Chapter 3 - Molecules, Compounds and Chemical Equations

Mixtures and Compounds

Hydrogen and Oxygen Mixture
Can have any ratio of hydrogen to oxygen.

Water (A Compound)
Water molecules have a fixed ratio of hydrogen (2 atoms) to oxygen (1 atom).

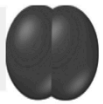
Selected Properties of Hydrogen

Boiling point, −253 °C

Gas at room temperature

Explosive

Selected Properties of Oxygen

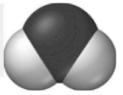


Boiling point, −183 °C

Gas at room temperature

Supports combustion

Selected Properties of Water



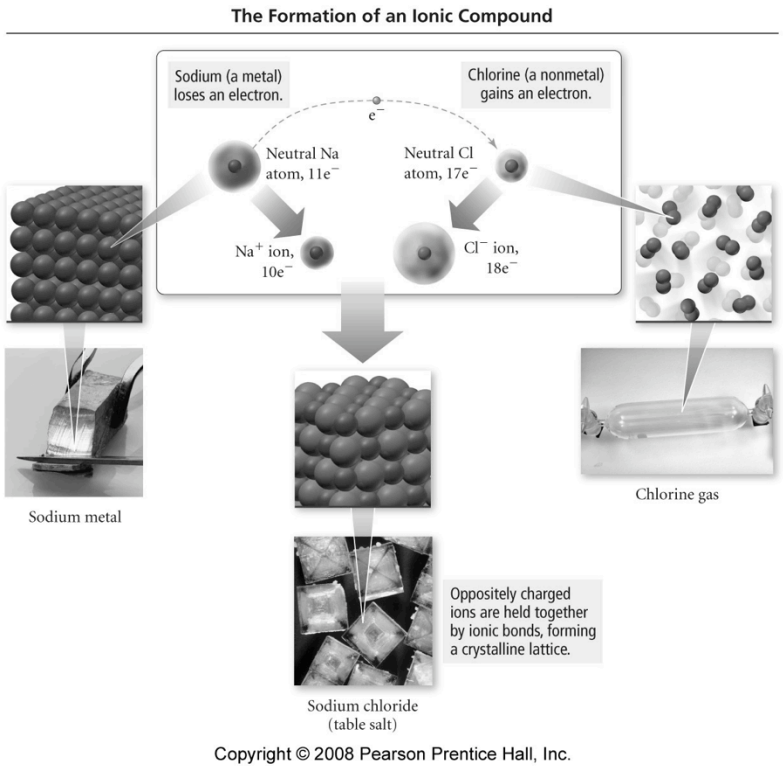
Boiling point, 100 °C

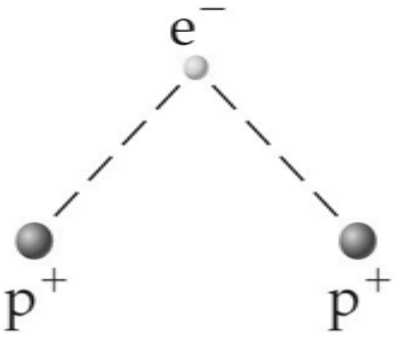
Liquid at room temperature

Used to extinguish flame

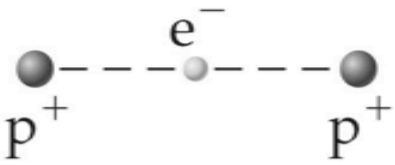
Section 3.2

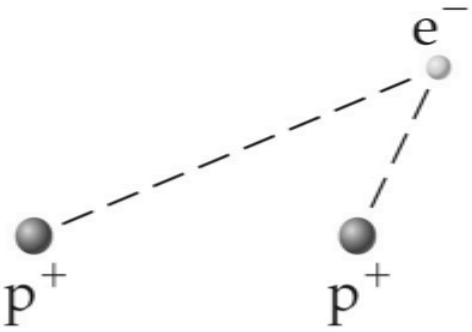
- two general types of bonding between atoms found in compounds, **ionic** and **covalent**
- **ionic bonds** result when electrons have been transferred between atoms, resulting in oppositely charged ions that attract each other
  - ✓generally found when metal atoms bonded to nonmetal atoms
- **covalent bonds** result when two atoms share some of their electrons
  - ✓generally found when nonmetal atoms bonded together





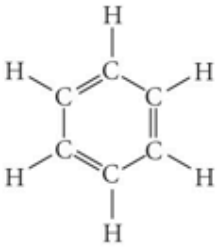
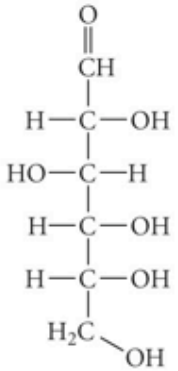
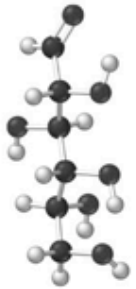
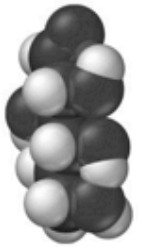
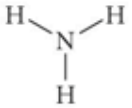
Lowest potential energy (most stable)





