Chapter 3

Chemical Reactions and Reaction Stoichiometry (化学计量)

By Zhen-Yu Wu

Key items

- Chemical Equations
- Types of Chemical Reactions
- Formula Weights
- Avogadro's Number and the Mole
- *Empirical Formulas from Analysis
- Quantitative Information from Balanced Equations
- *Limiting Reactants

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Stoichiometry

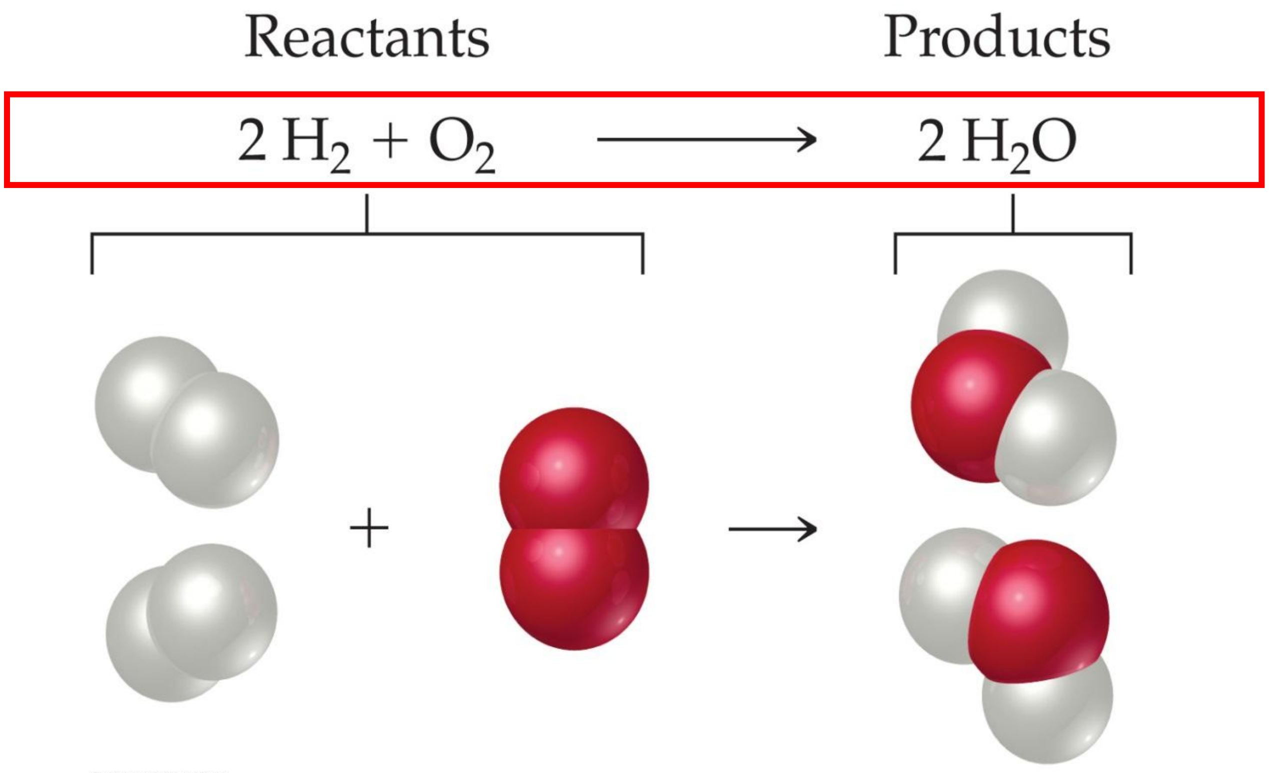
- The study of the mass relationships in chemical reactions
- Based on the Law of Conservation of Mass (Antoine Lavoisier, 1789)

"We may lay it down as an incontestable (无可争辩) axiom (原则) 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

➢ Chemical Equations(化学方程式)

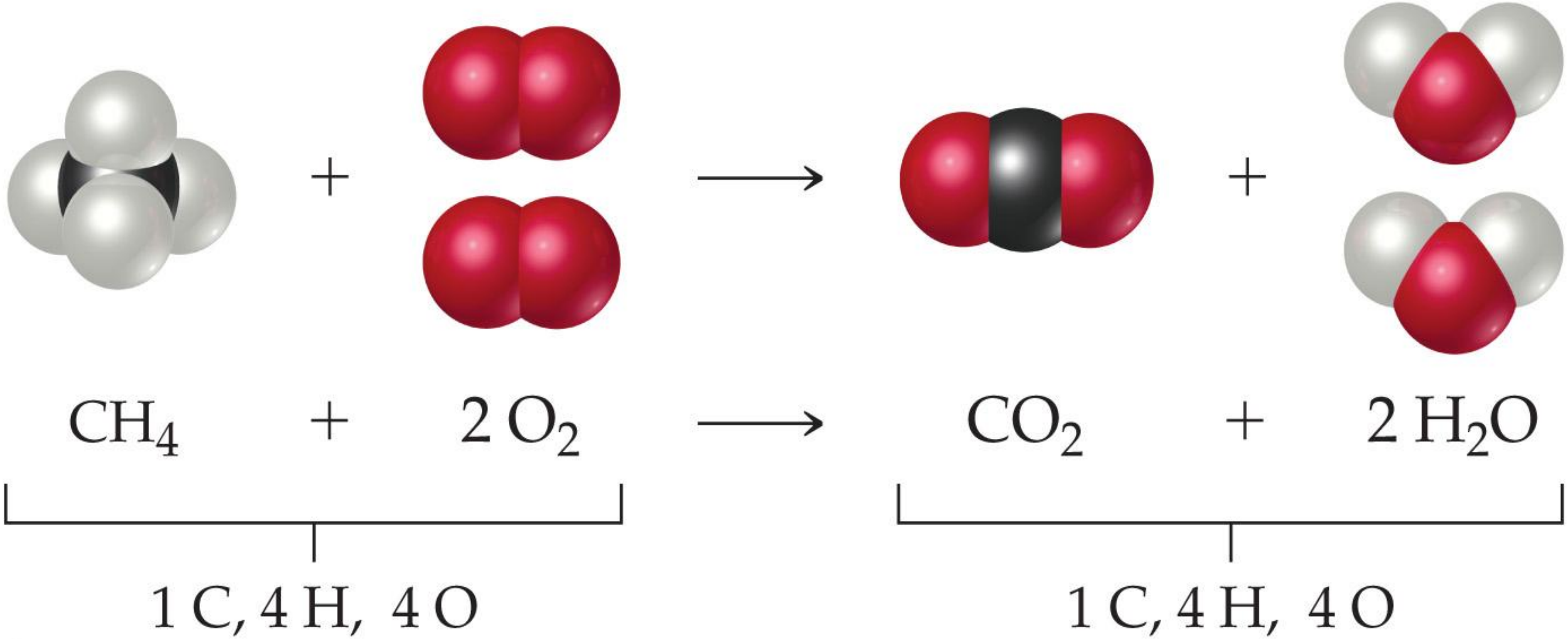
- **Chemical equations** are concise representations of chemical reactions.



concise (简明)

