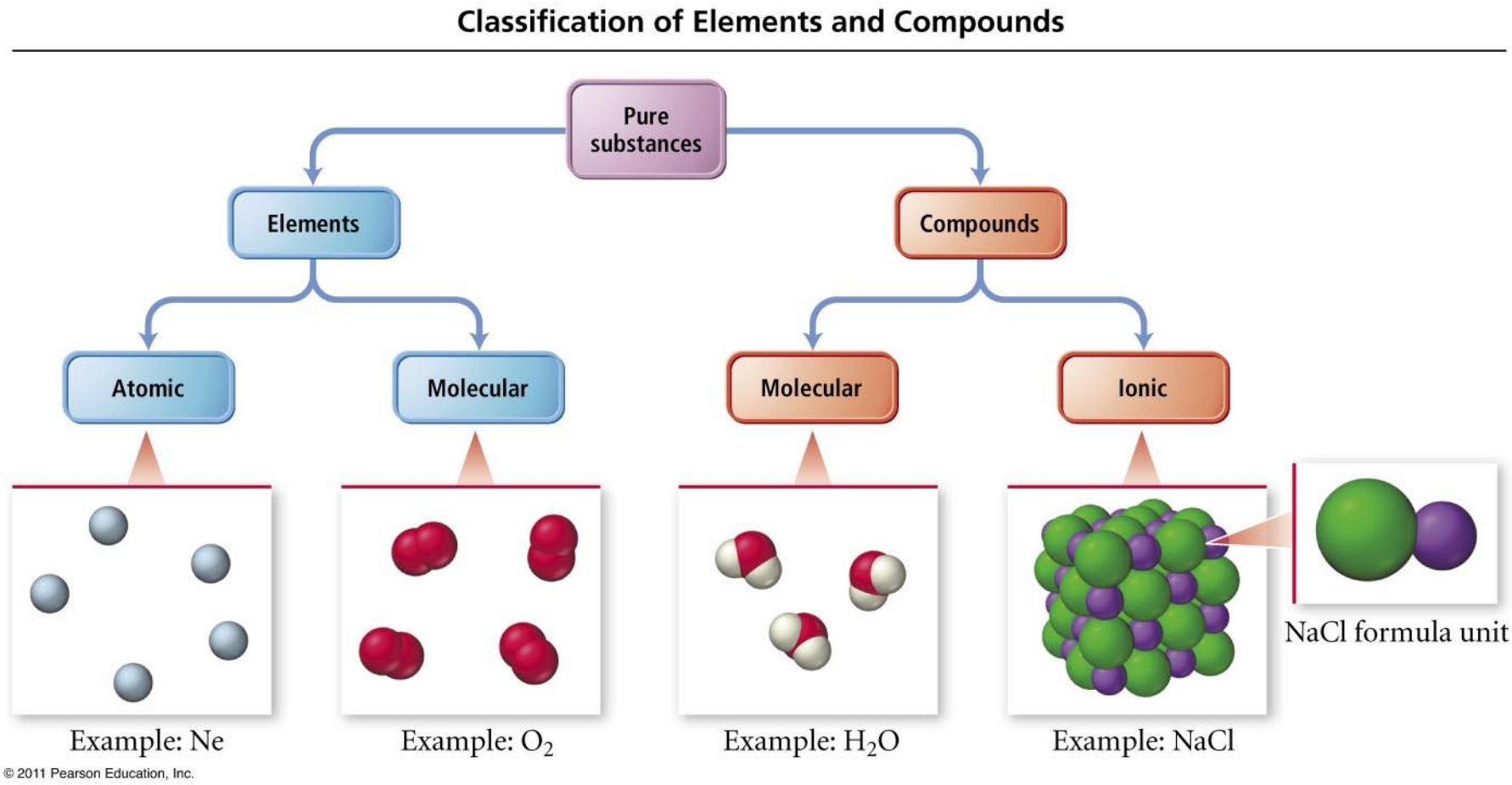
Elements and Compounds in Our World



Elements

Elements can be present as the following forms:

Free element (Atomic) : He, Ne, Ar….