Section 3.3 - Chemical Formulas and Molecular Models

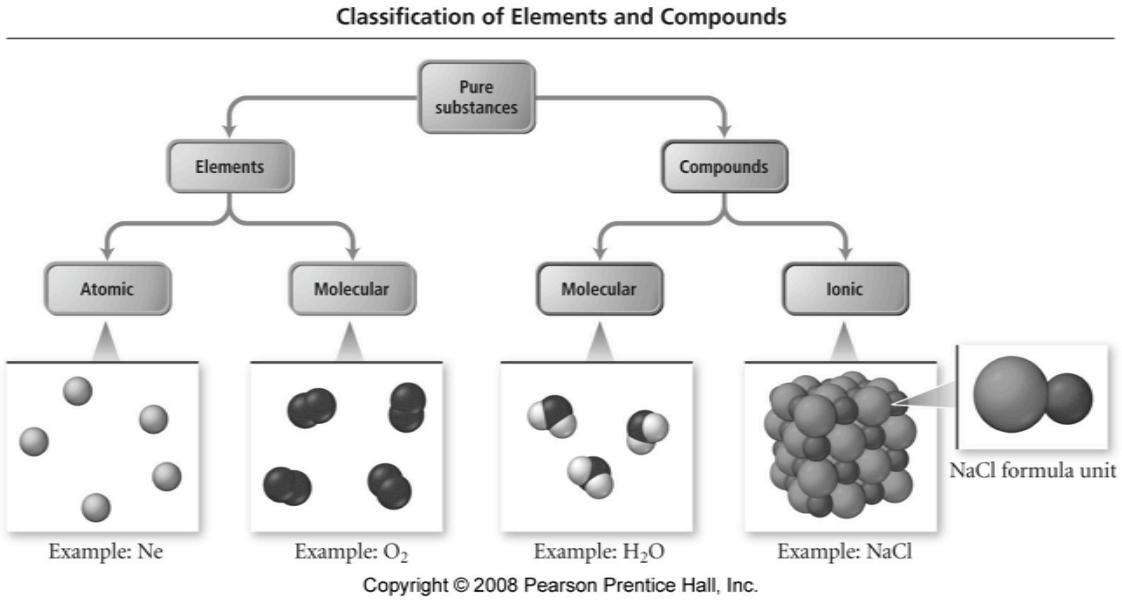
TABLE 3.1 **Benzene, Acetylene, Glucose, and Ammonia**

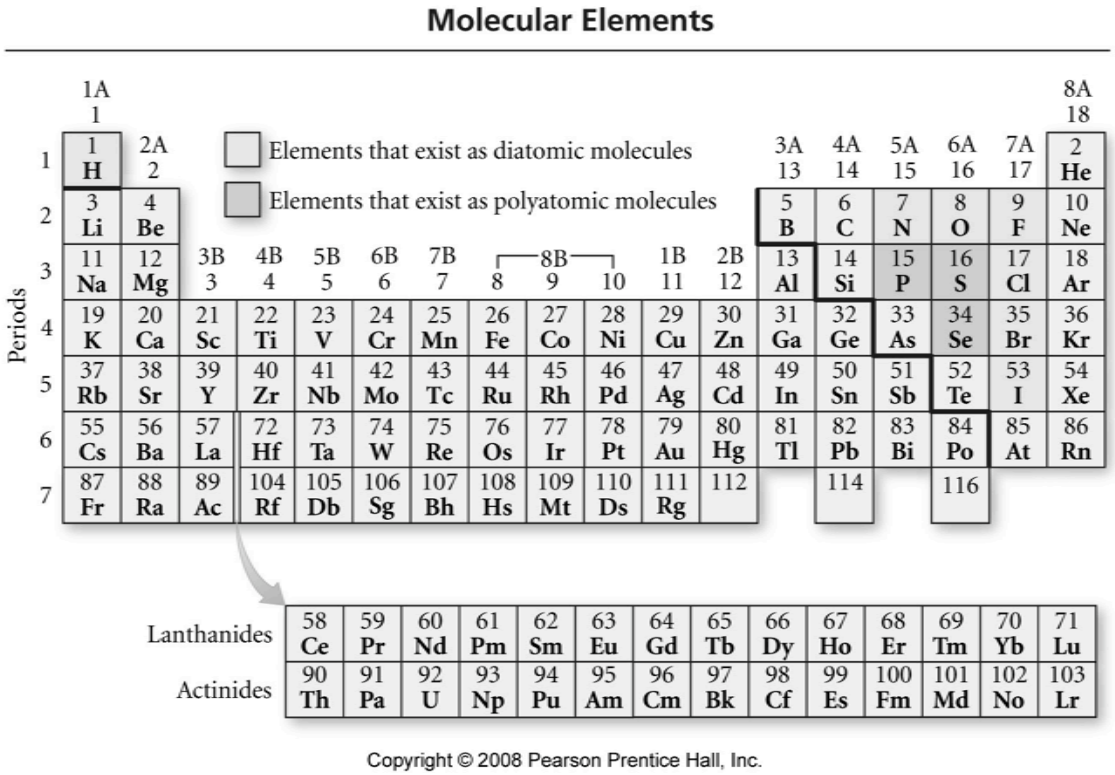
Name of Compound	Empirical Formula	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
Benzene	CH	C_6H_6			
Acetylene	CH	C_2H_2			
Glucose	CH_2O	$C_6H_{12}O_6$			
Ammonia	NH_3	NH_3			

What is the empirical formula for H_2O_2 and $C_2H_6O_2$?

