What is the correct formula for aluminum carbonate?

A) $AlCO_3$

B) $Al_2(CO_3)_3$

C) $Al_3(CO_3)_2$

D) Al_2CO_3

E) Al_3CO_3

Chemistry, The Central Science, 10th edition
Theodore L. Brown, H. Eugene LeMay, Jr.,
and Bruce E. Bursten

Chapter 3
Stoichiometry: Calculations with Chemical Formulas and Equations

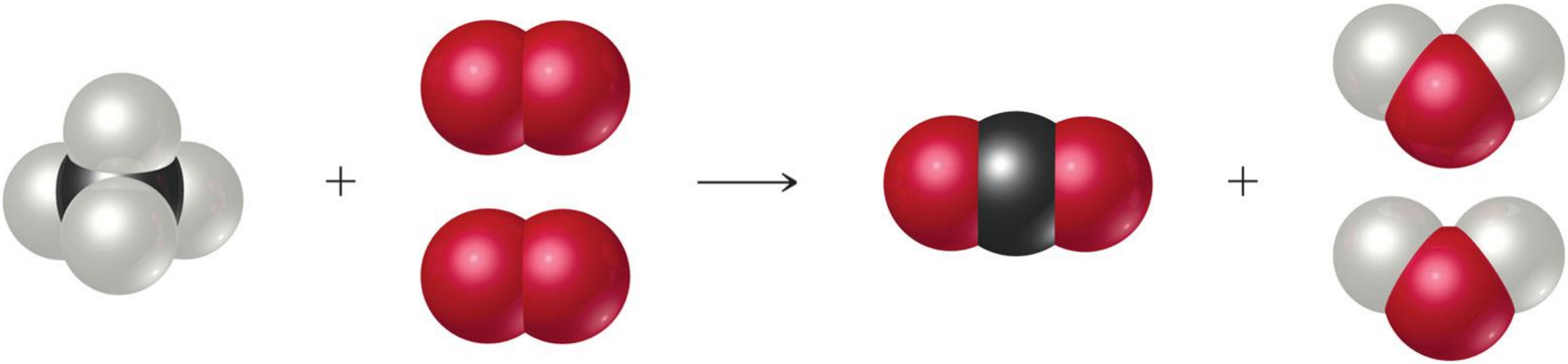
Law of Conservation of Mass

"We may lay it down as an incontestable axiom that, in all the operations of art and nature, nothing is created; an equal amount of matter exists both before and after the experiment. Upon this principle, the whole art of performing chemical experiments depends."

--Antoine Lavoisier, 1789

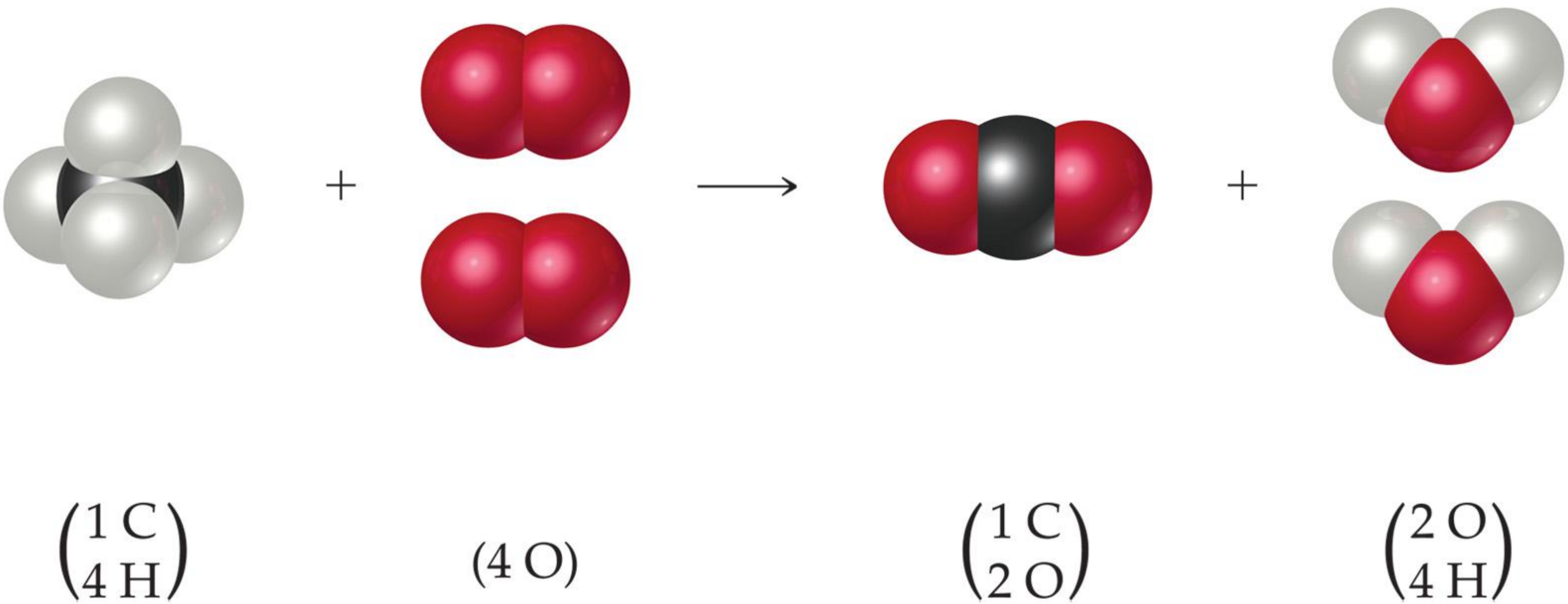
Chemical Equations

Concise representations of chemical reactions



Anatomy of a Chemical Equation

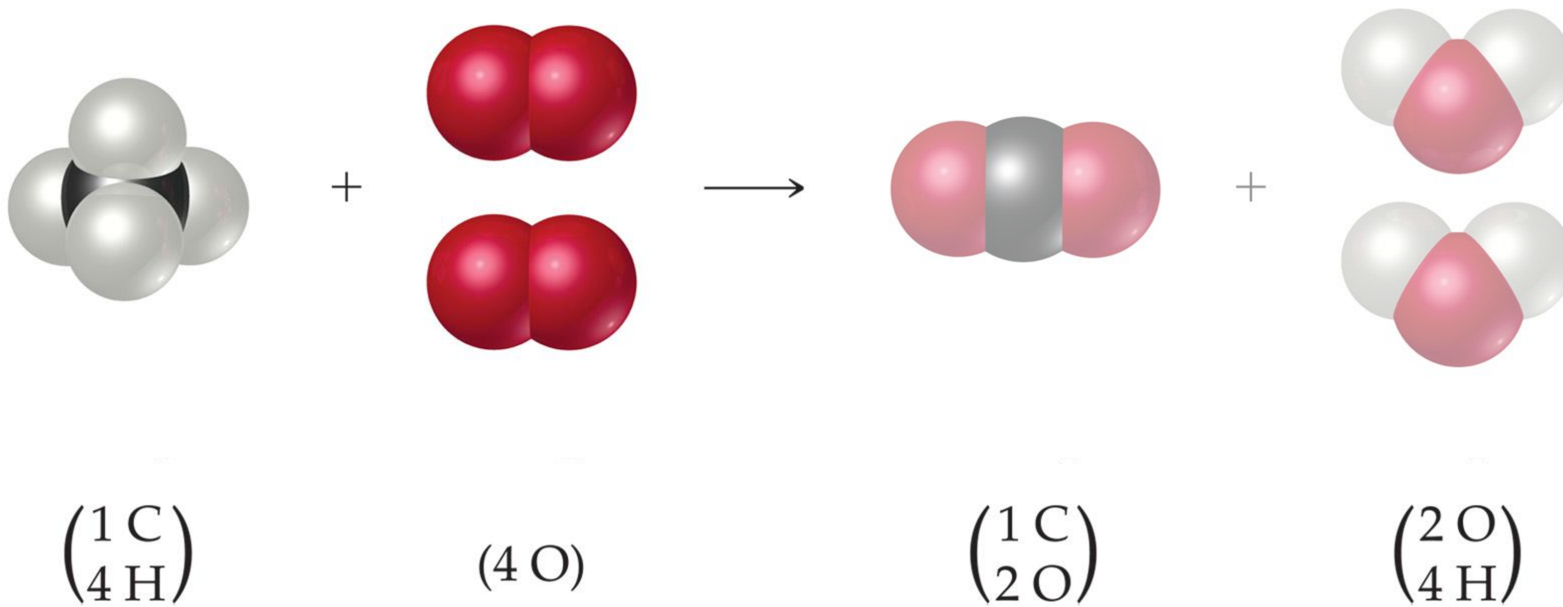
$$CH_{4\,(g)} + 2\ O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\ H_2O_{\,(g)}$$