➢ Anatomy(剖析) of a Chemical Equation

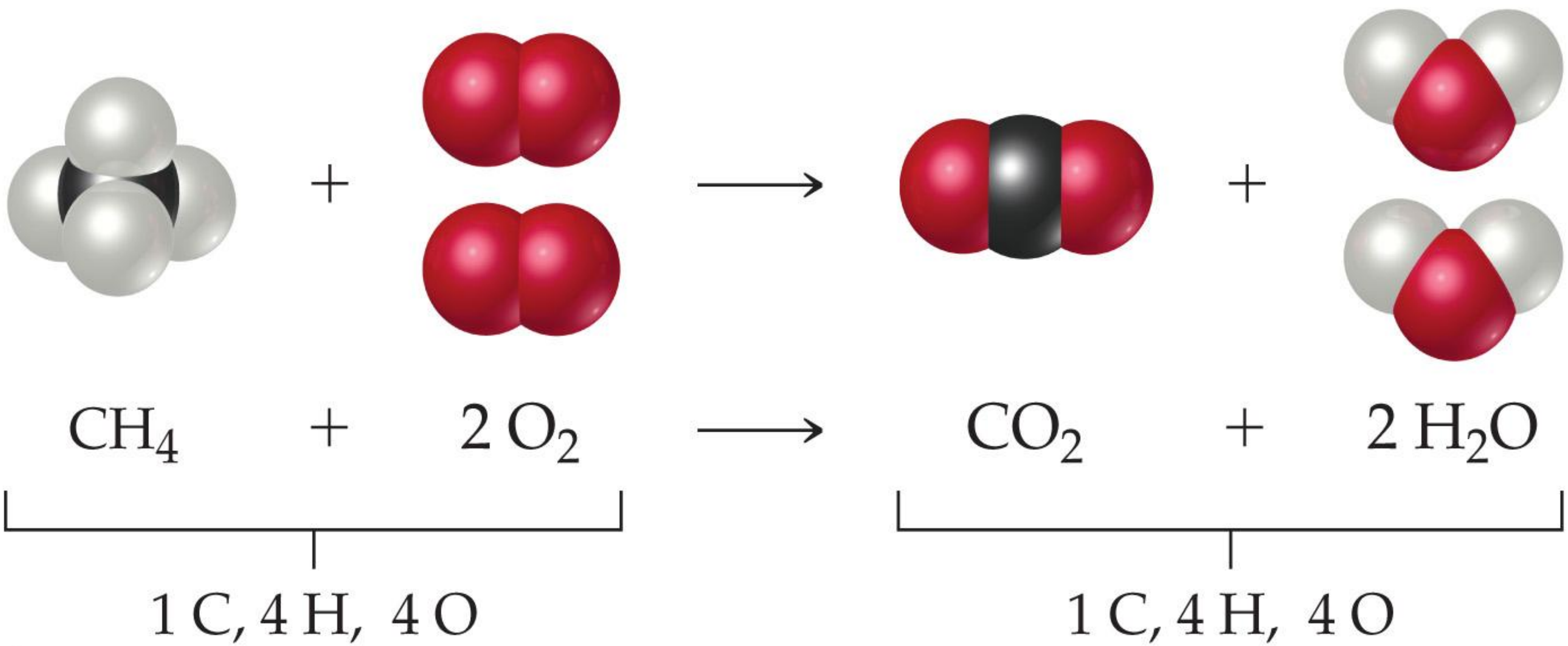
$$\boxed{CH_4(g) + 2O_2(g)} \longrightarrow CO_2(g) + 2H_2O(g)$$



Reactants appear on the left side of the equation

➢ Anatomy(分析) of a Chemical Equation

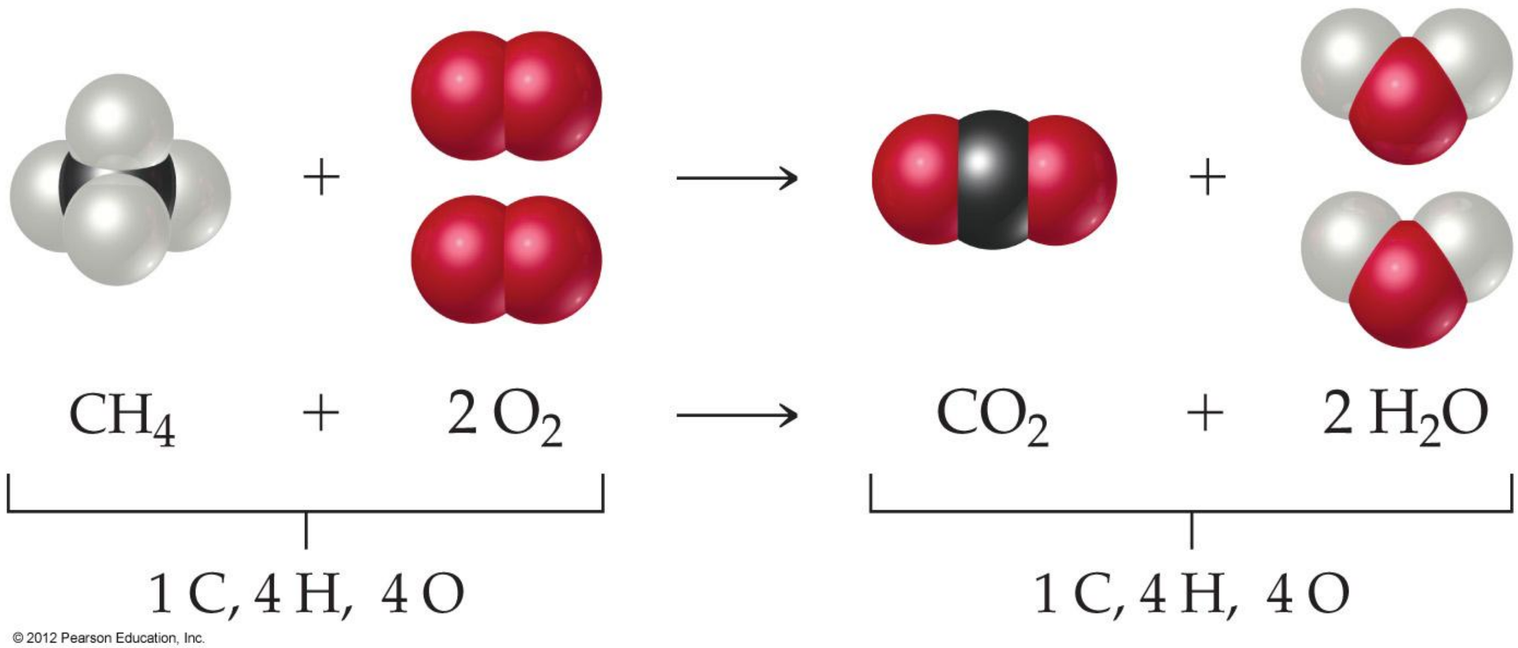
$$CH_4(g) + 2O_2(g) \longrightarrow \boxed{CO_2(g) + 2H_2O(g)}$$