Section 3.4 Molecular and Atomic Elements

- Certain elements occur as 2 atom molecules
- Other elements occur as polyatomic molecules
  - ✓ P_4, S_8, Se_8





$CaCl_2$

Hydrogen

Phosphorous

CO_2

Section 3.5 Ionic Compounds

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 cation cancels the sum of the anions

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

Al^{+3} column 3A

O^{2-} column 6A

$Al^{+3}\ O^{2-}$

$Al_2\ O_3$

$Al = (2)\cdot(+3) = +6$

$O = (3)\cdot(-2) = -6$

Naming Binary Ionic Compounds for Metals with Invariant Charge

- Contain Metal Cation + Nonmetal Anion
- Metal listed first in formula and name

1. name metal cation first, name nonmetal anion second
2. cation name is the metal name
3. nonmetal anion named by changing the ending on the nonmetal name to ***-ide***

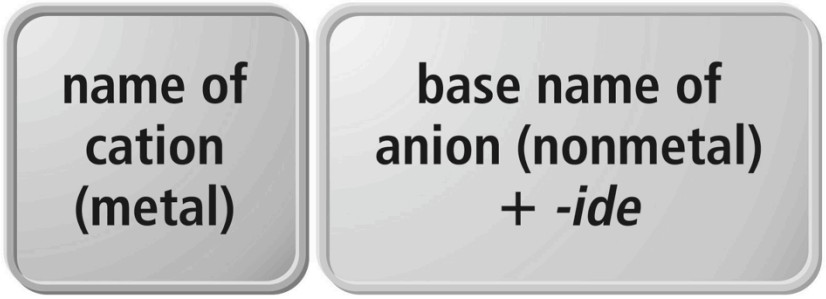


TABLE 3.2 Metals Whose Charge Is Invariant from One Compound to Another

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	*

Naming Binary Ionic Compounds for Metals with Variable Charge

- Contain Metal Cation + Nonmetal Anion
- Metal listed first in formula and name

1. name metal cation first, name nonmetal anion second
2. metal cation name is the metal name followed by a Roman numeral in parentheses to indicate its charge
   - ✓determine charge from anion charge
   - ✓common ions Table 3.4
3. nonmetal anion named by changing the ending on the nonmetal name to ***-ide***

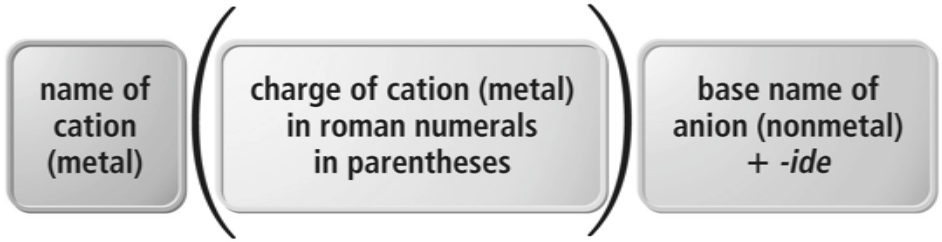


TABLE 3.4 Some Metals That Form Cations with Different Charges

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

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

copper (II) nitride and iron (III) bromide.

Compounds Containing Polyatomic Ions

- Polyatomic ions are single ions that contain more than one atom
- Often identified by (ion) in formula
- Name and charge of polyatomic ion do not change
- Name any ionic compound by naming cation first and then anion

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^-

Formulas and Names of Binary Ionic Compounds

•Binary ionic compounds are made up of monatomic cations and anions.

•These combinations must be electrically neutral.

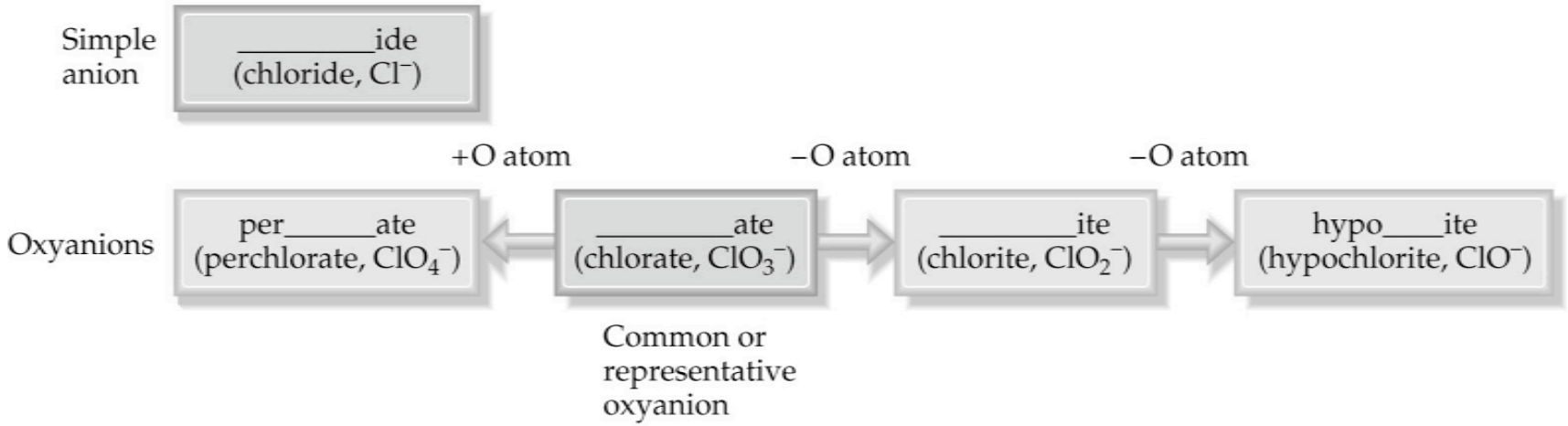
•The **formula unit** is the simplest collection of cations and anions that represents an electrically neutral unit.