Stoichiometry

Anatomy of a Chemical Equation

$$CH_{4\,(g)} + 2\,O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\,H_2O_{(g)}$$

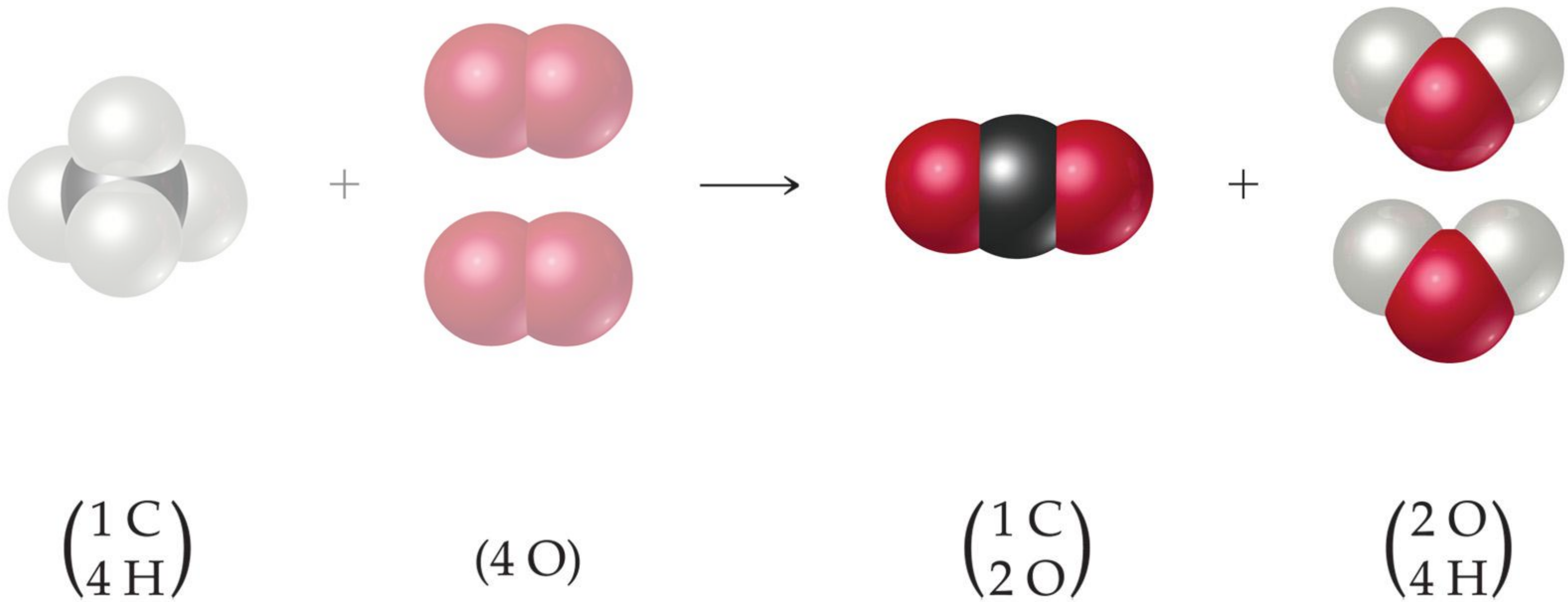


Reactants appear on the left side of the equation.

Stoichiometry

Anatomy of a Chemical Equation

$$CH_{4\,(g)} + 2\ O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\ H_2O_{(g)}$$

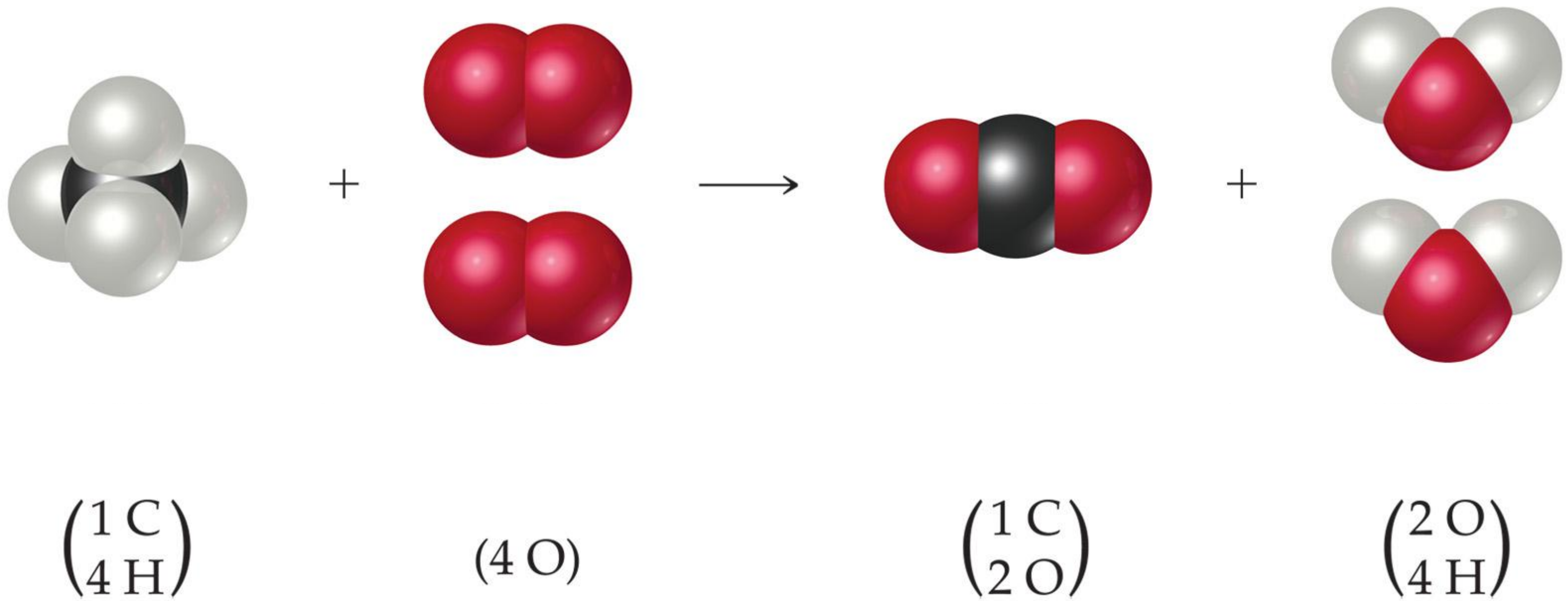


Products appear on the right side of the equation.