Products appear on the right side of the equation

➢ Anatomy(分析) of a Chemical Equation

$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$$

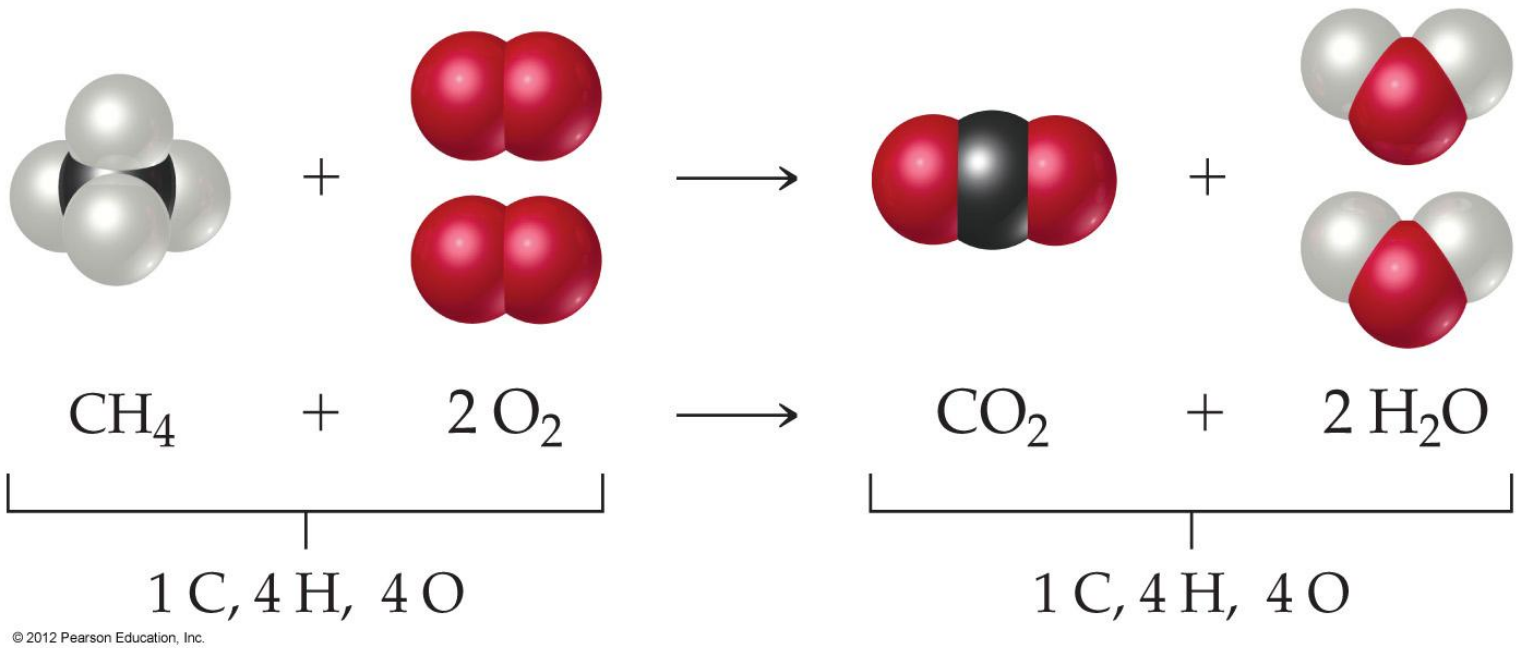


The **states** of the reactants and products are written in parentheses(括号) to the right of each compound

(*g*), (*l*), (*s*) and (*aq*) for gas, liquid, solid and aqueous solution, respectively

➢ Anatomy(分析) of a Chemical Equation

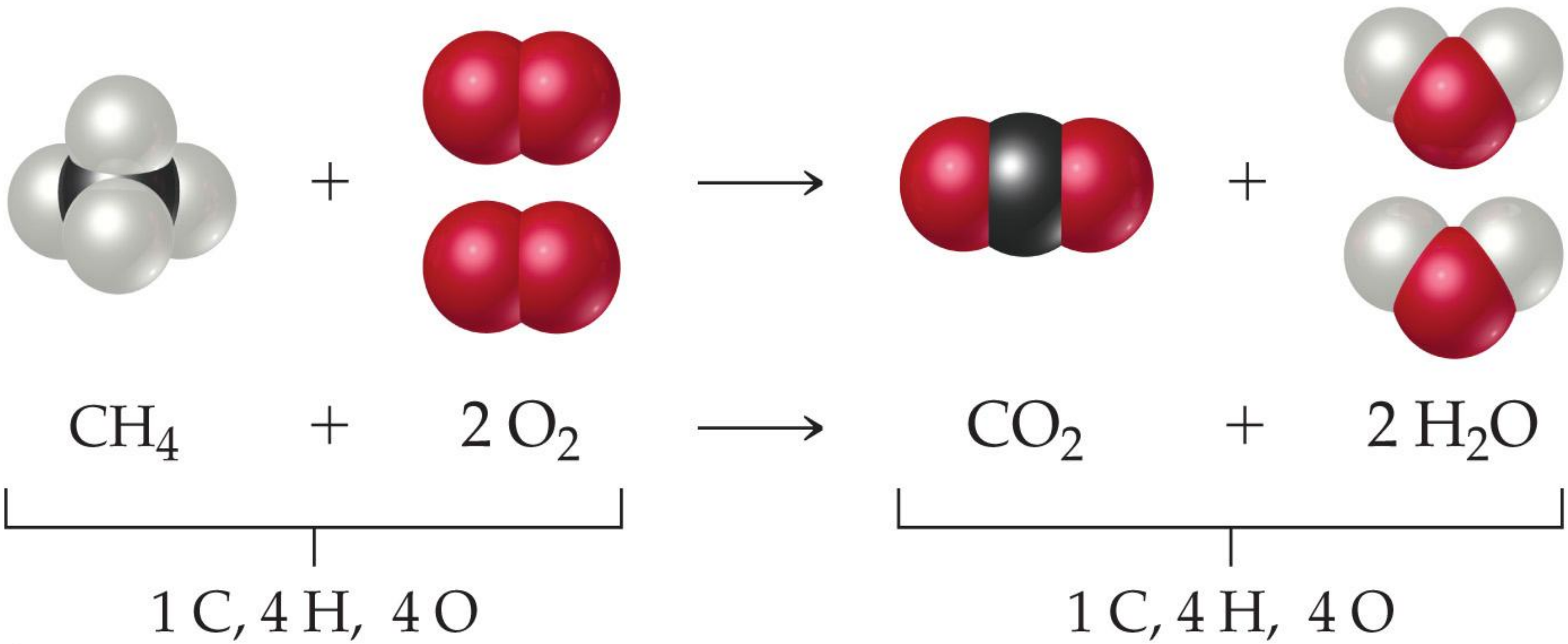
$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$$