Diatomic molecules: O_2, N_2, F_2……

Polyatomic molecules: P_4, S_8

Compounds

- **Ionic compounds** are composed of ions arranged in a 3-dimensional pattern
  - each cation is surrounded by anions, and vice-versa
  - Consisting of metal and nometal
  - Use only empirical formula (NaCl, KCl, etc)

- **Molecular compounds** are composed of individual molecule units
  - Each molecule contains atoms of different elements chemically attached by covalent bonds
  - Consisting of nonmetals
  - Use molecular formula (H_2O, $C_6H_{12}O_6$, etc)

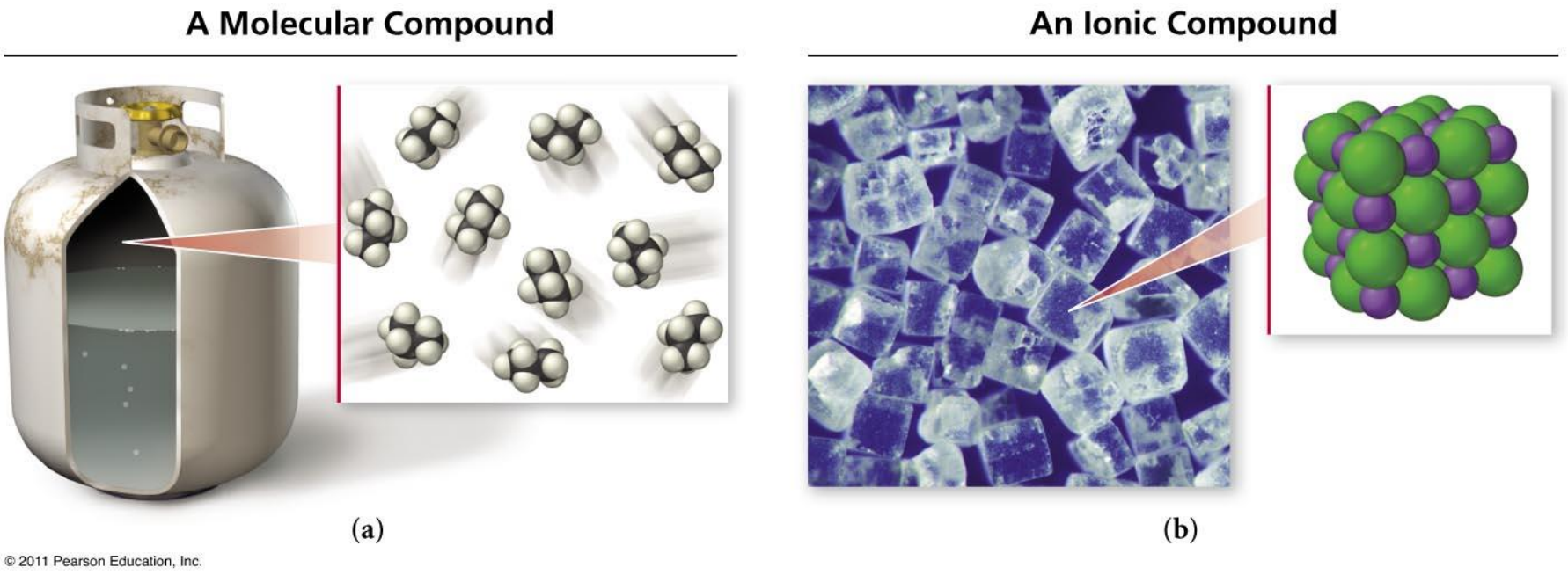
Chemical Bonds

- Compounds are made of atoms held together by chemical bonds

- **Ionic compounds via Ionic bonds:** oppositely charged ions that attract each other
  - Between metal atoms and nonmetal atoms (NaCl, MgO, etc)

- **Molecular compounds via covalent bonds**: two atoms share some of their electrons
  - Between nonmetal atoms (H_2O, CO, etc)

Ionic vs. Molecular Compounds



Propane – contains individual C_3H_8 molecules

Table salt – contains an array of Na^+ ions and Cl^- ions

Classify Each of the Following as Either an Atomic Element, Molecular Element, Molecular Compound, or Ionic Compound

