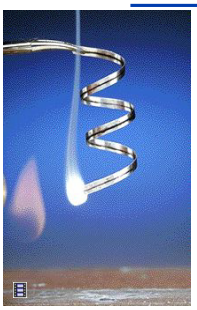
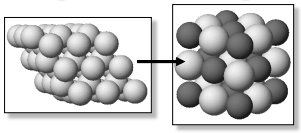
1

Counting Atoms



Mg burns in air (O_2) to produce white magnesium oxide, MgO.



How can we figure out how much oxide is produced from a given mass of Mg?

*

Syllabus Learning Outcomes : 5, 6, 7

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2

Counting Atoms

Chemistry is a quantitative science—we need a "counting unit."

MOLE

1 mole is the amount of substance that contains as many particles (atoms, molecules) as there are in exactly 12g of ^{12}C.

518 g of Pb, 2.50 mol

3

Particles in a Mole

Avogadro's Number

Amedeo Avogadro
1776-1856

$6.02214199 \times 10^{23}$

There is Avogadro's number of particles in a mole of any substance.

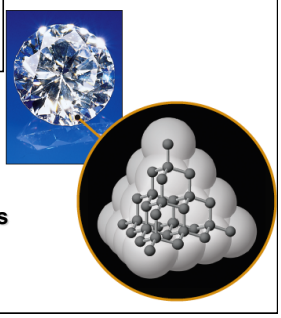
4

Molar Mass

1.000 mol of ^{12}C = 12.00 g of ^{12}C = 6.022×10^{23} atoms of ^{12}C

12.00 g of ^{12}C is its MOLAR MASS

Taking into account all of the isotopes of C, the molar mass of C is 12.011 g/mol



5

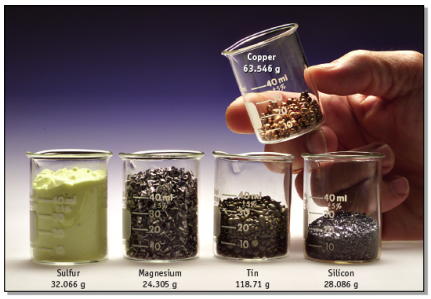
Atomic Mass & Molar Mass

- Atomic Mass (u) - mass of one atom of an element relative to one atom of another element (^{12}C) in atomic mass units.

- Molar Mass (g/mol) – mass in grams of 1 mole of atoms. Given on periodic table

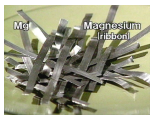
6

One-mole Amounts



These are molar masses

7



PROBLEM: 0.200 g of Mg is what amount in mol? in atoms?

Mg has a molar mass of 24.305 g/mol.

$$0.200\,\text{g} \bullet \frac{1\,\text{mol}}{24.305\,\text{g}} = 8.23 \times 10^{-3}\,\text{mol}$$

How many atoms in 0.200g of Mg?

$$8.23 \times 10^{-3}\ \text{mol} \cdot \frac{6.022 \times 10^{23}\ \text{atoms}}{1\ \text{mol}}$$

= 4.95×10^{21} atoms Mg

8

Summary

- Convert back and forth between number of atoms and moles of an element (Avogadro's Number)
- Convert from moles of an element to grams using the molar mass (g/mol) from the Periodic Table.
- Calculate the mass (g) of one average atom.

9

Laws of Chemical Combination

- Law of Conservation of Mass
  - The total mass remains constant during a chemical reaction.
- Law of Definite Proportions
  - All samples of a compound have the same composition, or …
  - All samples have the same proportions, by mass, of the elements present.
- Law of Multiple Proportions
  - When two or more different compounds of the same two elements are compared, the *masses* of one element that combine with a fixed mass of the second element are in the ratio of small *whole* numbers.

10

Mass is not the same as weight

- *Molecular mass*: sum of the masses of the atoms in a molecular formula in atomic mass units (u).
- Molecular mass is specifically for *molecules.*
- Ionic compounds don't exist as molecules; for them we use …
- *Formula mass*: sum of the masses of the atoms or ions present in a *formula unit* in u.
- ***Molar mass***: mass of 1 mole of molecules, atoms, or particles in grams (or grams/mol).