•*Formula unit* is to *ion* as _____ is to *atom.*

•To *write a formula*, combine the proper number of each ion to form a neutral unit.

•To *name* a binary ionic compound, name the cation, then the anion.

•Monatomic anion names end in *-ide*.



Determine the formula for **(a)** calcium chloride and **(b)** magnesium oxide.

What are the names of **(a)** MgS and **(b)** $CrCl_3$?

Write the formula for (**a**) sodium sulfite and (**b**) ammonium sulfate.

What is the name of **(a)** NaCN and **(b)** $Mg(ClO_4)_2$?

Naming Binary Molecular Compounds (Section 3.6)

•The name consists of two words.

•First word: name of the element that appears first in the formula.

•Second word: *stem* of the name of the second element, ending with -*ide*.

•Names are further modified by adding prefixes to denote the numbers of atoms of each element in the molecule.

•Rule of thumb: the element that is farthest *down* and to the *left* on the periodic table is usually written first.

Table 2.3 Numeric Prefixes in Names of Binary Molecular Compounds

Number of Atoms	Prefix	Examples[a]
1	mono	NO nitrogen monoxide
2	di	NO_2 nitrogen dioxide
3	tri	N_2O_3 dinitrogen trioxide
4	tetra	N_2O_4 dinitrogen tetroxide
5	penta	N_2O_5 dinitrogen pentoxide
6	hexa	SF_6 sulfur hexafluoride
7	hepta	IF_7 iodine heptafluoride
8	octa	P_4O_8 tetraphosphorus octoxide
9	nona	P_4S_9 tetraphosphorus nonasulfide
10	deca	As_4O_{10} tetraarsenic decoxide

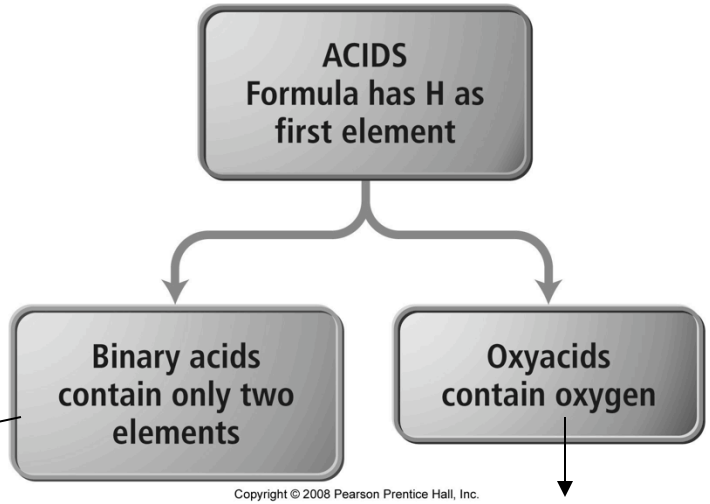
[a] When the prefix ends in "a" or "o" and the element name begins with "a" or "o," the final vowel of the prefix is usually dropped for ease of pronunciation. For example, nitrogen *mon*oxide and not nitrogen *mono*oxide, and

Hydrates

- hydrates are ionic compounds containing a specific number of waters for each formula unit
- water of hydration often "driven off" by heating
- in formula, attached waters follow ·
  - ✓$CoCl_2 \cdot 6H_2O$
- in name attached waters indicated by suffix *-hydrate* after name of ionic compound
  - ✓$CoCl_2 \cdot 6H_2O$ = cobalt(II) chloride hexahydrate
  - ✓$CaSO_4 \cdot ½H_2O$ = calcium sulfate hemihydrate

Acids

- Contain H^{+1} cation and anion
  - ✓in aqueous solution
- Binary acids have H^{+1} cation and nonmetal anion
- Oxyacids have H^{+1} cation and polyatomic anion

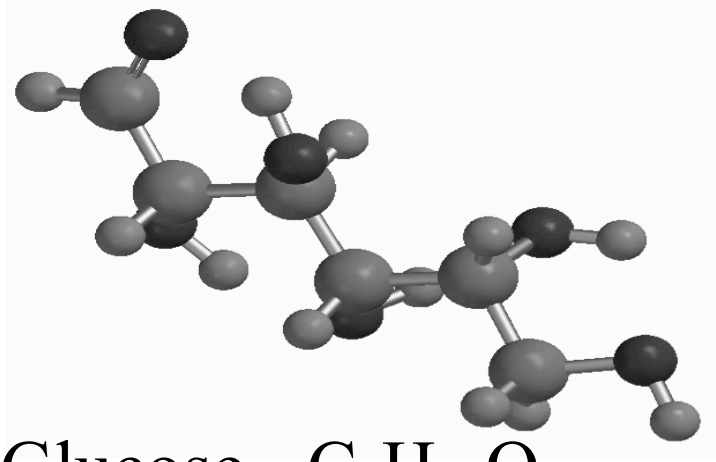


- write a **hydro** prefix
- follow with the nonmetal name
- change ending on nonmetal name to *–ic*
- write the word **acid** at the end of the name

- 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

Molecular Masses and Formula Masses (Section 3.7)

- ***Molecular mass***: sum of the masses of the atoms represented in a molecular formula.
- Simply put: the mass of a molecule.
- *Molecular* mass is specifically for *molecules*.