Stoichiometry

Anatomy of a Chemical Equation

$$CH_{4\,(g)} + 2\ O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\ H_2O_{\,(g)}$$

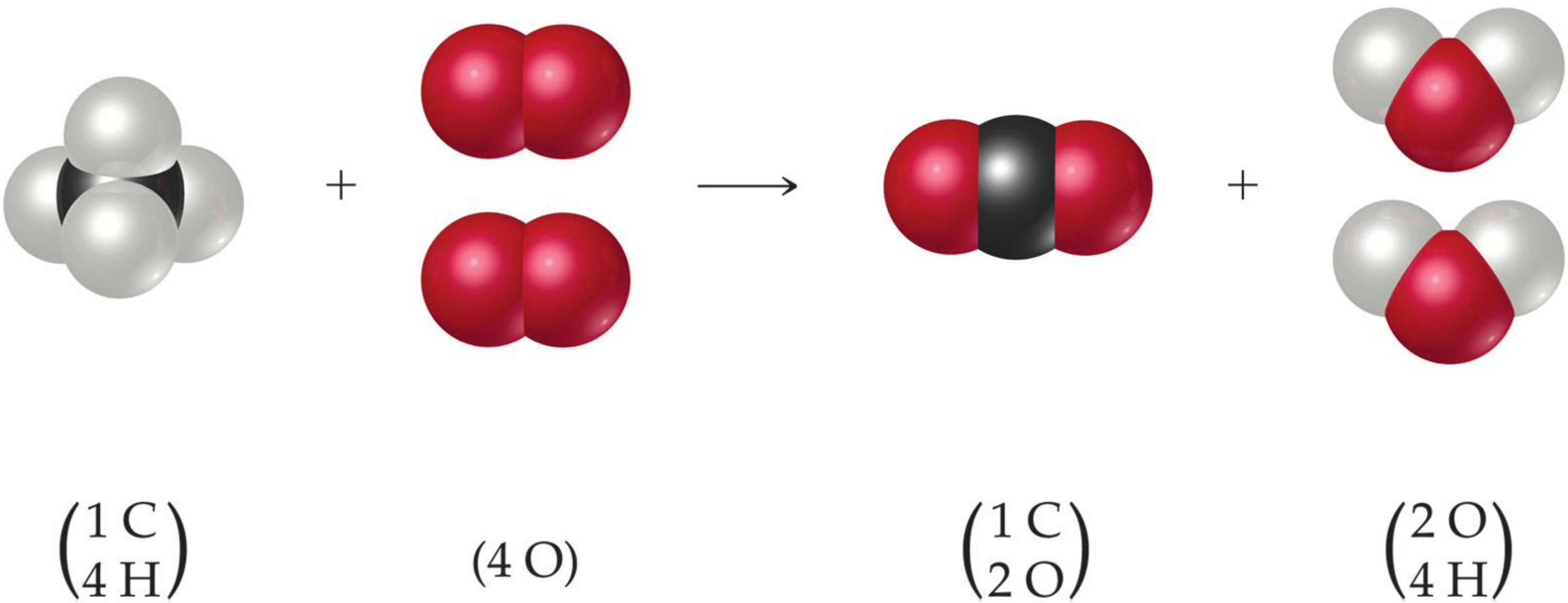


The states of the reactants and products are written in parentheses to the right of each compound.

Stoichiometry

Anatomy of a Chemical Equation

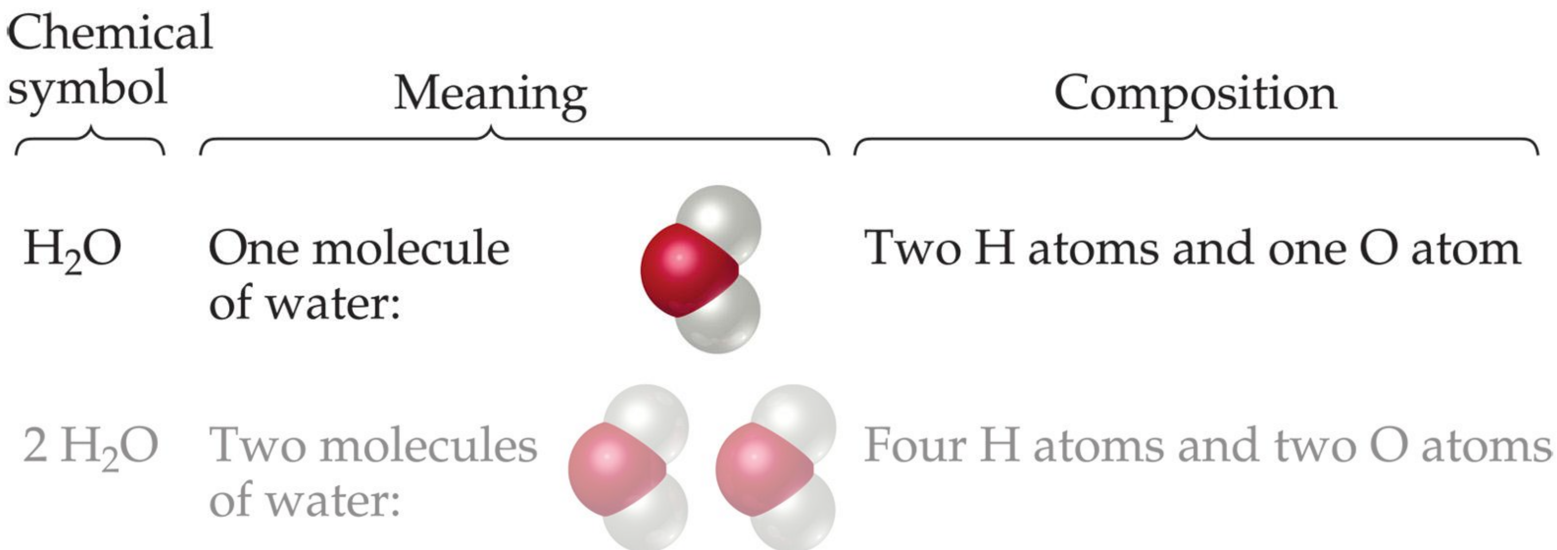
$$CH_{4\,(g)} + 2\ O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\ H_2O_{\,(g)}$$



Coefficients are inserted to balance the equation.