Terms frequently misused.

11

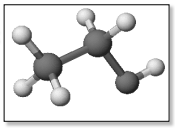
Molecular mass / molar mass

Molecular mass = sum of the atomic masses of all atoms in the molecule.

Molar mass = mass in grams of 1 mole of molecules, atoms, or particles

12

Find the molar mass of ethanol, C_2H_6O



1 mol C_2H_6O contains

2 mol C (12.011 g C/1 mol C) = 24.022 g C

6 mol H (1.008 g H/1 mol H) = 6.048 g H

1 mol O (15.999 g O/1 mol O) = 15.999 g O

TOTAL = molar mass = 46.069 g/mol

Calculate molar mass using all digits. Report correct SD for problem.

13

Molecular and empirical formulas

- A *molecule* is a group of two or more atoms held together by *covalent bonds*.
- A *molecular formula* gives the number of each kind of atom in a molecule.
- An *empirical formula* gives the simplest (whole number) *ratio* of atoms of elements in a compound.

Compound	*Molecular formula*	*Empirical formula*
Hydrogen peroxide	H_2O_2	HO
Octane	C_8H_{18}	????

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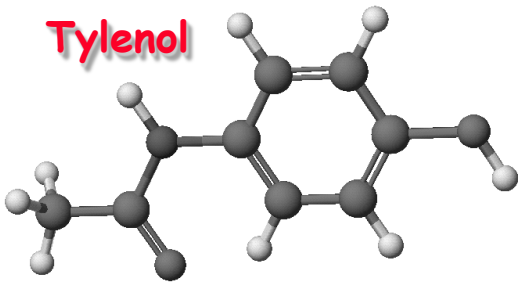
Tylenol



- Formula = $C_8H_9NO_2$
- Molar mass = 151.2 g/mol

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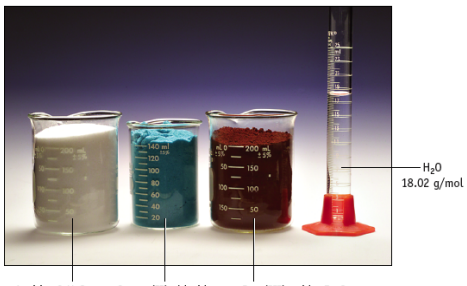
Calculate Molar Masses at Home



Count species

16

How many moles of alcohol are there in a "standard" can of beer if there are 21.3 g of C_2H_6O?

(a) Molar mass of C_2H_6O = 46.069 g/mol

(b) Calc. moles of alcohol

$$21.3\ \text{g} \cdot \frac{1\ \text{mol}}{46.069\ \text{g}} = 0.462\ \text{mol}$$

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How many molecules of alcohol are there in a "standard" can of beer if there are 21.3 g of C_2H_6O?

We know there are 0.462 mol of C_2H_6O.

$$0.462\ \text{mol} \cdot \frac{6.022 \times 10^{23}\ \text{molecules}}{1\ \text{mol}}$$

$$= 2.78 \times 10^{23}\ \text{molecules}$$

18

How many atoms of C are there in a "standard" can of beer if there are 21.3 g of C_2H_6O?

There are 2.78×10^{23} molecules.

Each molecule contains 2 C atoms.