Reaction conditions may be presented. Such as temperature, pressure, catalyst…

➢ Anatomy(分析) of a Chemical Equation

$$CH_4(g) + \underline{2}O_2(g) \longrightarrow CO_2(g) + \underline{2}H_2O(g)$$



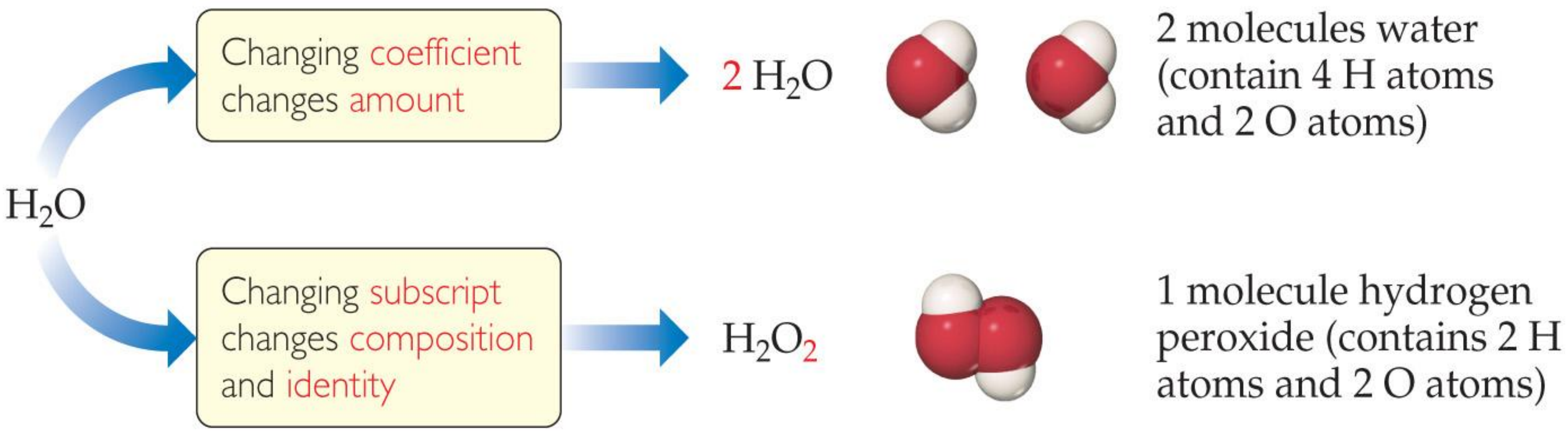
Coefficients(系数) are inserted to balance the equation, following the law of conservation of mass

Subscripts and Coefficients Give Different Information

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

$2H_2O$

- **Coefficients** tell the number of molecules



Subscripts and Coefficients Give Different Information

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

- **Coe**

Law of constant proportion 定比定律

即每一种化合物，不论是天然存在的，还是人工合成的，也不论它是用什么方法制备的，其组成元素的质量比一定。

Law of multiple proportion 倍比定律

若两元素可以生成两种或以上的化合物时，在这些化合物中，一元素的质量固定，则另一元素的质量呈简单整数比。

GIVE IT SOME THOUGHT

How many atoms of Mg, O, and H are represented by the notation 3 $Mg(OH)_2$?

A. 1 Mg, 2 O, and 2 H

B. 2 Mg, 2 O, and 2 H

C. 6 Mg, 6 O, and 6 H

D. 3 Mg, 6 O, and 6 H

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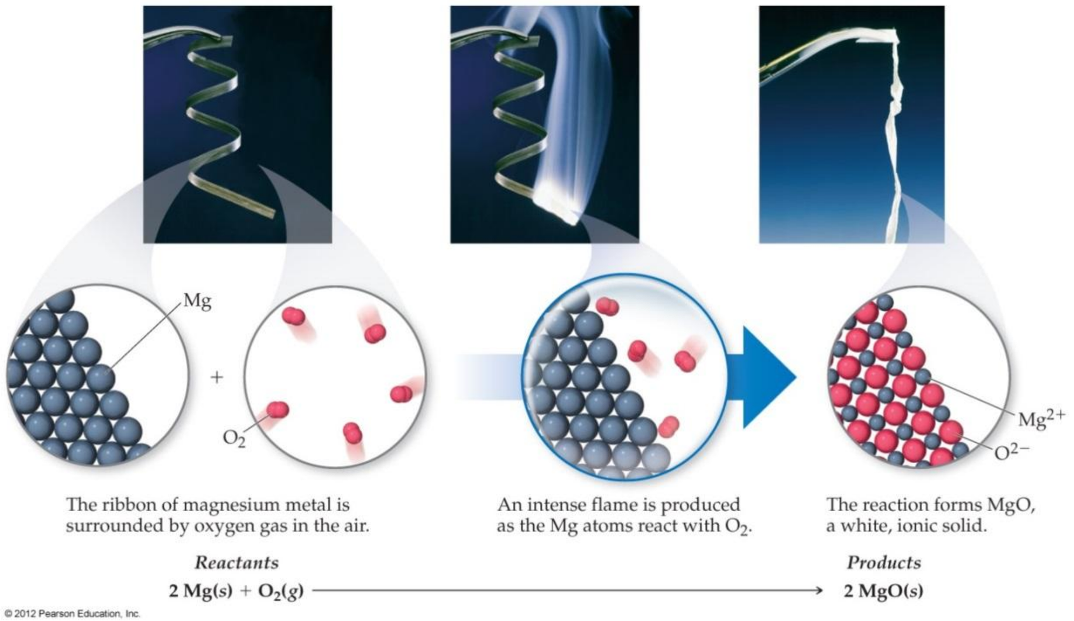
Reaction Types (Simple Reactions)

- Combination Reactions(化合反应)
- Decomposition Reactions(分解)
- Combustion Reactions(燃烧)
- many others...

Combination Reactions



- In **combination reactions** two or more substances react to form one product.

- Examples:
  - $2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$
  - $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$

(化学氮肥，集约化农业的基石)

  - $C_3H_6(g) + Br_2(l) \longrightarrow C_3H_6Br_2(l)$

GIVE IT SOME THOUGHT

If 20.00 g of a compound reacts completely with 30.00 g of another compound in a combination reaction, how many grams of product are formed?

A. 10.00 g

B. 20.00 g

C. 30.00 g

D. 50.00 g

GIVE IT SOME THOUGHT

If 20.00 g of a compound reacts completely with 30.00 g of another compound in a combination reaction, how many grams of product are formed?

A. 10.00 g

B. 20.00 g

C. 30.00 g

D. 50.00 g

Decomposition Reactions

- In a **decomposition reaction** one substance breaks down into two or more substances.

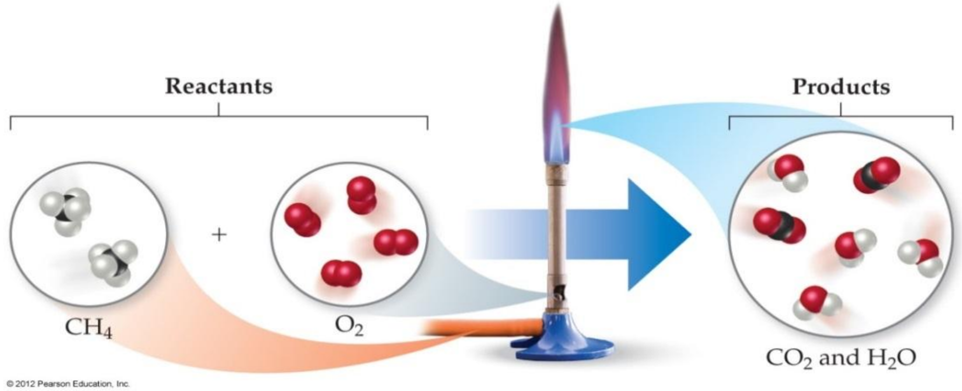
sodium trinitride

Sodium azide

(叠氮酸钠)