Aluminum, Al

Aluminum chloride, $AlCl_3$

Chlorine, Cl_2

Acetone, C_3H_6O

Carbon monoxide, CO

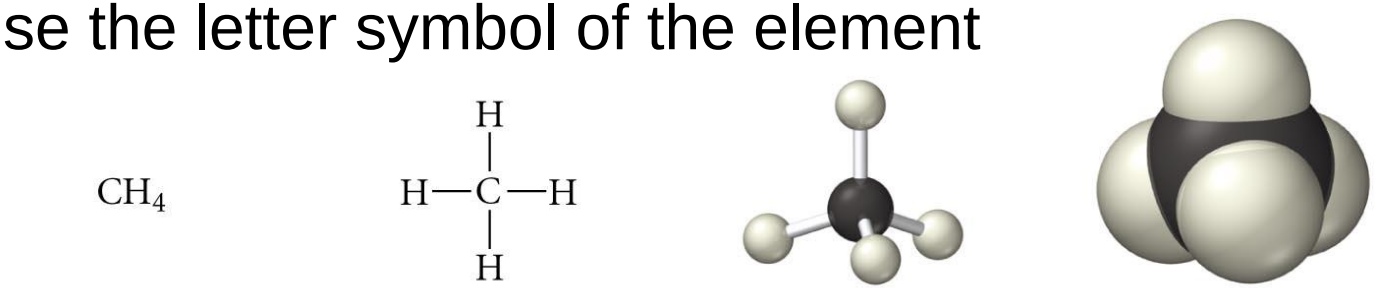
Cobalt, Co

Ex. 01 Element or compound

- He
- Ne
- K
- I_2
- NaCl
- $C_6H_{12}O_6$
- S_4

Representing Compounds with Chemical Formula

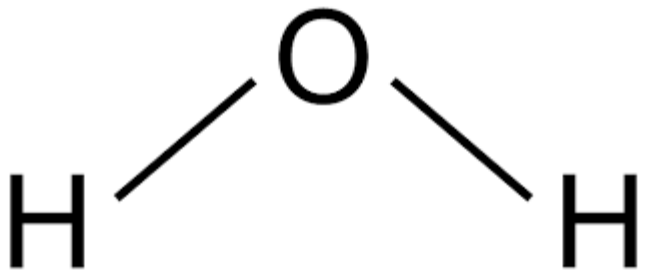
- Compounds are generally represented with a **chemical formula**
- The amount of information about the structure of the compound varies with the type of formula
  - all formula and models convey a limited amount of information – none are perfect representations
- All chemical formulas tell what elements are in the compound
  - use the letter symbol of the element



Molecular formula | Structural formula | Ball-and-stick model | Space-filling model

Types of Formula

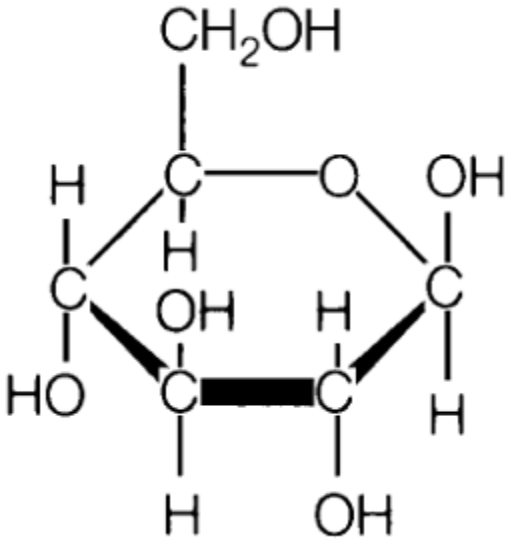
- An **empirical formula** gives the *relative number of atoms of each element* in a compound (NaCl, etc)
- A **molecular formula** gives the *actual number of atoms of each* element in a molecule compound
  - it does not describe the order of attachment, or the shape
  - H_2O
  - Structural formula



Types of Formula

- Glucose
- 12 H atoms, 6 O atoms, 6 C atoms in a molecule
- Molecular formula: $C_6H_{12}O_6$ (no further structural information, etc)
- Empirical formula: CH_2O (the ratio of C, H, and O atom in a molecule is 1:2:1)

Structural formula

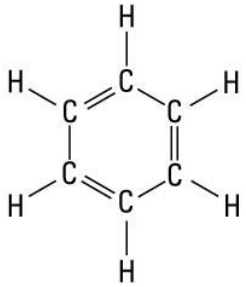
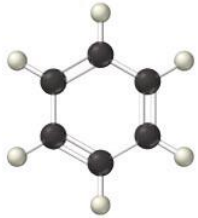
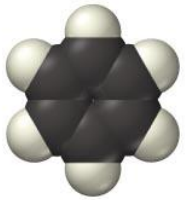
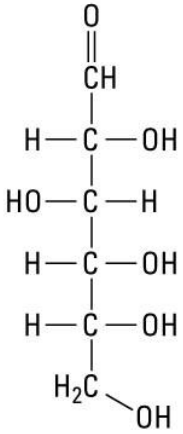
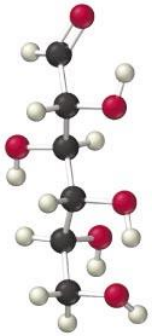
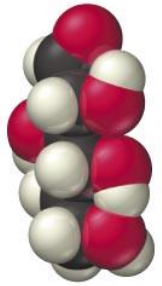
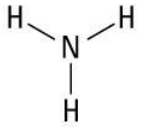