Therefore, the number of C atoms is

$$2.78 \times 10^{23}\ \text{molecules} \cdot \frac{2\ \text{C atoms}}{1\ \text{molecule}}$$

$$= 5.56 \times 10^{23}\ \text{C atoms}$$

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Summary

- Calculate molar mass of a molecule using the periodic table.
- Convert between mass in grams for a molecule and number of molecules in moles using the molar mass of a molecule.
- Convert between moles and number of molecules using Avogadro's Number.
- Calculate the number of any particular atoms in a molecule using the chemical formula
- Define molecular and empirical formulas

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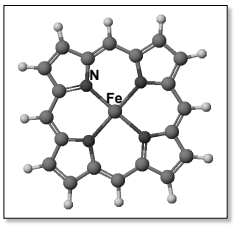
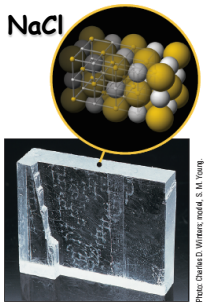
Molecular & Ionic Compounds

Heme



NaCl



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Ions are atoms or groups of atoms with a charge

- When a metal reacts with a nonmetal, ions form.
- Ions arrange in a network called a crystal lattice.

22

Ionic compounds are made of ions

- Ionic compounds are called salts.
- Usually contain a metal and a nonmetal
- Tend to have high melting points
- Tend to be hard solids and be crystalline
- Can be cleaved along a sharp boundary by causing breakage along the crystal lattice

23

Define Cations and Anions

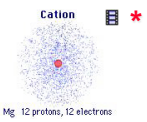
- Taking away an electron from an atom gives a CATION with a positive charge
- Adding an electron to an atom gives an ANION with a negative charge.

24

Forming Cations & Anions

metals *nonmetals*

A CATION forms when an atom loses one or more electrons.



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

An ANION forms when an atom gains one or more electrons

$F + e^- \rightarrow F^-$

25

PREDICTING ION CHARGES

In general

- **metals (Mg)** lose electrons → **cations**
- **nonmetals (F)** gain electrons → **anions**

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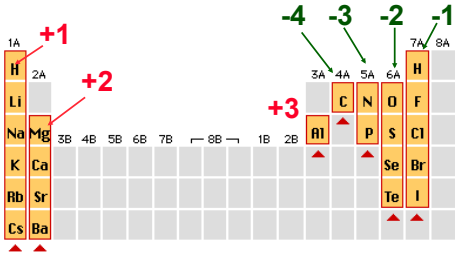
Charges on Common Ions



By losing or gaining e-, atom has same number of e-'s as nearest Group 8A atom.

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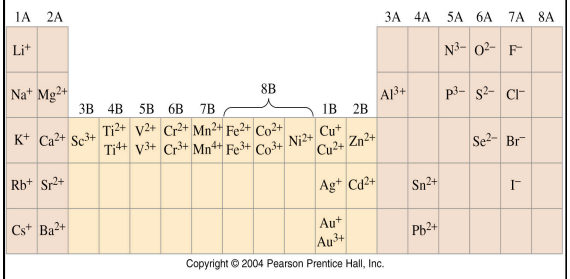
Predicting Charges on Monatomic Ions



28

Predicting Charges on Monatomic Ions

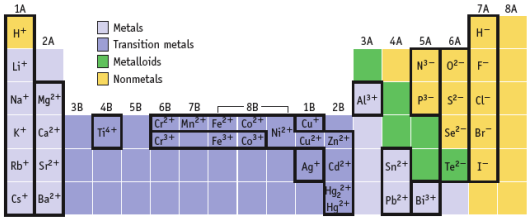


Figure 3.7 **Charges on some common monatomic cations and anions.** Metals usually form cations and nonmetals usually form anions. (The boxed areas show ions of identical charge.)

9

Naming Metal Ions

M → n e⁻ + M^{n+}

where n = Group A number

Na^+ **sodium ion**

Mg^{2+} **magnesium ion**

Al^{3+} **aluminum ion**

Except name tin and lead ions as below

Transition metals use **Stock system**

Fe^{2+} **iron(II) ion**

Fe^{3+} **iron(III) ion**

Except name Ag^+, Zn^{2+}, Cd^{2+} as above

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Naming Nonmetal Ions

NONMETAL + n e⁻ → X^{n-}
where n = 8 - Group A number

Group 4A	Group 5A	Group 6A	Group 7A
C^{4-},carbide	N^{3-}, nitride	O^{2-}, oxide	F^-, fluoride
		S^{2-}, sulfide	Cl^-, chloride
			Br^-, bromide
			I^-, iodide