- Examples:
  - $CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$
  - $2KClO_3(s) \longrightarrow 2KCl(s) + O_2(g)$
  - $\mathbf{2NaN_3(s) \longrightarrow 2Na(s) + 3N_2(g)}$

Combustion Reactions



- **Combustion reactions** are generally rapid reactions that produce a flame
- **Combustion reactions** most often involve reacting with oxygen in the air
- Examples:
  - $CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$
  - $C_3H_8(g) + 5O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(g)$

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➢ Formula Weight (FW化学式量)

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

$$\begin{array}{r} \text{Ca: } 1(40.08 \text{ amu}) \\ \underline{+\ \text{Cl: } 2(35.453 \text{ amu})} \\ 110.99 \text{ amu} \end{array}$$

- Formula weights are generally reported for **ionic compounds**

➢ Molecular Weight (MW)

- A **molecular weight** is the sum of the atomic weights of the atoms in a molecule
- For the molecule ethane, C_2H_6, the molecular weight would be

$$\begin{array}{rl} C: & 2(12.011\ \text{amu}) \\ +\ H: & 6(1.00794\ \text{amu}) \\ \hline & 30.070\ \text{amu} \end{array}$$

NaCl-----formula weight!

Percent Composition

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

- So the percentage of carbon in ethane (C_2H_6) is

atomic weight of C = 12.011 amu
MW of C_2H_6 = 30.070 amu

Element analysis
(元素分析)

$$\%C = \frac{(2)(12.011 \text{ amu})}{(30.070 \text{ amu})}$$

$$= \frac{24.022 \text{ amu}}{30.070 \text{ amu}} \times 100$$

$$= 79.887\%$$

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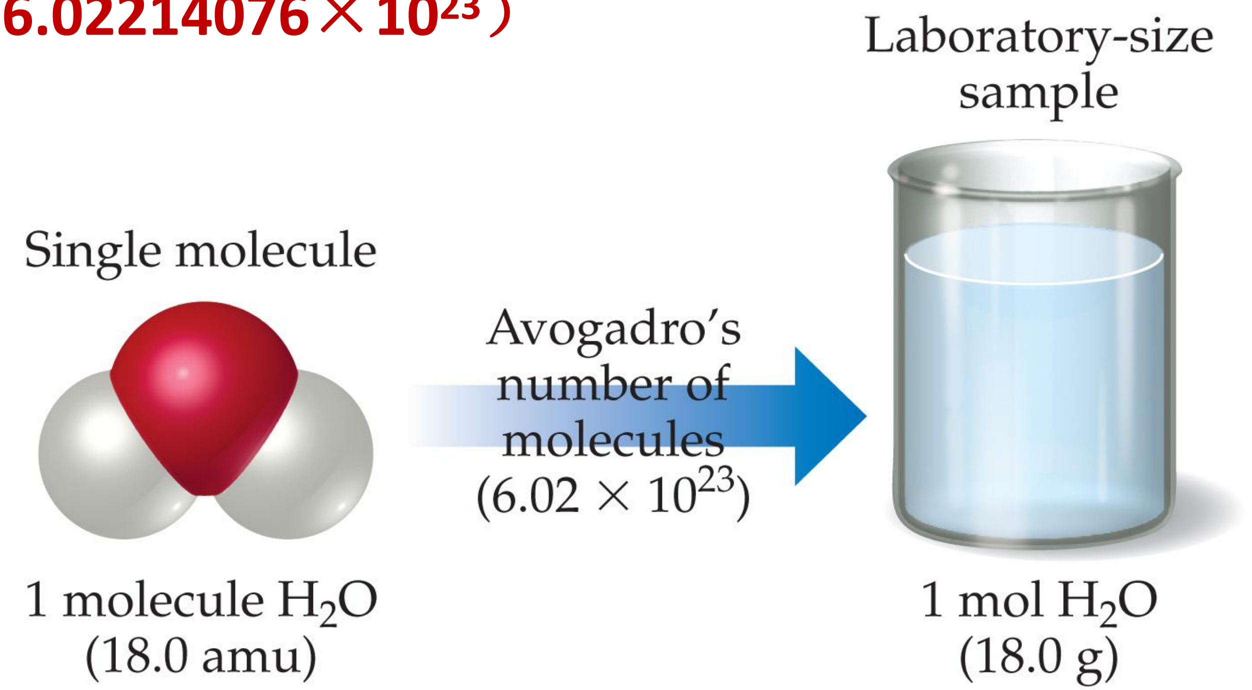
Moles

物理量	常用符号	单位名称	单位符号
长度	*L*	米（又称“公尺”）	m
质量	*m*	千克（又称“公斤”）	kg
时间	*t*	秒	s
电流	*I*	安[培]	A
热力学温度	*T*	开[尔文]	K
物质的量	***n***	**摩[尔]**	**mol**
发光强度	*Iv*	坎[德拉]	cd

Avogadro's Number

- 1 mole of ^{12}C has a mass of 12.000 g
- Then from experiments, **1 amu ≈ 1.66 × 10^(-24) g**
- 1 mole (objects) ~ 6.02×10^{23} (objects)

（2018年11月16日，国际计量大会通过决议，1mol精确为$6.02214076 \times 10^{23}$）



Molar Mass

- By definition, **molar mass** is the mass of 1 mol of a substance (i.e., g/mol)
  - How many grams of a substance per mole
  - The molar mass of an element is the atomic weight (atomic mass) for the element that we find on the periodic table. If it is diatomic, it is twice that atomic weight.
  - The formula weight (in amu's) will be the same number as the molar mass (in g/mol)

!

GIVE IT SOME THOUGHT

a. Which has more mass, a mole of water (H_2O) or a mole of glucose ($C_6H_{12}O_6$)?

b. Which contains more molecules, a mole of water or a mole of glucose?

a.

A. Mole of glucose

B. Mole of water

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b.

A. Mole of water

B. Mole of glucose

C. Requires Avogadro’s number to answer question

D. They both contain the same number of molecules

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b.

A. Mole of water

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➢ Mole Relationships

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

TABLE 3.2 • 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	6.02×10^{23} N atoms
Molecular nitrogen	N_2	28.0	28.0	6.02×10^{23} N_2 molecules $2(6.02 \times 10^{23})$ N atoms
Silver	Ag	107.9	107.9	6.02×10^{23} Ag atoms
Silver ions	Ag^+	107.9*	107.9	6.02×10^{23} Ag^+ ions
Barium chloride	$BaCl_2$	208.2	208.2	6.02×10^{23} $BaCl_2$ formula units 6.02×10^{23} Ba^{2+} ions $2(6.02 \times 10^{23})$ Cl^- ions

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

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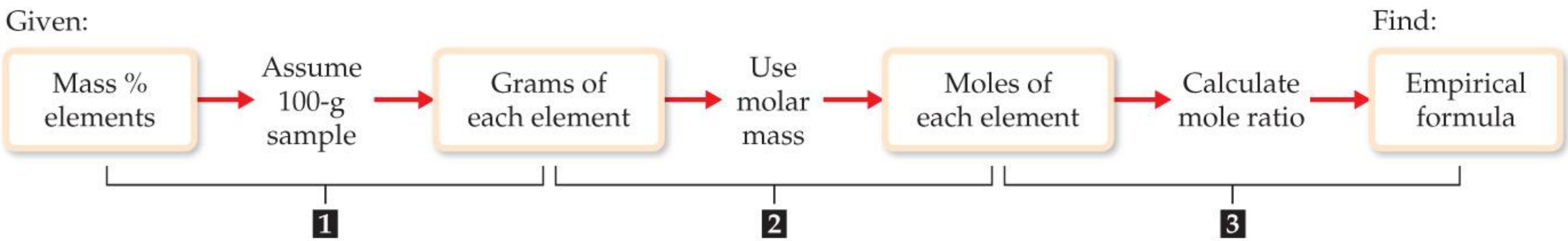
Calculating Empirical Formulas

- One can calculate the empirical formula from the percent composition.