Glucose - $C_6H_{12}O_6$

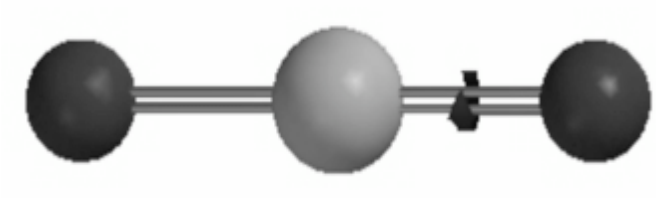
$= 6(\mathbf{12.0107\ u}) + 12(\mathbf{1.0079\ u}) + 6(\mathbf{15.9994\ u})$

$= \mathbf{180.1154}$ u

Sulfur dioxide - SO_2

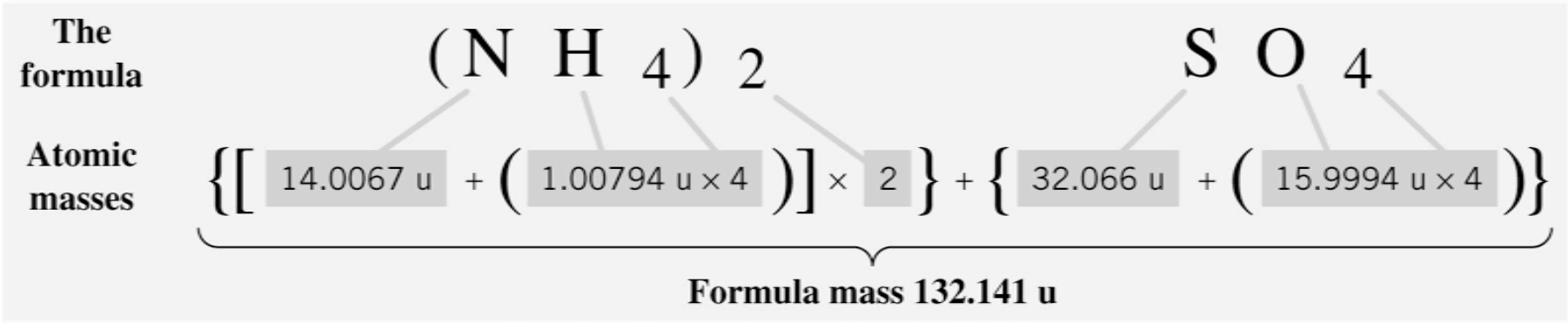
$= \mathbf{32.066\ u} + 2(\mathbf{15.9994\ u})$

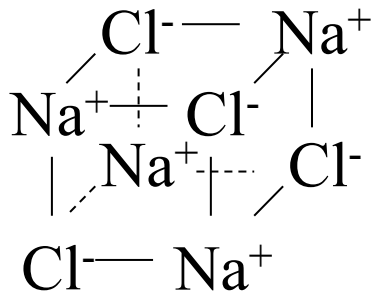
$= \mathbf{64.065}$ u



•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*.





Crystal of sodium chloride

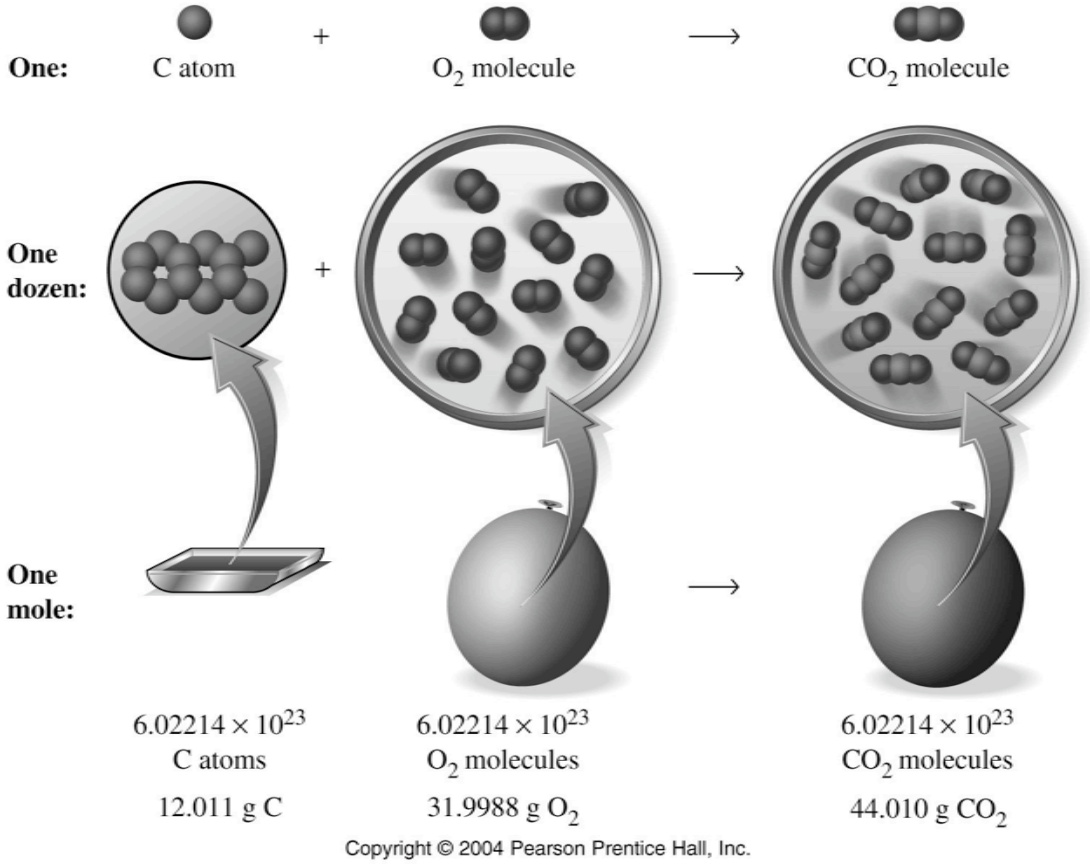
One Na^+ and one Cl^- make a formula unit for sodium chloride