Name derived by adding -ide to stem

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Table 2.4 Some Common Polyatomic Ions

Name	Formula	Typical Compound
Cation		
Ammonium ion	NH_4^+	NH_4Cl
Anions		
Acetate ion	$^aC_2H_3O_2^-$	$NaC_2H_3O_2$
Carbonate ion	CO_3^{2-}	Li_2CO_3
Hydrogen carbonate ion (or bicarbonate ion)[b]	HCO_3^-	$NaHCO_3$
Hypochlorite ion	ClO^-	$Ca(ClO)_2$
Chlorite ion	ClO_2^-	$NaClO_2$
Chlorate ion	ClO_3^-	$NaClO_3$
Perchlorate ion	ClO_4^-	$KClO_4$
Chromate ion	CrO_4^{2-}	K_2CrO_4
Dichromate ion	$Cr_2O_7^{2-}$	$(NH_4)_2Cr_2O_7$
Cyanate ion	OCN^-	$KOCN$
Thiocyanate ion[c]	SCN^-	$KSCN$
Cyanide ion	CN^-	KCN
Hydroxide ion	OH^-	$NaOH$
Nitrite ion	NO_2^-	$NaNO_2$
Nitrate ion	NO_3^-	$NaNO_3$
Oxalate ion	$C_2O_4^{2-}$	CaC_2O_4
Permanganate ion	MnO_4^-	$KMnO_4$
Phosphate ion	PO_4^{3-}	Na_3PO_4
Hydrogen phosphate ion	HPO_4^{2-}	Na_2HPO_4
Dihydrogen phosphate ion	$H_2PO_4^-$	NaH_2PO_4
Sulfite ion	SO_3^{2-}	Na_2SO_3
Hydrogen sulfite ion (or bisulfite ion)[b]	HSO_3^-	$NaHSO_3$
Sulfate ion	SO_4^{2-}	Na_2SO_4
Hydrogen sulfate ion (or bisulfate ion)[b]	HSO_4^-	$NaHSO_4$
Thiosulfate ion[c]	$S_2O_3^{2-}$	$Na_2S_2O_3$

[a] The acetate ion is also represented as CH_3COO^-. [b] The prefix "bi-" means that the ion contains a replaceable H atom. This should not be confused with the prefix "di-," which means two (usually used to represent a doubling of a simpler unit). [c] The prefix "thio-" means that a sulfur atom has replaced an oxygen atom.

Note: many O containing anions have names ending in –ate (or -ite).

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Naming Polyatomic Ions

- Sulfate
- Sulfite
- Nitrate
- Nitrite
- Phosphate
- Hydrogen phosphate
- Dihydrogen phosphate
- Hydroxide
- Cyanide
- Acetate
- Ammonium
- Hypochlorite
- Chlorite
- Chlorate
- Perchlorate

Use exam handout for your homework

Note: most oxygen-containing anions end in –ate (or -ite).

33

Writing Formulas of Compounds

- The total positive and negative charge must sum to zero (or to the charge on an ion).
- To write a proper formula, use the least common multiple or the crossover rule.
- The factors needed to balance the charge appear as subscripts in the formula.
- Use parentheses to group numbers of more than one polyatomic ion

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Writing Formulas and Naming Ionic Compounds

- Names of ionic compounds are built from the names of the positive and negative ions in the compound.
- The charge of elements that can have more than one charge is indicated with a Roman numeral in parentheses (Stock System).
- Be able to go back and forth between writing and naming compounds

$CaBr_2$

- When writing a formula, the total charge must add to the charge on the substance, which is often zero

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Naming Ionic Compounds

NH_4NO_3	ammonium nitrate
$CoSO_4$	Cobalt(II) sulfate
V_2O_3	Vanadium(III) oxide
$Ca(ClO)_2$	Calcium hypochlorite
$KMnO_4$	potassium permanganate
$(NH_4)_2S$	ammonium sulfide
$CuCl$	copper(I) chloride
$CuCl_2$	copper(II) chloride

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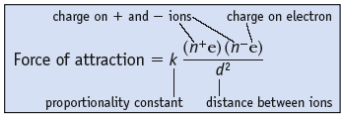
Electrostatic Forces

COULOMB'S LAW



As ion charge increases, the attractive force _____.