Examples

- Write empirical formulas for the following compounds

- C_4H_8
- B_2H_6
- CCl_4
- $C_4H_8O_4$

TABLE 3.1 Benzene, Acetylene, Glucose, and Ammonia

Name of Compound	Empirical Formula	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
Benzene	CH	C_6H_6			
Acetylene	CH	C_2H_2			
Glucose	CH_2O	$C_6H_{12}O_6$			
Ammonia	NH_3	NH_3			

Ionic Compounds

- total 0 charge
- Na^{+} and S^{2-} >>> Na_2S

Write a formula for ionic compound that forms between calcium and oxygen

Writing Formulas for Ionic Compounds

1. Write the symbol for the metal cation and its charge
2. Write the symbol for the nonmetal anion and its charge
3. Charge (without sign) becomes subscript for other ion
4. Reduce subscripts to smallest whole number ratio
5. Check that the sum of the charges of the cations cancels the sum of the anions

Write the formula of a compound made from aluminum ions and oxide ions

Practice — What are the formulas for compounds made from the following ions?

- Potassium ion with a nitride ion
- Calcium ion with a bromide ion
- Aluminum ion with a sulfide ion

Formula-to-Name
Rules for Ionic Compounds

- Made of cation and anion
- Write systematic name by simply naming the ions
  - ✓ if cation is:
    - ➢ metal with invariant charge = metal name
    - ➢ metal with variable charge = metal name(charge)
    - ➢ polyatomic ion = name of polyatomic ion
  - ✓ if anion is:
    - ➢ nonmetal = stem of nonmetal name + ide
    - ➢ polyatomic ion = name of polyatomic ion

Naming Metal Cations

- Metals with invariant charge
  - metals whose ions can only have one possible charge
    - Groups $1A^{1+}$ & $2A^{2+}$, Al^{3+}, Ag^{1+}, Zn^{2+}, Sc^{3+}
  - cation name = metal name

TABLE 3.2 Metals Whose Charge Is Invariant from One Compound to Another

Metal	Ion	Name	Group Number
Li	Li^+	Lithium	1A
Na	Na^+	Sodium	1A
K	K^+	Potassium	1A
Rb	Rb^+	Rubidium	1A
Cs	Cs^+	Cesium	1A
Be	Be^{2+}	Beryllium	2A
Mg	Mg^{2+}	Magnesium	2A
Ca	Ca^{2+}	Calcium	2A
Sr	Sr^{2+}	Strontium	2A
Ba	Ba^{2+}	Barium	2A
Al	Al^{3+}	Aluminum	3A
Zn	Zn^{2+}	Zinc	*
Sc	Sc^{3+}	Scandium	*
Ag**	Ag^+	Silver	*

*The charge of these metals cannot be inferred from their group number.
**Silver sometimes forms compounds with other charges, but these are rare.

Naming Metal Cations

- Metals with variable Charges (transition metals)
  - ✓ metals whose ions can have more than one possible charge
  - ✓ determine charge by charge on anion and cation
  - ✓ name = metal name with Roman numeral charge in parentheses

TABLE 3.4 Some Metals That Form Cations with Different Charges

Metal	Ion	Name	Older Name*
Chromium	Cr^{2+}	Chromium(II)	Chromous
	Cr^{3+}	Chromium(III)	Chromic
Iron	Fe^{2+}	Iron(II)	Ferrous
	Fe^{3+}	Iron(III)	Ferric
Cobalt	Co^{2+}	Cobalt(II)	Cobaltous
	Co^{3+}	Cobalt(III)	Cobaltic
Copper	Cu^{+}	Copper(I)	Cuprous
	Cu^{2+}	Copper(II)	Cupric
Tin	Sn^{2+}	Tin(II)	Stannous
	Sn^{4+}	Tin(IV)	Stannic
Mercury	Hg_2^{2+}	Mercury(I)	Mercurous
	Hg^{2+}	Mercury(II)	Mercuric
Lead	Pb^{2+}	Lead(II)	Plumbous
	Pb^{4+}	Lead(IV)	Plumbic