- The compound *para*-**a**mino**b**enzoic **a**cid(对氨基苯甲酸 you may have seen it listed as PABA on your bottle of sunscreen/sunblock) 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,

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

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

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

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

Calculating Empirical Formulas

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

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

$$\text{H:} \quad \frac{5.09 \text{ mol}}{0.7288 \text{ mol}} = 6.98 \approx 7$$

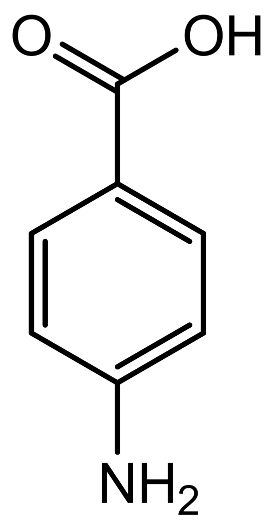
$$\text{N:} \quad \frac{0.7288 \text{ mol}}{0.7288 \text{ mol}} = 1.000$$

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

Calculating Empirical Formulas

These are the subscripts for the empirical formula:

$C_7H_7NO_2$



para-aminobenzoic acid

对氨基苯甲酸

机体细胞生长和分裂所必需的物质

叶酸的组成部分之一

Determining a Molecular Formula

(empirical formula) x n = molecular formula

empirical formula weight

(real) formula weight or molar mass

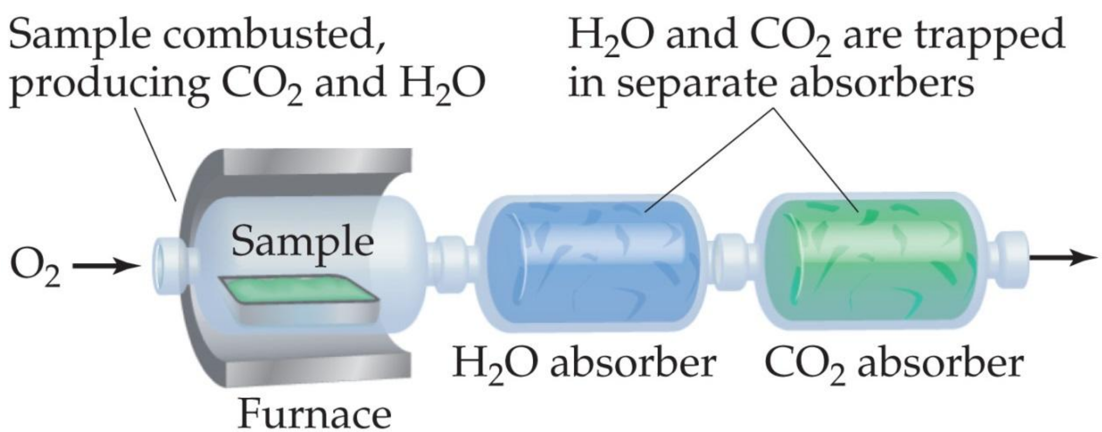
- The empirical formula of a compound was found to be CH. (13 amu)
- It has a molar mass of 78 g/mol. (78 amu)

What is its molecular formula? (78/13 = 6 =n) M.F. = 6(EF) = 6(CH) = $\mathbf{C_6H_6}$.

Combustion Analysis

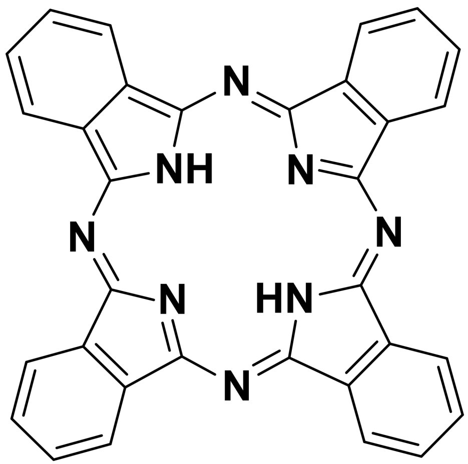
- Compounds containing C, H, and O are routinely(常规) analyzed through combustion in a chamber like the one shown in Figure 3.14.
  - C is determined from the mass of CO_2 produced.
  - H is determined from the mass of H_2O produced.
  - O is determined by difference after the C and H have been determined.

Reacts completely!