As the distance between ions increases, the attractive force _____.

This idea is important and will come up many times in future discussions!

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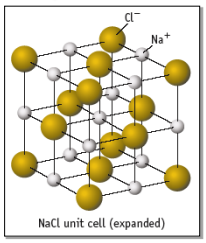
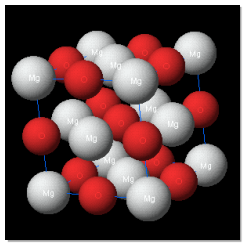
Importance of Coulomb's Law



NaCl, Na^+ and Cl^-, m.p. 804 °C



MgO, Mg^{2+} and O^{2-} m.p. 2800 °C

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Molecular Compounds

- Molecular compounds are molecules (not ions) because electrons are shared by nonmetals.
- Can be gases to liquids to solids at room temperature
- Larger and more complex molecules tend to be solids

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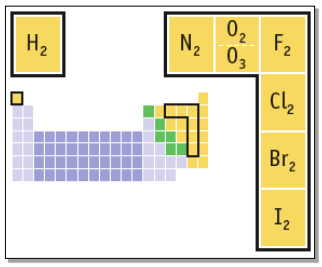
Compounds & Molecules

- **COMPOUNDS** are a combination of 2 or more elements in definite ratios by mass.
- The character of each element is lost when forming a compound.
- **MOLECULES** are the smallest unit of a compound that retains the characteristics of the compound.

40

ELEMENTS THAT EXIST AS DIATOMIC MOLECULES



H O N Cl Br I F

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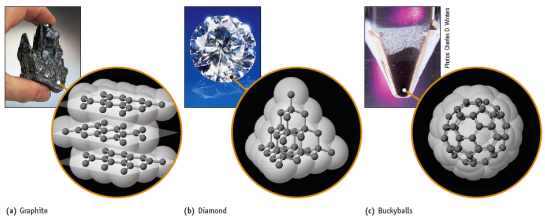
ELEMENTS THAT EXIST AS MOLECULES



Allotropes of C

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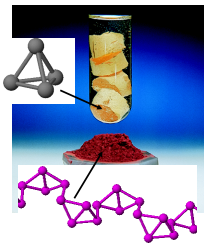
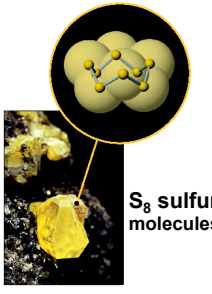
ELEMENTS THAT EXIST AS POLYATOMIC MOLECULES



White P_4 and polymeric red phosphorus



S_8 sulfur molecules

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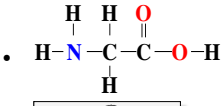
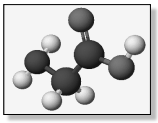
Write molecular formulas for glycine

- $C_2H_5NO_2$
- H_2NCH_2COOH
- 
- 

- One molecule contains
  - 2 C atoms
  - 5 H atoms
  - 1 N atom
  - 2 O atoms

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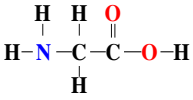
WRITING FORMULAS

- Can also write glycine formula as
  $-H_2NCH_2COOH$
  to show atom ordering
- or in the form of a **structural formula**



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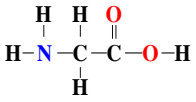
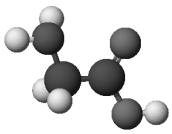
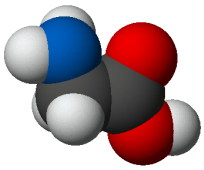
MOLECULAR MODELING



Structural formula of glycine



Ball & stick



Space-filling

Molecular Formula = $C_2H_5NO_2$

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Naming Molecular Compounds

- Binary compounds of hydrogen with oxygen, sulfur and the halogens (not aqueous):

HF

47

Naming Molecular Compounds

- For binary compounds for Groups 4A to 7A, write formulas with elements in order of increasing group number. Greek prefixes indicate numbers of atoms.