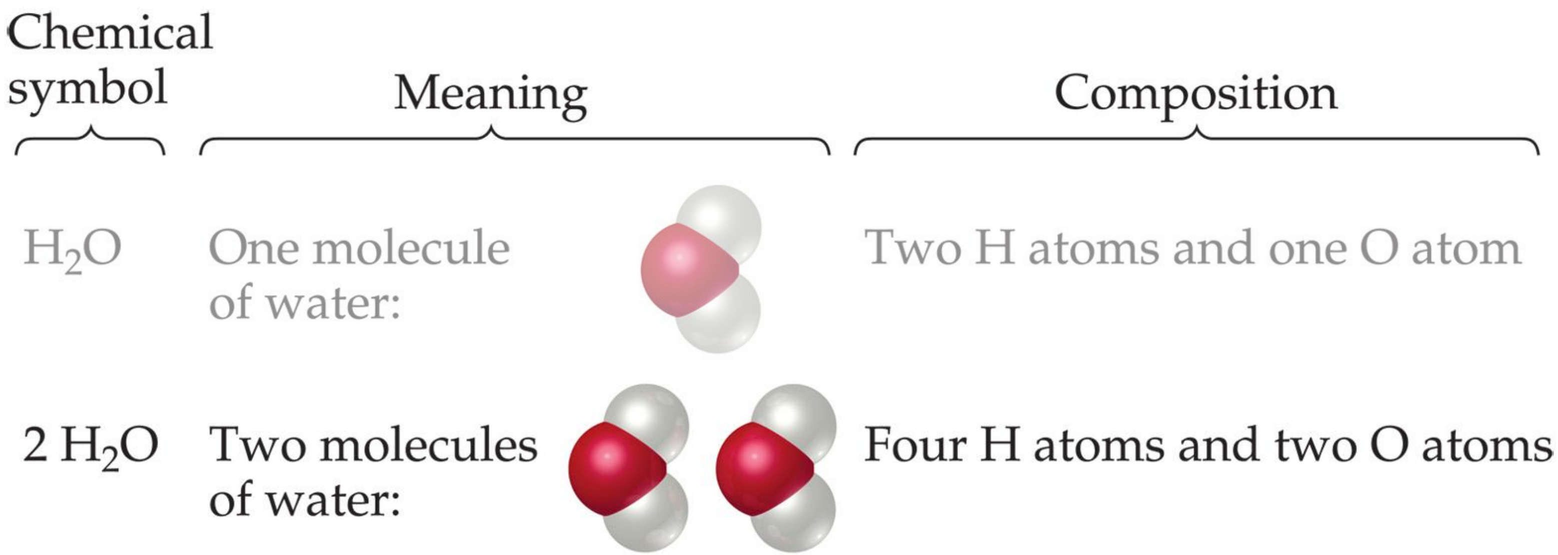
Stoichiometry

Subscripts and Coefficients Give Different Information



- Subscripts tell the number of atoms of each element in a molecule

Subscripts and Coefficients Give Different Information



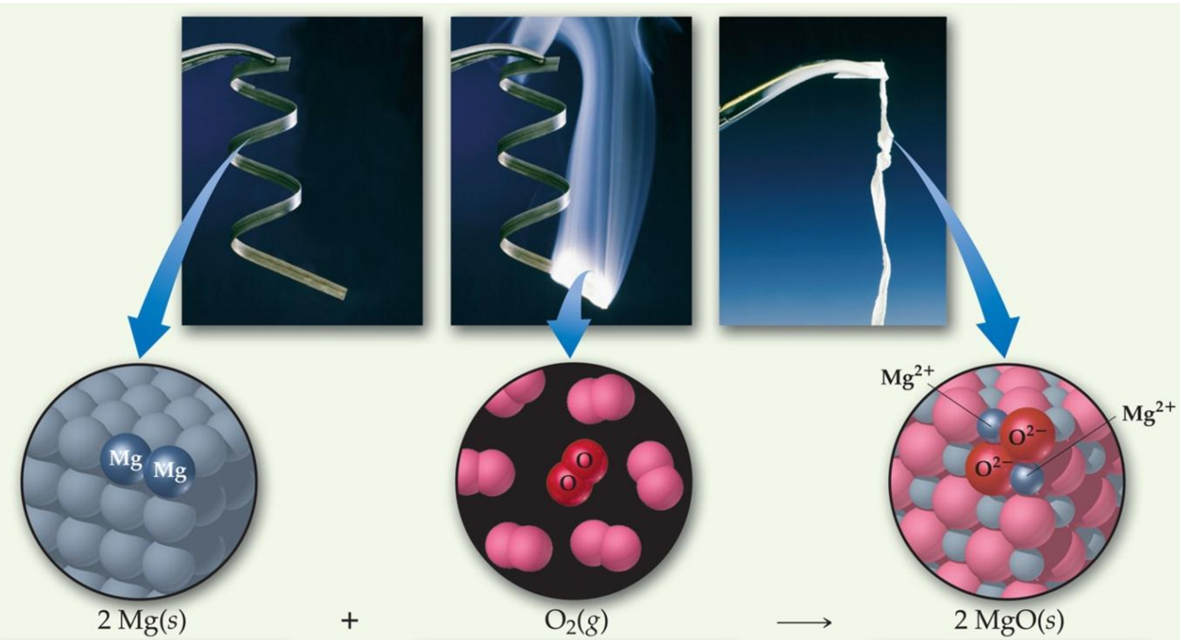
- Subscripts tell the number of atoms of each element in a molecule
- Coefficients tell the number of molecules

- Mass number is an integer equal to the sum of the number of protons and neutrons of an atomic nucleus

- Atomic mass is the average mass of atoms of an element calculated using the relative abundance of isotopes in a naturally-occurring element

Reaction Types

Combination Reactions



- Two or more substances react to form one product

- Examples:

$$N_{2\,(g)} + 3\,H_{2\,(g)} \longrightarrow 2\,NH_{3\,(g)}$$

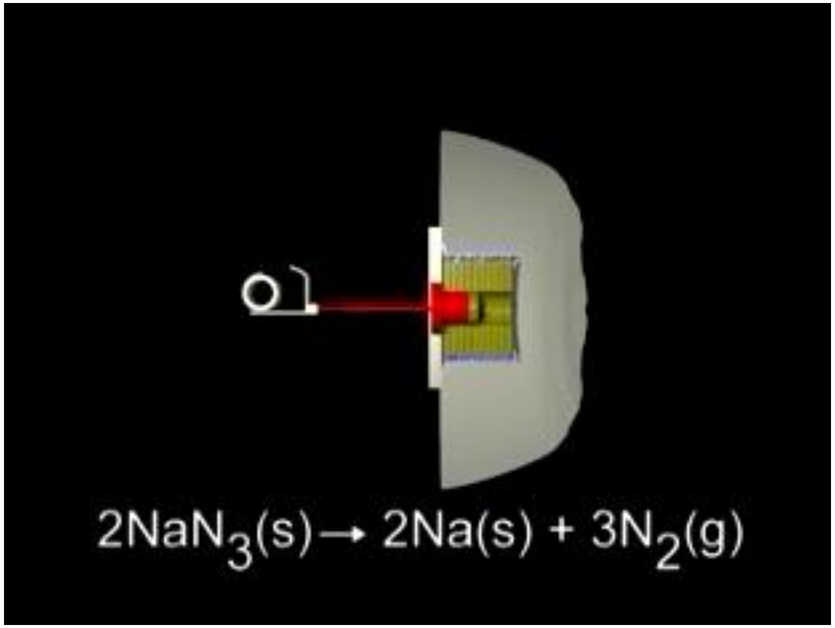
$$C_3H_{6\,(g)} + Br_{2\,(l)} \longrightarrow C_3H_6Br_{2\,(l)}$$

$$2\,Mg_{(s)} + O_{2\,(g)} \longrightarrow 2\,MgO_{(s)}$$

$$2\,Mg_{(s)} + O_{2\,(g)} \longrightarrow 2\,MgO_{(s)}$$

Stoichiometry

Decomposition Reactions



- One substance breaks down into two or more substances

- Examples:

$CaCO_{3\ (s)} \longrightarrow CaO_{\ (s)} + CO_{2\ (g)}$

$2\ KClO_{3\ (s)} \longrightarrow 2\ KCl_{\ (s)} + 3\ O_{2\ (g)}$

$2\ NaN_{3\ (s)} \longrightarrow 2\ Na_{\ (s)} + 3\ N_{2\ (g)}$

Combustion Reactions

- Rapid reactions that produce a flame
- Most often involve hydrocarbons reacting with oxygen in the air

- Examples:

$$CH_{4\,(g)} + 2\,O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\,H_2O_{\,(g)}$$

$$C_3H_{8\,(g)} + 5\,O_{2\,(g)} \longrightarrow 3\,CO_{2\,(g)} + 4\,H_2O_{\,(g)}$$

Formula Weights

Formula Weight (FW)

- Sum of the atomic weights for the atoms in a chemical formula
- So, the formula weight of calcium chloride, $CaCl_2$, would be

Ca: 1(40.1 amu)

+ Cl: 2(35.5 amu)

111.1 amu

- These are generally reported for ionic compounds

Molecular Weight (MW)

- Sum of the atomic weights of the atoms in a molecule
- For the molecule ethane, C_2H_6, the molecular weight would be

$$\begin{array}{rr} C: & 2(12.0\ \text{amu}) \\ +\ H: & 6(1.0\ \text{amu}) \\ \hline & 30.0\ \text{amu} \end{array}$$

Percent Composition

One can find the percentage of the mass of a compound that comes from each of the elements in the compound by using this equation:

$$\% \text{ element} = \frac{(\text{number of atoms})(\text{atomic weight})}{(\text{FW of the compound})} \times 100$$

Percent Composition

So the percentage of carbon in ethane is…

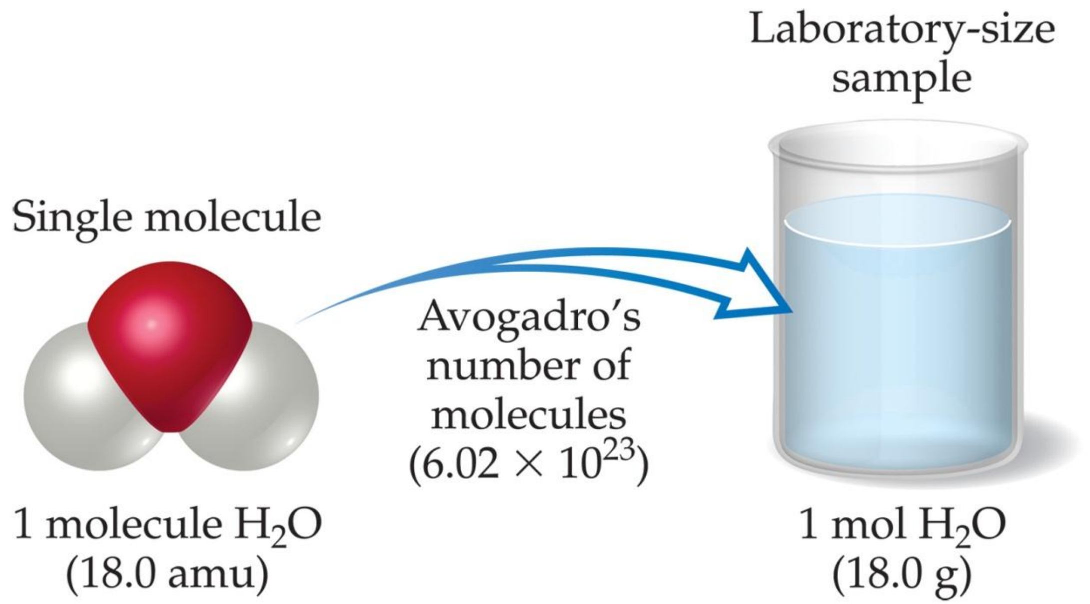
$$\%C = \frac{(2)(12.0\text{ amu})}{(30.0\text{ amu})}$$

$$= \frac{24.0\text{ amu}}{30.0\text{ amu}} \times 100$$

$$= 80.0\%$$

Moles

Avogadro's Number

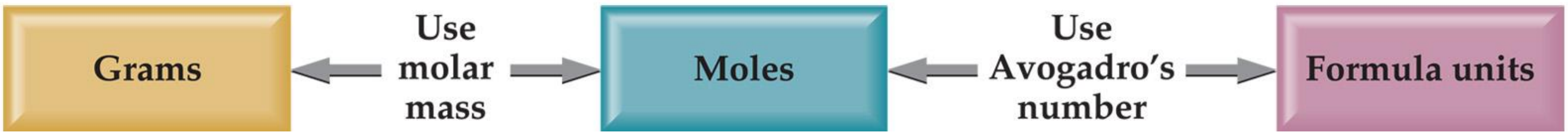


- 6.02×10^{23}
- 1 mole of ^{12}C has a mass of 12 g

Molar Mass

- By definition, these are the mass of 1 mol of a substance (i.e., g/mol)
  - The molar mass of an element is the mass number for the element that we find on the periodic table
  - The formula weight (in amu's) will be the same number as the molar mass (in g/mol)

Using Moles



Moles provide a bridge from the molecular scale to the real-world scale

Mole Relationships

Name of substance	Formula	Formula Weight (amu)	Molar Mass (g/mol)	Number and Kind of Particles in One Mole
Atomic nitrogen	N	14.0	14.0	6.022×10^{23} N atoms
Molecular nitrogen	N_2	28.0	28.0	6.022×10^{23} N_2 molecules $2(6.022 \times 10^{23})$ N atoms
Silver	Ag	107.9	107.9	6.022×10^{23} Ag atoms
Silver ions	Ag^+	107.9[a]	107.9	6.022×10^{23} Ag^+ ions
Barium chloride	$BaCl_2$	208.2	208.2	6.022×10^{23} $BaCl_2$ units 6.022×10^{23} Ba^{2+} ions $2(6.022 \times 10^{23})$ Cl^- ions

[a]Recall that the electron has negligible mass; thus, ions and atoms have essentially the same mass.

- One mole of atoms, ions, or molecules contains Avogadro's number of those particles
- One mole of molecules or formula units contains Avogadro's number times the number of atoms or ions of each element in the compound

- Examples
- 125 g of Fe = ? Moles of Fe

- $$125 \text{ g Fe} \times \frac{1 \text{ mole Fe}}{55.845 \text{ g Fe}} = 2.238 \text{ moles Fe}$$

$$= 2.24 \text{ moles Fe}$$

- 125 g of Fe = ? atoms of Fe

- $$125 \text{ g Fe} \times \frac{1 \text{ mole Fe}}{55.845 \text{ g Fe}} \times \frac{6.02 \times 10^{BB} \text{ atoms of Fe}}{1 \text{ mole of Fe}}$$

$$= 1.35 \times 10^{24} \text{ atoms of Fe}$$

- 125 g NaCl = ? Moles of NaCl

- 125 g NaCl x <u>1 mole of NaCl</u>
-

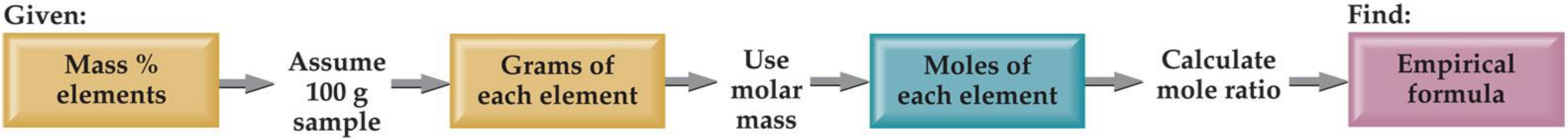
- 10.00×10^{35} atoms of Cu = ? g of Cu

- A sample of iron weighing 16.8 g contains how many moles of iron atoms?
- A) 0.0874 moles
- B) 0.301 moles
- C) 0.646 moles
- D) 0.132 moles
- E) 3.32 moles

- *Ans: B*

Finding Empirical Formulas

Calculating Empirical Formulas



One can calculate the empirical formula from the percent composition

Calculating Empirical Formulas

The compound *para*-aminobenzoic acid (you may have seen it listed as PABA on your bottle of sunscreen) is composed of carbon (61.31%), hydrogen (5.14%), nitrogen (10.21%), and oxygen (23.33%). Find the empirical formula of PABA.