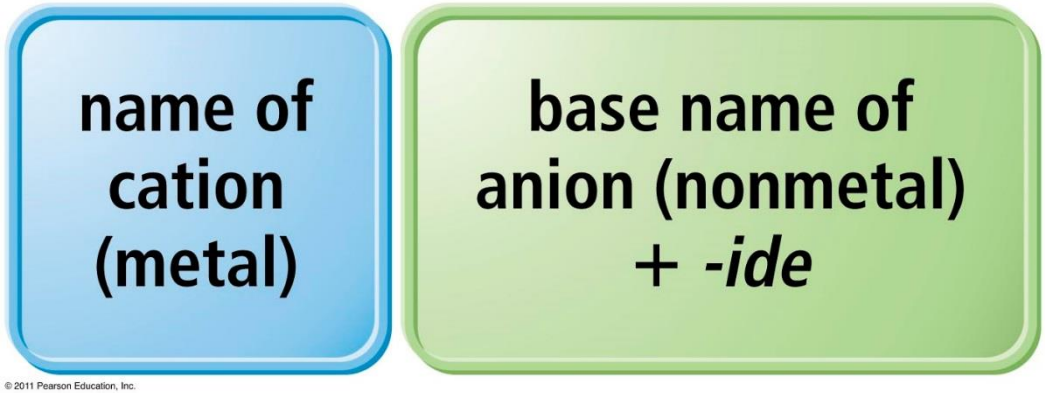
*An older naming system substitutes the names found in this column for the name of the metal and its charge. Under this system, chromium(II) oxide is named chromous oxide. In this system, the suffix *-ous* indicates the ion with the lesser charge and *-ic* indicates the ion with the greater charge. We will *not* use the older system in this text.

Naming Monatomic Nonmetal Anion

- Determine the charge from position on the Periodic Table
- To name anion, change ending on the element name to ***–ide***

4A = 4–	5A = 3–	6A = 2–	7A = 1–
C = carbide	N = nitride	O = oxide	F = fluoride
Si = silicide	P = phosphide	S = sulfide	Cl = chloride

Naming Binary (Two) Ionic Compounds for Metals with Invariant Charge



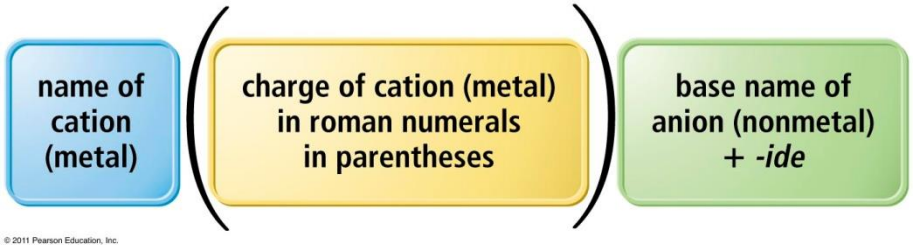
NaCl: sodium chloride

Al_2O_3: aluminum oxide

Practice — Name the following compounds

1. KCl
2. $MgBr_2$
3. Al_2S_3

Naming Binary Ionic Compounds for Metals with Variable Charge



Fe_2O_3: Iron(III) oxide

How do I know the charge of Fe is +3?

Find the charge on the cation

1. $TiCl_4$
2. CrO_3
3. Fe_3N_2

Example: Naming binary ionic with variable charge metal, CuF_2

1. Identify cation and anion

   F = F^- because it is Group 7

   Cu = Cu^{2+} to balance the two (−) charges from 2 F^-

2. Name the cation

   Cu^{2+} = copper(II)

3. Name the anion

   F^- = fluoride

4. Write the cation name first, then the anion name

   copper(II) fluoride

Name the following compounds

1. $TiCl_4$
2. $PbBr_2$
3. Fe_2S_3

Example: Writing formula for binary ionic compounds containing variable charge metal

manganese(IV) sulfide

Practice — What are the formulas for compounds made from the following ions?