The mass of one formula unit is:
= 22.9898 u + 35.4527 u
= **58.4425** u

•***Molar mass*** is the mass of ***one mole*** of a substance.

•Molar mass is ***numerically*** equal to atomic mass, molecular mass, or formula mass. However …

•… the ***units*** of molar mass are grams (g/mol).



•Examples:

1 ***atom*** Na = 22.99 ***u***

1 ***mol*** Na = 22.99 ***g***

1 ***molecule*** CO_2 = 44.01 ***u***

1 ***mol*** CO_2 = 44.01 ***g***

1 ***formula unit*** KCl = 74.56 ***u***

1 ***mol*** KCl = 74.56 ***g***

Avogadro's Number, N_A

The *number* of elementary entities in one mole of anything

$$N_A = 6.02214199 \times 10^{23} \text{ entities mol}^{-1}$$

-or- $1 \text{ mole} \approx 6.022 \times 10^{23}$ entities

A **mole** (mol) is an amount of substance that contains as many elementary entities as there are atoms in exactly 12 g of the carbon-12 isotope.

1 mole of stars in the universe	$= 6.022 \times 10^{23}$ stars
1 mole of pennies	$= 6.022 \times 10^{23}$ pennies (beats the lottery!)
1 mole of tennis balls	$= 6.022 \times 10^{23}$ tennis balls
1 mole of glucose molecules	$= 6.022 \times 10^{23}$ molecules
1 mole of helium atoms	$= 6.022 \times 10^{23}$ atoms
1 mole of potassium ions (K^+)	$= 6.022 \times 10^{23}$ ions

One mole each of helium, sulfur, copper, and mercury.

Determine **(a)** the mass of a 0.0750-mol sample of Na, **(b)** the number of moles of Na in a 62.5-g sample, **(c)** the mass of a sample of Na containing 1.00×10^{25} Na atoms, and **(d)** the mass of a single Na atom.

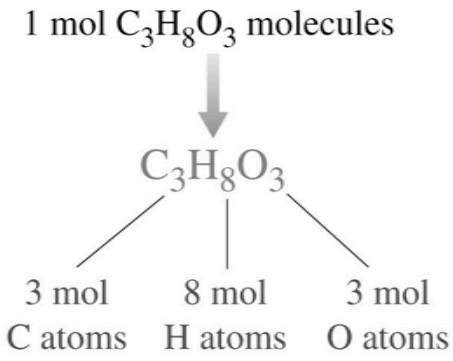
Conversions involving Mass, Moles, and Number of Atoms/ Molecules

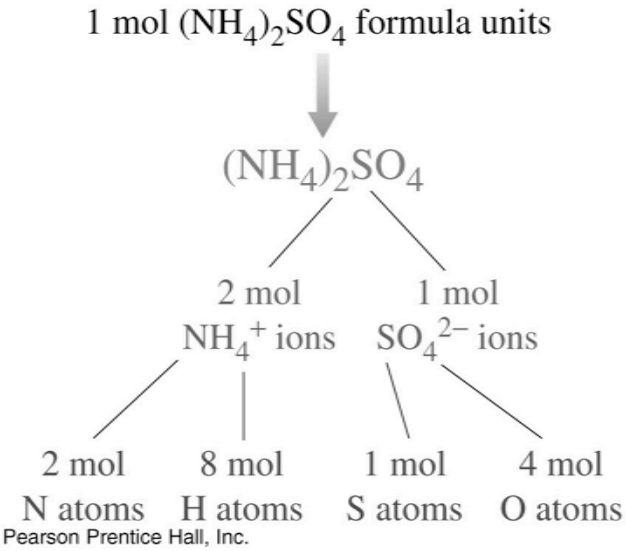
1 mol Na = 6.022 x 10^{23} Na atoms = 22.99 g Na

We can use these equalities to construct conversion factors, such as:

$$\frac{1 \text{ mol Na}}{22.99 \text{ g Na}} \qquad \frac{22.99 \text{ g Na}}{1 \text{ mol Na}} \qquad \frac{1 \text{ mol Na}}{6.022 \times 10^{23} \text{ Na atoms}}$$

Determine **(a)** the number of NH_4^+ ions in a 145-g sample of $(NH_4)_2SO_4$ and **(b)** the volume of 1,2,3-propanetriol (glycerol, ***d*** = 1.261 g/mL) that contains 1.00 mol O atoms.