Calculating Empirical Formulas

Assuming 100.00 g of *para*-aminobenzoic acid,

$$\text{C:} \quad 61.31\text{ g} \times \frac{1\text{ mol}}{12.01\text{ g}} = 5.105\text{ mol C}$$

$$\text{H:} \quad 5.14\text{ g} \times \frac{1\text{ mol}}{1.01\text{ g}} = 5.09\text{ mol H}$$

$$\text{N:} \quad 10.21\text{ g} \times \frac{1\text{ mol}}{14.01\text{ g}} = 0.7288\text{ mol N}$$

$$\text{O:} \quad 23.33\text{ g} \times \frac{1\text{ mol}}{16.00\text{ g}} = 1.456\text{ mol O}$$

Calculating Empirical Formulas

Calculate the mole ratio by dividing by the smallest number of moles:

$$\text{C:} \quad \frac{5.105 \cancel{\text{ mol}}}{0.7288 \cancel{\text{ mol}}} = 7.005 \approx 7$$

$$\text{H:} \quad \frac{5.09 \cancel{\text{ mol}}}{0.7288 \cancel{\text{ mol}}} = 6.984 \approx 7$$

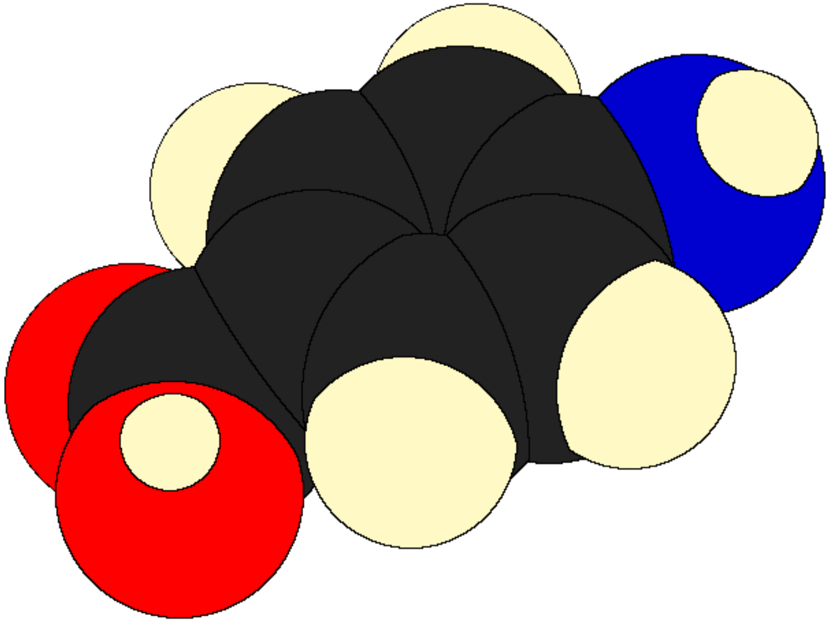
$$\text{N:} \quad \frac{0.7288 \cancel{\text{ mol}}}{0.7288 \cancel{\text{ mol}}} = 1.000$$

$$\text{O:} \quad \frac{1.458 \cancel{\text{ mol}}}{0.7288 \cancel{\text{ mol}}} = 2.001 \approx 2$$

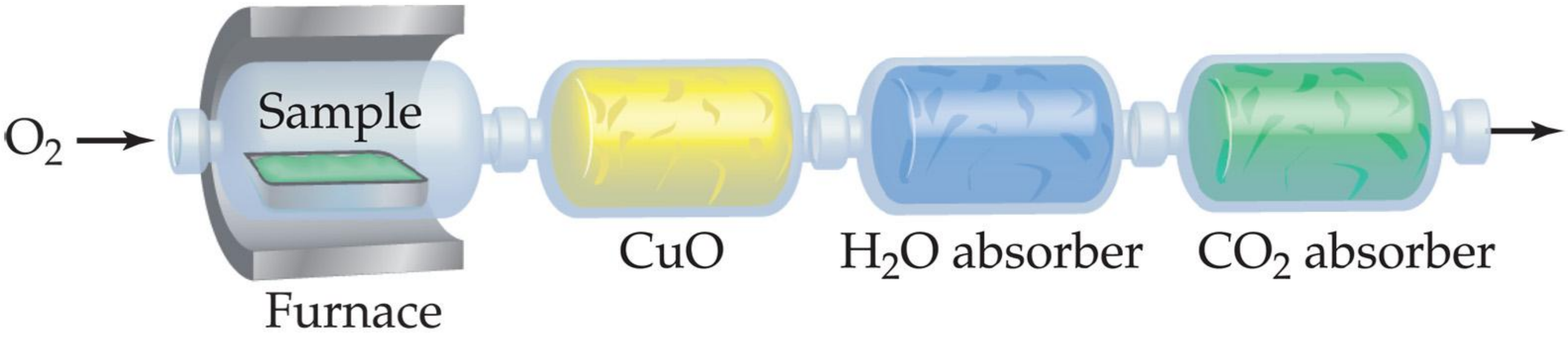
Calculating Empirical Formulas

These are the subscripts for the empirical formula:

$C_7H_7NO_2$



Combustion Analysis

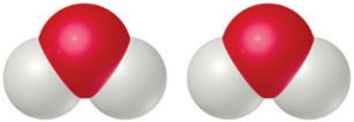


- Compounds containing C, H and O are routinely analyzed through combustion in a chamber like this
  - C is determined from the mass of CO_2 produced
  - H is determined from the mass of H_2O produced
  - O is determined by difference after the C and H have been determined

Elemental Analyses

Compounds containing other elements are analyzed using methods analogous to those used for C, H and O