Mass gained by each absorber corresponds to mass of CO_2 or H_2O produced

➢ Elemental analysis



Phthalocyanine酞菁

$C_{32}H_{18}N_8$, MW 514.17

Anal%: C 74.7, H 3.53, N 21.78

Mass spectrometry
Optical spectrometry
Various electron spectrometry
…

TQ-3A型碳氢元素分析仪

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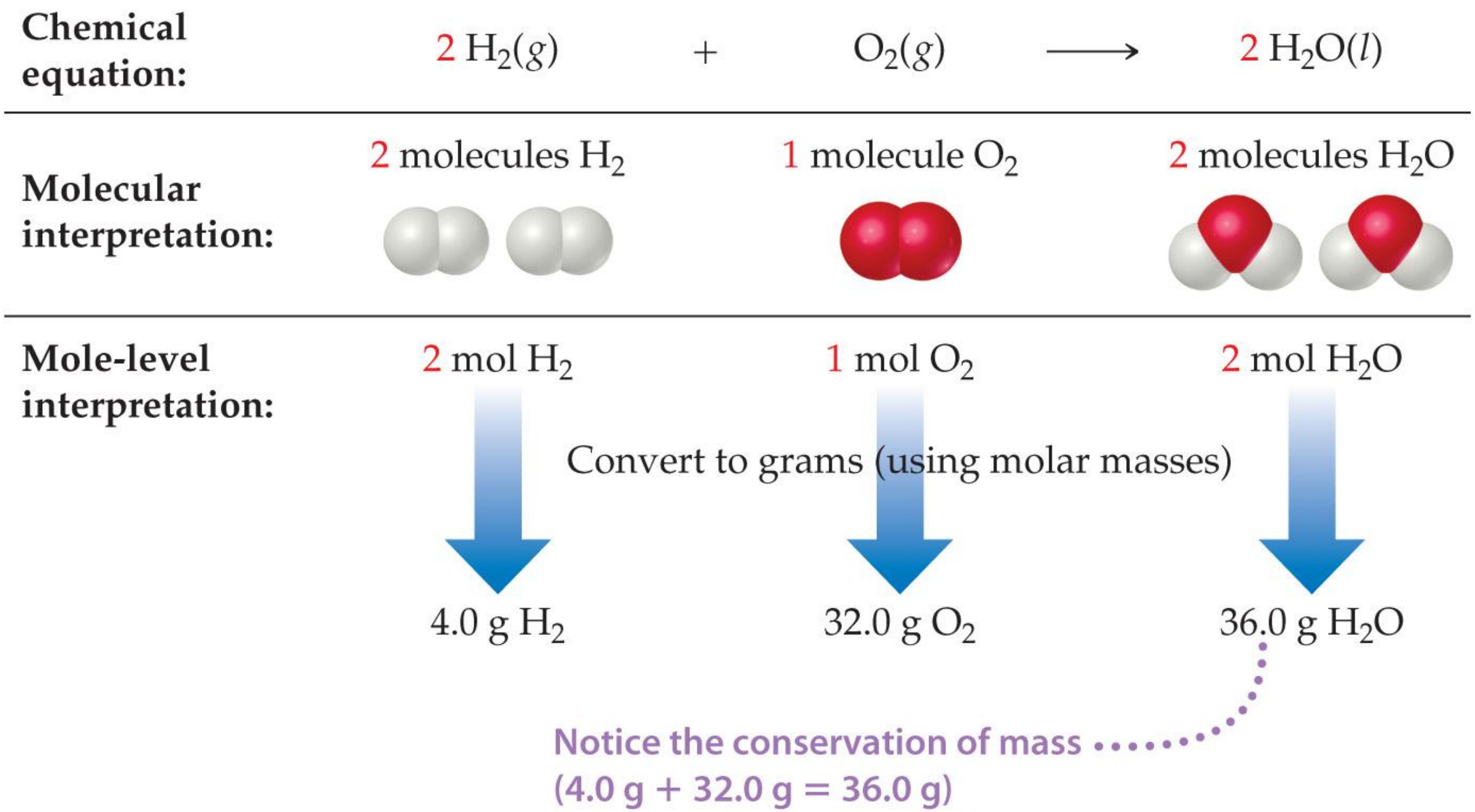
➢ Balancing Equations

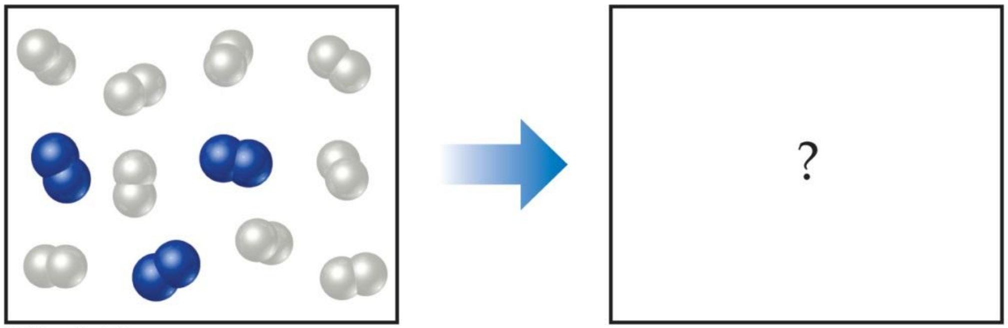
- The coefficients in the balanced equation give the ratio of *moles* of reactants and products.



Sample Exercise 3.1 Interpreting and Balancing Chemical Equations

Practice Exercise

In the following diagram, the white spheres represent hydrogen atoms and the blue spheres represent nitrogen atoms.



To be consistent with the law of conservation of mass, how many NH_3 molecules should be shown in the right (products) box?

Answer:

Six NH_3 molecules; $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$

Writing Balanced Equations for Combustion Reactions

Sample Exercise 3.4 Write the balanced equation for the reaction that occurs when methanol, $CH_3OH(l)$, is burned in air.

Solution

When any compound containing C, H, and O is combusted, it reacts with the $O_2(g)$ in air to produce $CO_2(g)$ and $H_2O(g)$. The unbalanced equation is

$$CH_3OH(l) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$

C atoms are balanced, the coefficient 2 in front of H_2O was placed to balance H atoms

$$CH_3OH(l) + O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$$

C and H atoms are balanced, the products have 4 O atoms, then add 3/2 to O_2

$$CH_3OH(l) + 3/2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$$

Conventionally, change the coefficients into integer

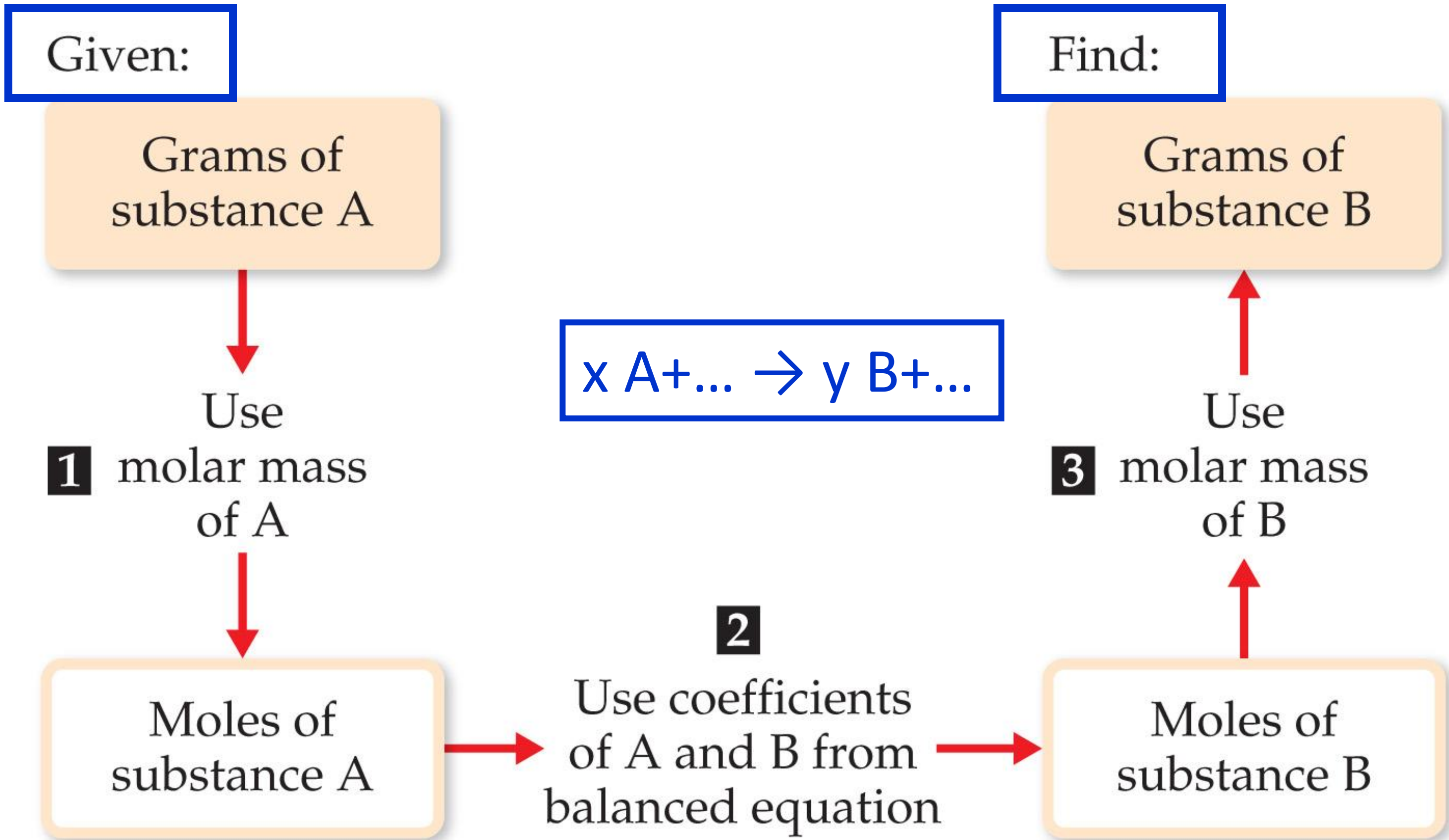
$$2\ CH_3OH(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 4\ H_2O(g)$$