Mass Percent Composition from Chemical Formulas (Section 3.8)

The ***mass percent composition*** of a compound refers to the proportion of the constituent elements, expressed as the number of grams of each element per 100 grams of the compound. In other words …

$$\textbf{X}\ \%\ \text{element} = \frac{\textbf{X g element}}{100\ \text{g compound}} \quad \textbf{\textit{OR}} \ldots$$

$$\%\ \text{element} = \frac{\text{g element}}{\text{g compound}} \times 100$$

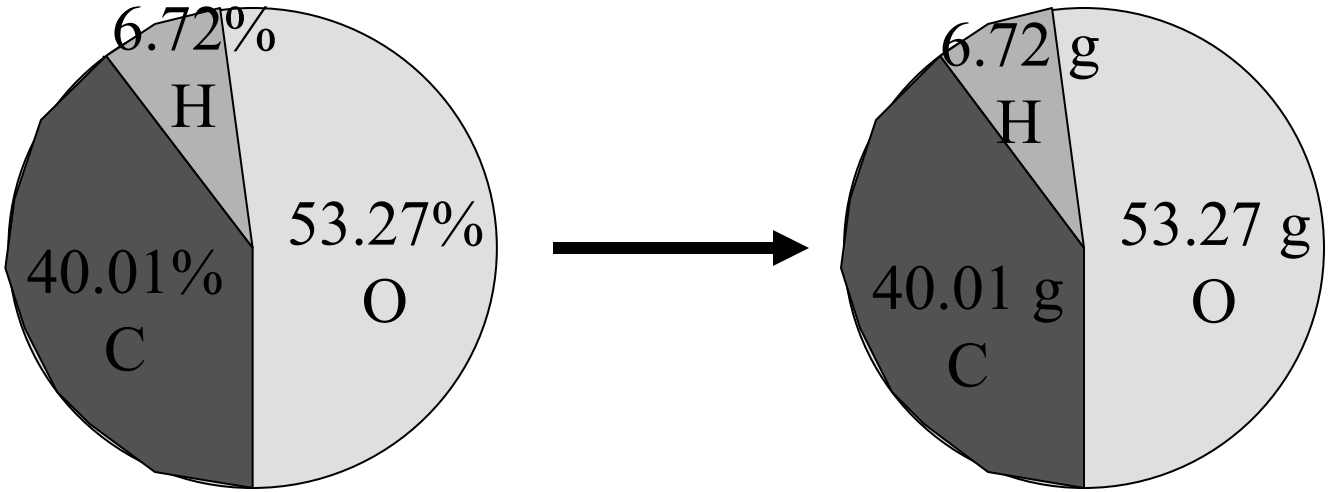
Molecular formula of butane	C_4H_{10}
Mass of C in 1 mol C_4H_{10}	$4\ \text{mol C} \times 12.011\ \text{g C/mol C} = 48.044\ \text{g C}$
Mass of H in 1 mol C_4H_{10}	$10\ \text{mol H} \times 1.0079\ \text{g H/mol H} = 10.079\ \text{g H}$
Molar mass of C_4H_{10}	$48.044\ \text{g C} + 10.079\ \text{g H} = 58.123\ \text{g/mol } C_4H_{10}$
Mass percent C in C_4H_{10}	$\frac{48.044\ \text{g C}}{58.123\ \text{g } C_4H_{10}} \times 100\% = 82.66\%\ \text{C}$
Mass percent H in C_4H_{10}	$\frac{10.079\ \text{g C}}{58.123\ \text{g } C_4H_{10}} \times 100\% = 17.34\%\ \text{H}$

Chemical Formulas from Mass Percent Composition (Section 3.9)

- We can "reverse" the process of finding percentage composition.
- First we use the percentage or mass of each element to find ***moles*** of each element.
- Then we can obtain the empirical formula by finding the smallest ***whole-number ratio*** of moles.
  - –Find the whole-number ratio by dividing each number of moles by the *smallest* number of moles.

A compound is comprised of 40.01% carbon, 6.72% hydrogen, and 53.27% oxygen. Calculate the empirical formula of the compound.

1) Given the percent composition, assume a mass of sample - use 100.00 g for convenience



Relating Molecular Formulas to Empirical Formulas

•A molecular formula is a simple integer multiple of the empirical formula.

•That is, an empirical formula of CH_2 means that the molecular formula is CH_2, or C_2H_4, or C_3H_6, or C_4H_8, etc.

•So: we find the molecular formula by:

$$\frac{\textbf{molecular formula mass}}{\textbf{empirical formula mass}} = \textbf{integer (nearly)}$$

Elemental Analysis . . .