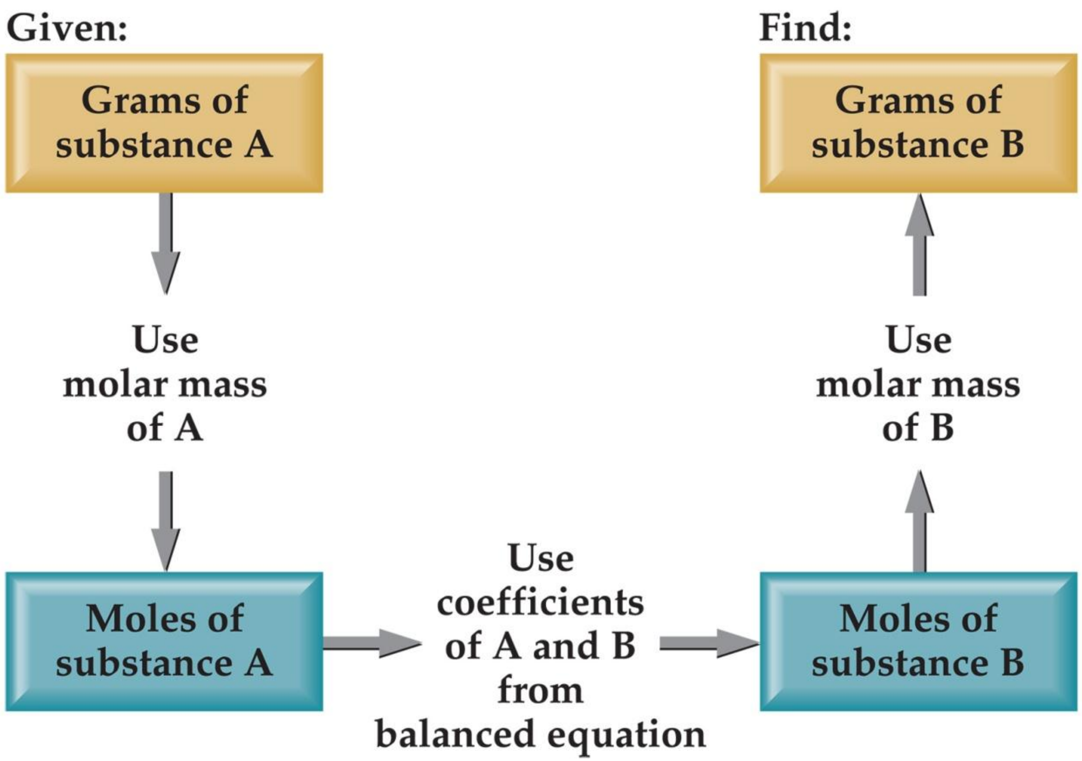
Stoichiometric Calculations

Equation:	**$2\ H_2(g)$**	**+**	**$O_2(g)$**	**⟶**	**$2\ H_2O(l)$**
Molecules:	2 molecules H_2	+	1 molecule O_2	⟶	2 molecules H_2O
					
Mass (amu):	4.0 amu H_2	+	32.0 amu O_2	⟶	36.0 amu H_2O
Amount (mol):	2 mol H_2	+	1 mol O_2	⟶	2 mol H_2O
Mass (g):	4.0 g H_2	+	32.0 g O_2	⟶	36.0 g H_2O

The coefficients in the balanced equation give the ratio of *moles* of reactants and products

Stoichiometric Calculations

From the mass of Substance A you can use the ratio of the coefficients of A and B to calculate the mass of Substance B formed (if it's a product) or used (if it's a reactant)



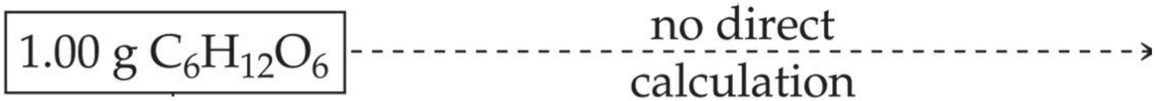
How many grams of water are produced in the oxidation of 1.00 g of glucose, $C_6H_{12}O_6$?

$$C_6H_{12}O_6(s) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$$

$$C_6H_{12}O_6(s) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$$

Stoichiometric Calculations

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$



Starting with 1.00 g of $C_6H_{12}O_6$…

we calculate the moles of $C_6H_{12}O_6$…

use the coefficients to find the moles of H_2O…

and then turn the moles of water to grams

Stoichiometry

- The decomposition of $KClO_3$ is commonly used to prepare small amounts of O_2 in the laboratory:

  $KClO_3(s) \rightarrow KCl(s) + O_2(g)$.

  How many grams of O_2 can be prepared from 4.50 g of $KClO_3$?

$$2\ KClO_3(s) \rightarrow 2\ KCl(s) + 3\ O_2(g).$$

Molar masses:

$KClO_3$ = K + Cl + O x 3 =

KCl = K + Cl =

Solid lithium hydroxide is used in space vehicles to remove the carbon dioxide exhaled by astronauts. The lithium hydroxide reacts with gaseous carbon dioxide to form solid lithium carbonate and liquid water.

How many grams of carbon dioxide can be absorbed by 1.00 g of lithium hydroxide

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How many grams of carbon dioxide can be absorbed by 1.00 g of lithium hydroxide

$$2\ LiOH(s) + CO_2(g) \rightarrow Li_2CO_3(s) + H_2O(l)$$

Grams LiOH → moles LiOH → moles CO_2 → grams CO

Molar mass of LiOH= 6.94 + 16.00 + 1.01 = 23.95 g/mol

CO_2=12.01 + 2(16.00) = 44.01 g/mol.

$$2\ \text{LiOH}(s) + \text{CO}_2(g) \rightarrow \text{Li}_2\text{CO}_3(s) + \text{H}_2\text{O}(l)$$

olve

$$(1.00\ \text{g LiOH})\left(\frac{1\ \text{mol LiOH}}{23.95\ \text{g LiOH}}\right)\left(\frac{1\ \text{mol CO}_2}{2\ \text{mol LiOH}}\right)\left(\frac{44.01\ \text{g CO}_2}{1\ \text{mol CO}_2}\right) = 0.919\ \text{g CO}_2$$

Questions/11th edition

1. 3.52 (b) and
2. 3.77

Due Monday 21st June 2010

Limiting Reactants

Stoichiometry

- To make cookies you need 2 eggs
-

Stoichiometry

To Make 24 cookies you need

- 2 3/4 cups all-purpose flour
- 1 teaspoon baking soda
- 1/2 teaspoon baking powder
- 1 cup butter, softened
- 1 1/2 cups white sugar
- 1 egg
- 1 teaspoon vanilla extract

How many cookies can you make with 1 cup sugar and unlimited amount of other ingredients