NF_3

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Naming Molecular Compounds

- For binary compounds for Groups 4A to 7A, write formulas with elements in order of increasing group number

CO_2 carbon dioxide
PI_3 phosphorous triiodide
SCl_2 sulfur dichloride
N_2F_4 dinitrogen tetrafluoride
P_4O_{10} tetraphosphorous decaoxide

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Naming Molecular Compounds

- Many binary compounds of nonmetals were discovered years ago and have common names

H_2O	water
NH_3	ammonia
CH_4	methane
C_2H_6	ethane
C_3H_8	propane
C_4H_{10}	butane
N_2H_4	hydrazine
PH_3	phosphine
NO	nitric oxide
N_2O	nitrous oxide

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Table 2.5 Formulas and Names of Some Common Acids and Their Salts

		Sodium Salt	
Formula of Acid	Name of Acid	Formula	Name
HCl	*Hydro*chlor*ic* acid	NaCl	Sodium chlor*ide*
HClO	*Hypo*chlor*ous* acid	NaClO	Sodium *hypo*chlor*ite*
$HClO_2$	Chlor*ous* acid	$NaClO_2$	Sodium chlor*ite*
$HClO_3$	Chlor*ic* acid	$NaClO_3$	Sodium chlor*ate*
$HClO_4$	*Per*chlor*ic* acid	$NaClO_4$	Sodium *per*chlor*ate*
H_2S	*Hydro*sulfur*ic* acid	Na_2S	Sodium sulf*ide*
H_2SO_3[a]	Sulfur*ous* acid	Na_2SO_3	Sodium sulf*ite*
H_2SO_4[a]	Sulfur*ic* acid	Na_2SO_4	Sodium sulf*ate*
HNO_2	Nitr*ous* acid	$NaNO_2$	Sodium nitr*ite*
HNO_3	Nitr*ic* acid	$NaNO_3$	Sodium nitr*ate*
H_3PO_4[a]	Phosphor*ic* acid	Na_3PO_4	Sodium phosph*ate*
H_2CO_3[a]	Carbon*ic* acid	Na_2CO_3	Sodium carbon*ate*

[a] Table 2.4 lists anions found in some salts of these acids in which not all of the available H atoms are replaced. If one or more H atoms remains unreplaced, formulas and names must be written accordingly; for example, $NaHSO_4$ is sodium hydrogen sulfate and NaH_2PO_4 is sodium dihydrogen phosphate.

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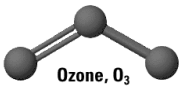
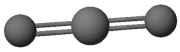
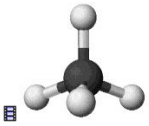
Molecular Compounds
Compounds without Ions



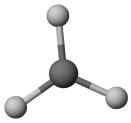
Ozone, O_3



CO_2 Carbon dioxide



CH_4 methane



BCl_3 boron trichloride

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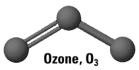
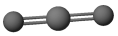
Naming Molecular Compounds



Ozone, O_3



CO_2 Carbon dioxide

All are formed from two or more nonmetals.

CH_4 methane

BCl_3
boron trichloride

Ionic compounds generally involve a metal and nonmetal (NaCl)

Naming Transition Metal Ions

- Most transition metals form more than one ion (Fe^{2+}, Fe^{3+}), so the Roman numeral is required for naming iron(II), iron(III).
- Common exceptions include Ag^+, Zn^{2+}, Cd^{2+}, which form only these ions, and Sn and Pb, non-transition metals which form multiple ions.

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End