copper(II) ion with a nitride ion

iron(III) ion with a bromide ion

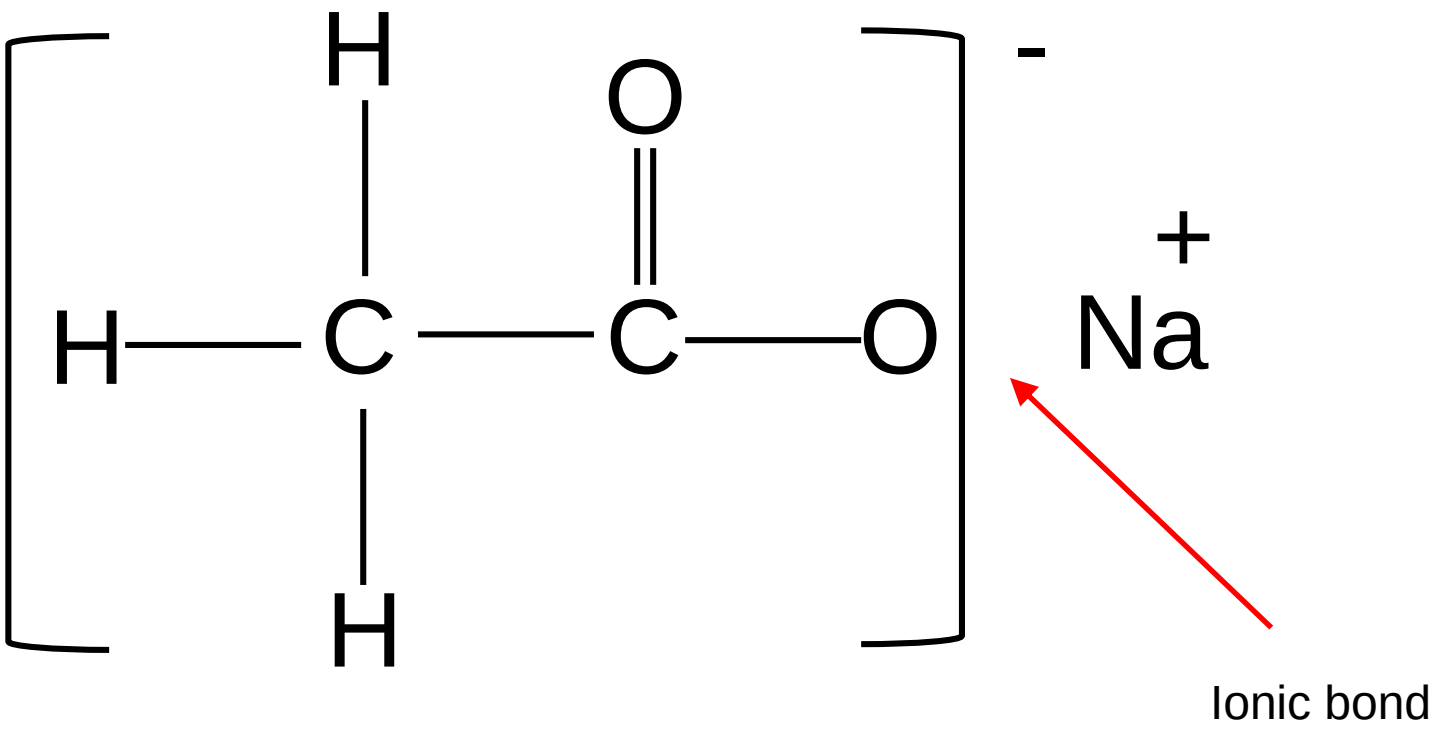
Some Common Polyatomic Ions (formed by covalent bonds)

Name	Formula
acetate	$C_2H_3O_2^-$
carbonate	CO_3^{2-}
hydrogen carbonate (aka bicarbonate)	HCO_3^-
hydroxide	OH^-
nitrate	NO_3^-
nitrite	NO_2^-
chromate	CrO_4^{2-}
dichromate	$Cr_2O_7^{2-}$
ammonium	NH_4^+

Name	Formula
hypochlorite	ClO^-
chlorite	ClO_2^-
chlorate	ClO_3^-
perchlorate	ClO_4^-
sulfate	SO_4^{2-}
sulfite	SO_3^{2-}
hydrogen sulfate (aka bisulfate)	HSO_4^-
hydrogen sulfite (aka bisulfite)	HSO_3^-

Structure of Polyatomic Ions

CH_3COONa: sodium acetate



Compounds Containing Polyatomic Ions

- $NaNO_2$: Sodium nitrite
- $FeSO_4$: Iron(II) sulfate
- NH_4NO_3: Ammonium nitrate

Example – Writing formula for ionic compounds containing polyatomic ion

Iron(III) phosphate

Practice — What are the formulas for compounds made from the following ions?