A. As many as you want

B. 10 cookies

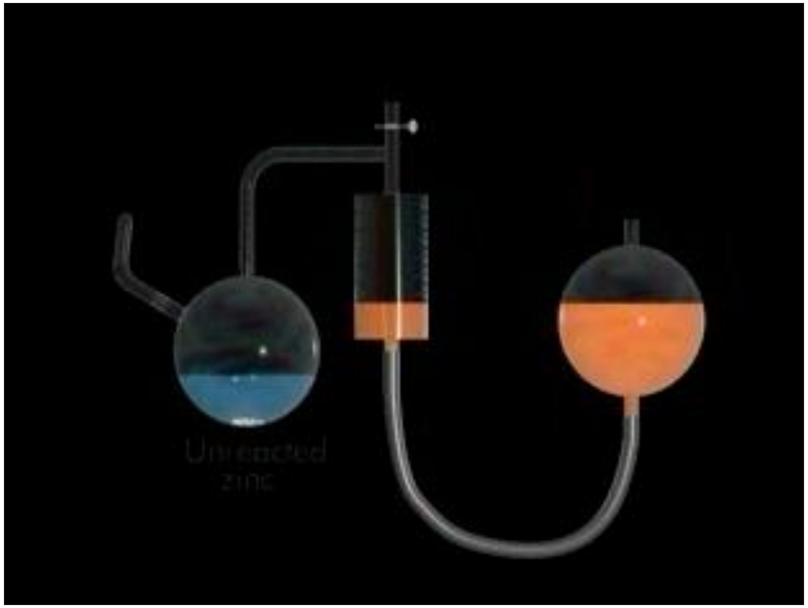
C. 16 cookies

D. 24 cookies

Stoichiometry

Limiting Reactants

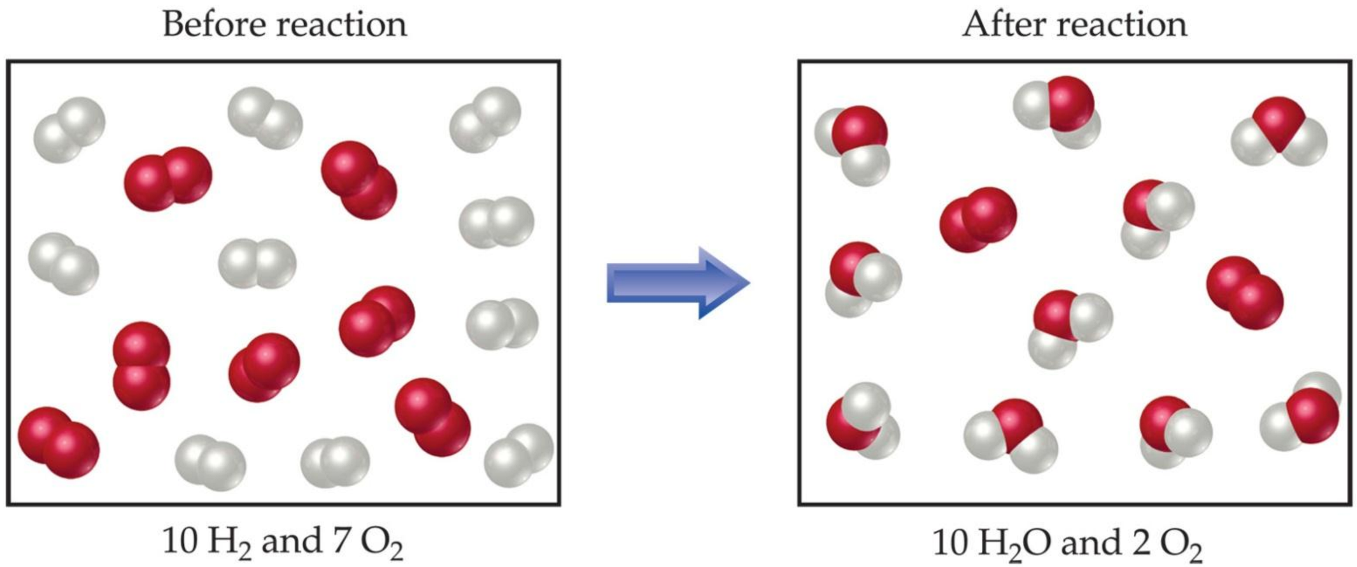
The limiting reactant is the reactant present in the smallest stoichiometric amount



Limiting Reactants

In a reaction :

$$2H_2 + O_2 \rightarrow 2H_2O$$

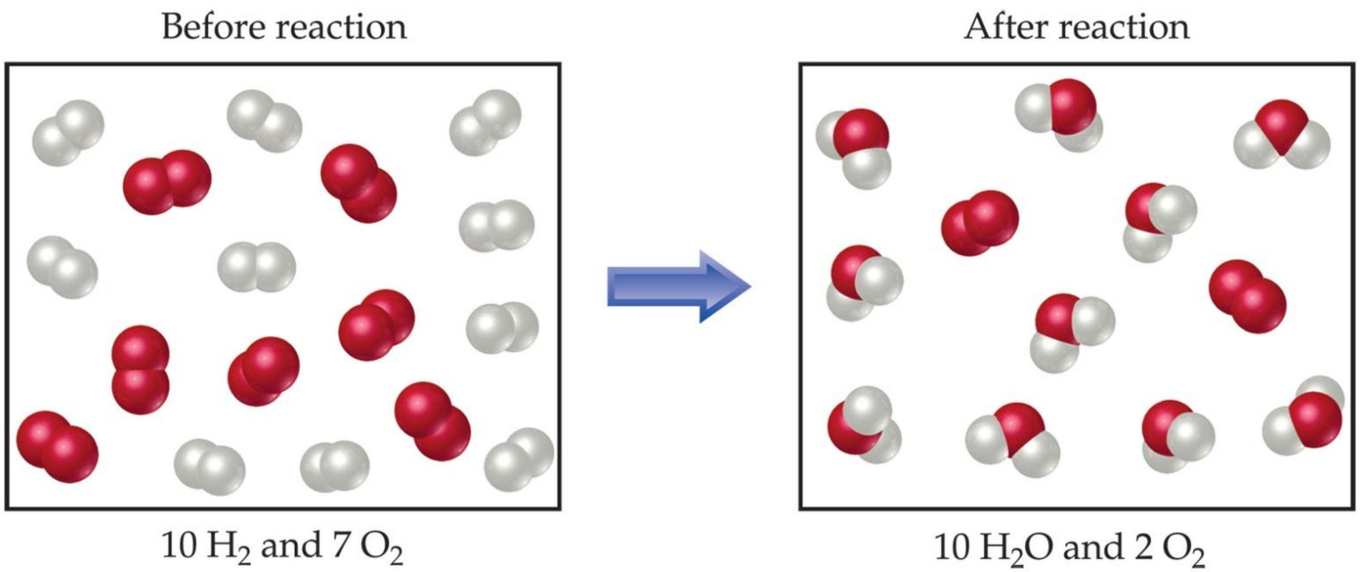


The limiting reactant is the reactant present in the smallest stoichiometric amount

- In other words, it's the reactant you'll run out of first (in this case, the H_2)

Limiting Reactants

In the example below, the O_2 would be the excess reagent



Stoichiometry

Suppose if we take 5 g of H_2 and 5 g of O_2

Can you tell which component is limiting without converting it to moles?

Suppose if we take 5 g of H_2 and 5 g of O_2

Can you tell which component is limiting without converting it to moles?

No

The most important commercial process for converting N_2 from the air into nitrogen-containing compounds is based on the reaction of N_2 and H_2 to form ammonia (NH_3):

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

How many moles of NH_3 can be formed from 3.0 mol of N_2 and 6.0 mol of H_2?

Consider the reaction 2 Al(*s*) + 3 Cl_2(*g*) $\rightarrow$ 2 $AlCl_3$(*s*). A mixture of 1.50 mol of Al and 3.00 mol of Cl_2 is allowed to react.

(a) Which is the limiting reactant?

(b) How many moles of $AlCl_3$ are formed?

(c) How many moles of the excess reactant remain at the end of the reaction?

Consider the following reaction that occurs in a fuel cell:

$$2\ H_2(g) + O_2\ (g) \rightarrow 2\ H_2O\ (g)$$

This reaction, properly done, produces energy in the form of electricity and water. Suppose a fuel cell is set up with 150 g of hydrogen gas and 1500 grams of oxygen gas (each measurement is given with two significant figures). How many grams of water can be formed

150 g of hydrogen =75 moles of H_2

1500 grams of oxygen = 47 moles of O_2

Theoretical Yield

- The theoretical yield is the amount of product that can be made
  - In other words it's the amount of product possible as calculated through the stoichiometry problem
- This is different from the actual yield, the amount one actually produces and measures

Percent Yield

A comparison of the amount actually obtained to the amount it was possible to make

$$\text{Percent Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100$$

Stoichiometry