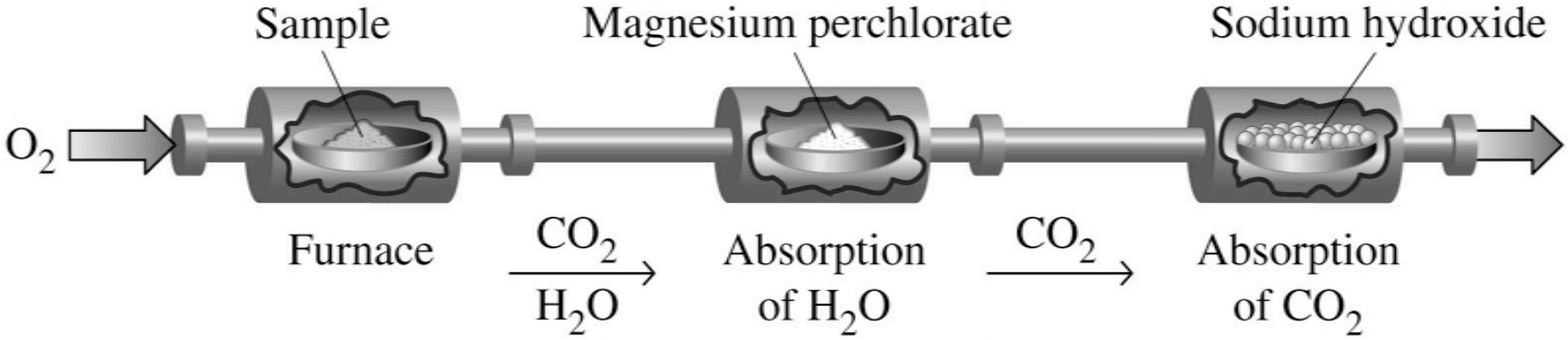
•… is one method of determining empirical formulas in the laboratory.

•This method is used primarily for simple organic compounds (that contain carbon, hydrogen, oxygen).

–The organic compound is burned in oxygen.

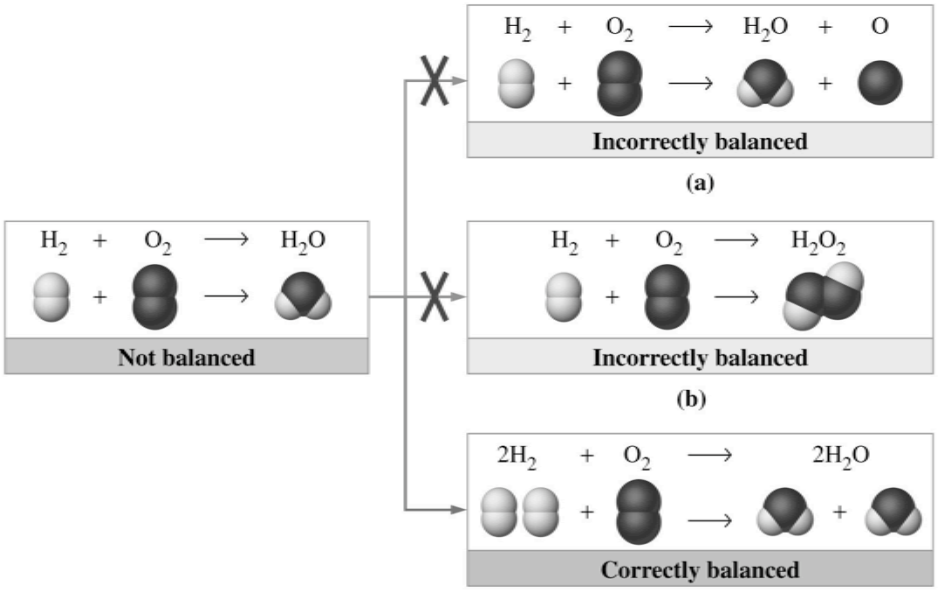
–The products of combustion (usually CO_2 and H_2O) are weighed.

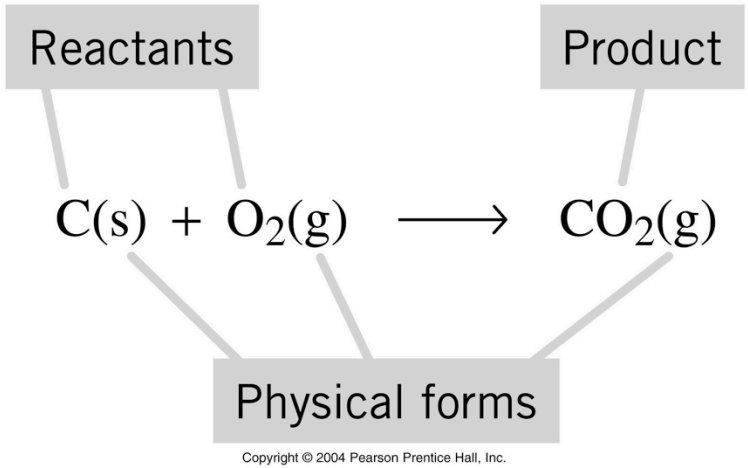
–The amount of each element is determined from the mass of products.



Writing Chemical Equations (Section 3.10)

A **chemical equation** is a shorthand description of a chemical reaction, using symbols and formulas to represent the elements and compounds involved.





Elevated temperature

$$NH_4Cl(s) \xrightarrow{\Delta} NH_3(g) + HCl(g)$$

Actual temperature at which reaction is carried out

$$HCOOH(g) \xrightarrow{160\ ^\circ C} CO_2(g) + H_2(g)$$

- If an element is present in just one compound on each side of the equation, try balancing that element ***first***.
- Balance any reactants or products that exist as the ***free*** element ***last***.
- In some reactions, certain groupings of atoms (such as polyatomic ions) remain unchanged. In such cases, treat these groupings as a unit.
- At times, an equation can be balanced by first using a fractional coefficient(s). The fraction is then cleared by multiplying each coefficient by a common factor.