aluminum ion with a sulfate ion

chromium(II) with hydrogen carbonate

Hydrates

- Hydrates are ionic compounds containing a number of water molecules for each formula unit
- Water molecules are physically attached not chemically bonded
- Water of hydration often "driven off" by heating
- In formula, attached waters follow ·
  - ✓ $CoCl_2 \cdot 6H_2O$
- In name attached waters indicated by prefix+***hydrate*** after name of ionic compound
  - ✓ $CoCl_2 \cdot 6H_2O$ = cobalt(II) chloride hexahydrate
  - ✓ $CaSO_4 \cdot ½H_2O$ = calcium sulfate hemihydrate

Prefix	No. of Waters
hemi	½
mono	1
di	2
tri	3
tetra	4
penta	5
hexa	6
hepta	7
octa	8

Cobalt(II) chloride hexahydrate

Hydrate

Anhydrous

$CoCl_2 \cdot 6H_2O$

$CoCl_2$

Moisture Indicator

Practice

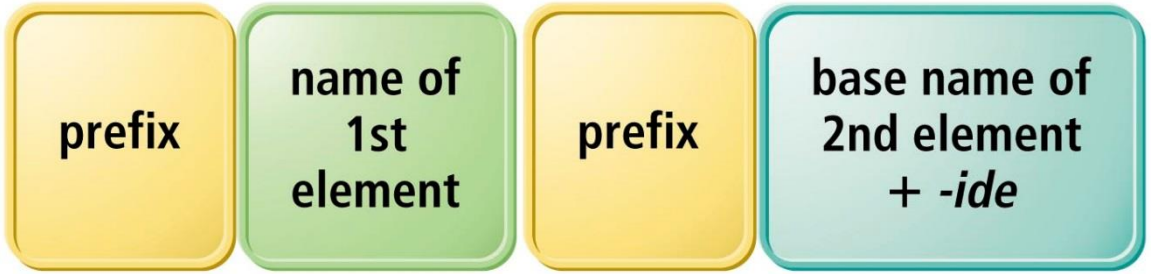
What is the formula of

magnesium sulfate heptahydrate?

What is the name of $NiCl_2 \cdot 6H_2O$?

Writing Names of Binary Molecular Compounds of Two Nonmetals

1. Write name of first element in formula
   a) element furthest left and down on the Periodic Table
   b) use the full name of the element
2. Writes name the second element in the formula with an -**ide** suffix
   a) as if it were an anion, *however, remember these compounds do not contain ions*!
3. Use a prefix in front of each name to indicate the number of atoms
   a) Never use the prefix ***mono-*** on the first element



Subscript – Prefixes

- 1 = mono-
  - ✓ not used on first nonmetal
- 2 = di-
- 3 = tri-
- 4 = tetra-
- 5 = penta-
- 6 = hexa-
- 7 = hepta-
- 8 = octa-
- 9 = nona-
- 10 = deca-

- Drop last “a” if name begins with a vowel

Example: Naming Binary Molecular BF_3

Name the Following

NO_2

PCl_5

I_2F_7

Example: Binary Molecular

dinitrogen pentoxide

Write Formulas for the Following

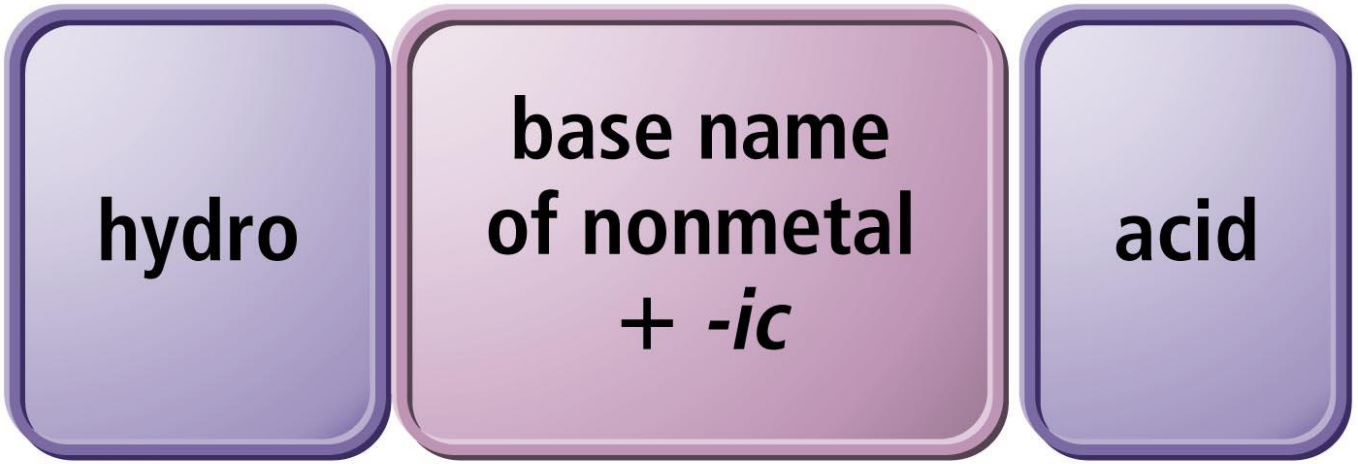
dinitrogen tetroxide

sulfur hexafluoride

diarsenic trisulfide

Naming Binary Acids

- Write a **hydro** prefix
- Follow with the nonmetal name
- Change ending on nonmetal name to *–ic*
- Write the word **acid** at the end of the name



Names of Binary Acids

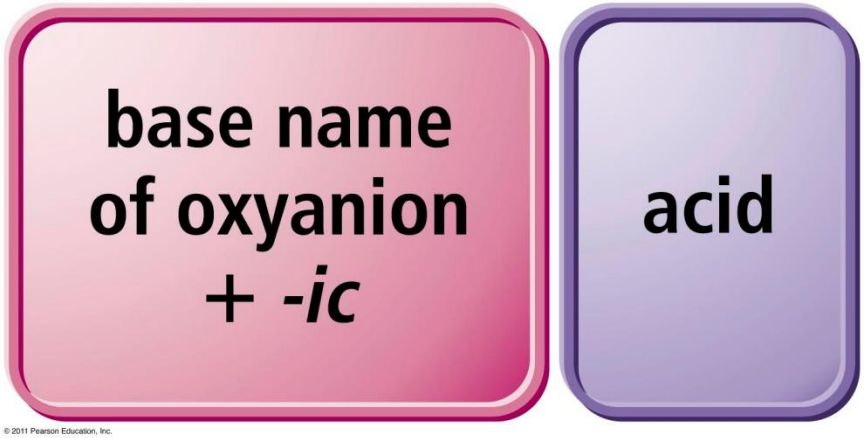
HF(aq) - hydrofluoric acid
HCl(aq) - hydrochloric acid
HBr(aq) - hydrobromic acid
HI(aq) - hydriodic acid
H_2S(aq) - hydrosulfuric acid

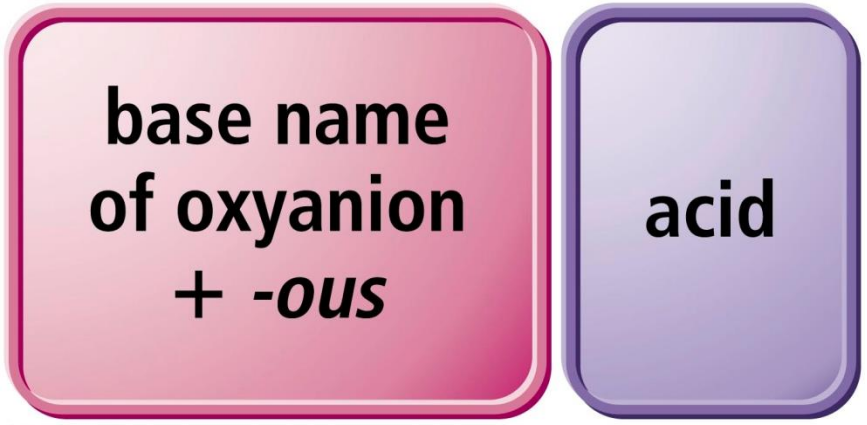
HCl: Hydrogen chloride (this is gas)

HCl (aq): hydrochloric acid formed by dissolving HCl in water

Naming Oxyacids

- If polyatomic ion name ends in *–ate*, then change ending to *–ic* suffix
- If polyatomic ion name ends in *–ite*, then change ending to *–ous* suffix
- Write word **acid** at end of all names





Names of Oxyacids

NO_3^- is nitrate, and HNO_3 is nitric acid.
NO_2^- is nitrite, and HNO_2 is nitrous acid.
$C_2H_3O_2^-$ is acetate, and $HC_2H_3O_2$ is acetic acid.
SO_4^{2-} is sulfate, and H_2SO_4 is sulfuric acid.
SO_3^{2-} is sulfite, and H_2SO_3 is sulfurous acid.
CO_3^{2-} is carbonate, and H_2CO_3 is carbonic acid.
PO_4^{3-} is phosphate, and H_3PO_4 is phosphoric acid.

Homework

HW Chapter 2: will be announced