Practice Exercise: Write the balanced equation for the reaction that occurs when ethanol, $C_2H_5OH(l)$, burns in air

Answer: $C_2H_5OH(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$

➢ Stoichiometric Calculations (molar ratio)

- Starting with 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).

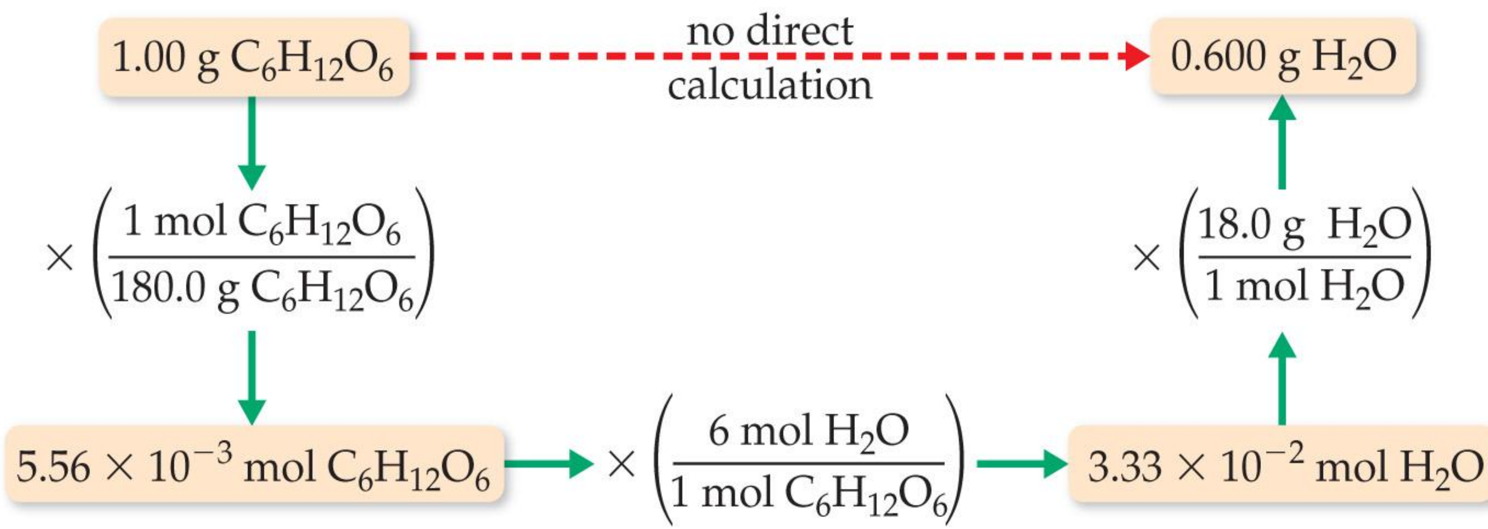


➢ Stoichiometric Calculations (molar ratio)

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

1.00 g ? g

Determine how many grams of water are produced in the oxidation of 1.00g of glucose, $C_6H_{12}O_6$:



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

Sample Exercise 3.17 Calculating Amounts of Reactants and Products

Continued

Practice Exercise

Propane, C_3H_8 (Figure 3.8), is a common fuel used for cooking and home heating. What mass of O_2 is consumed in the combustion of 1.00 g of propane?

FIGURE 3.8 Propane burning in air. Liquid propane in the tank, C_3H_8, vaporizes and mixes with air as it escapes through the nozzle. The combustion reaction of C_3H_8 and O_2 produces a blue flame.

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

$1.00g\ C_3H_8 = 1/44 = 0.0227$ mole

$0.0227x5 = 0.1136$ mole O_2 required

$= 0.1136x32 = 3.636 = 3.64g$

Answer: 3.64 g

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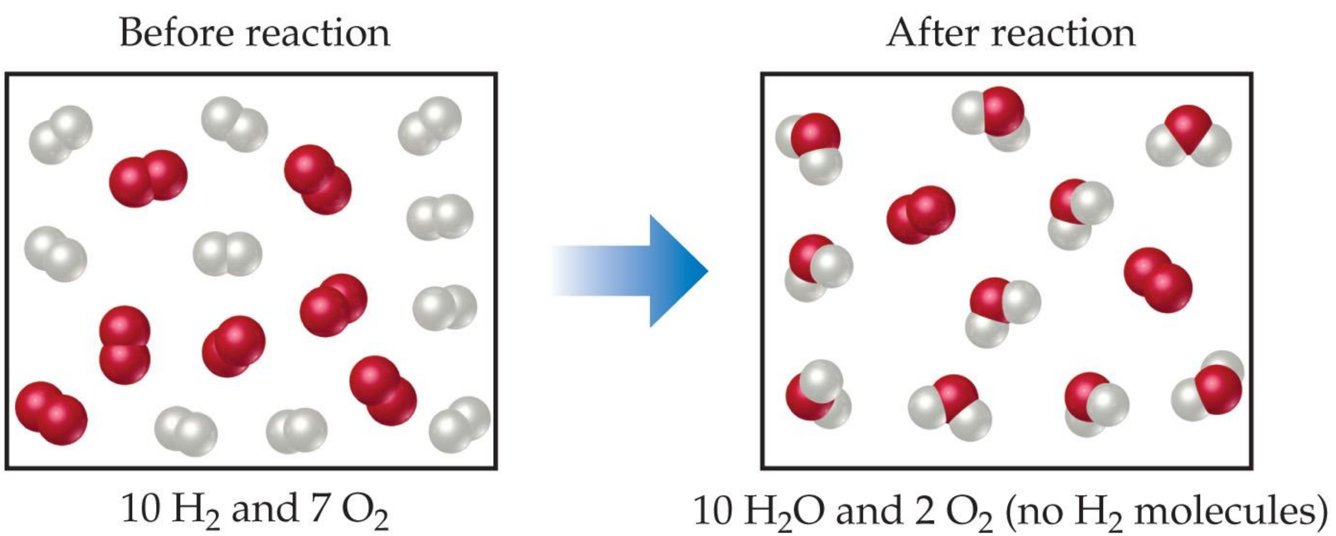
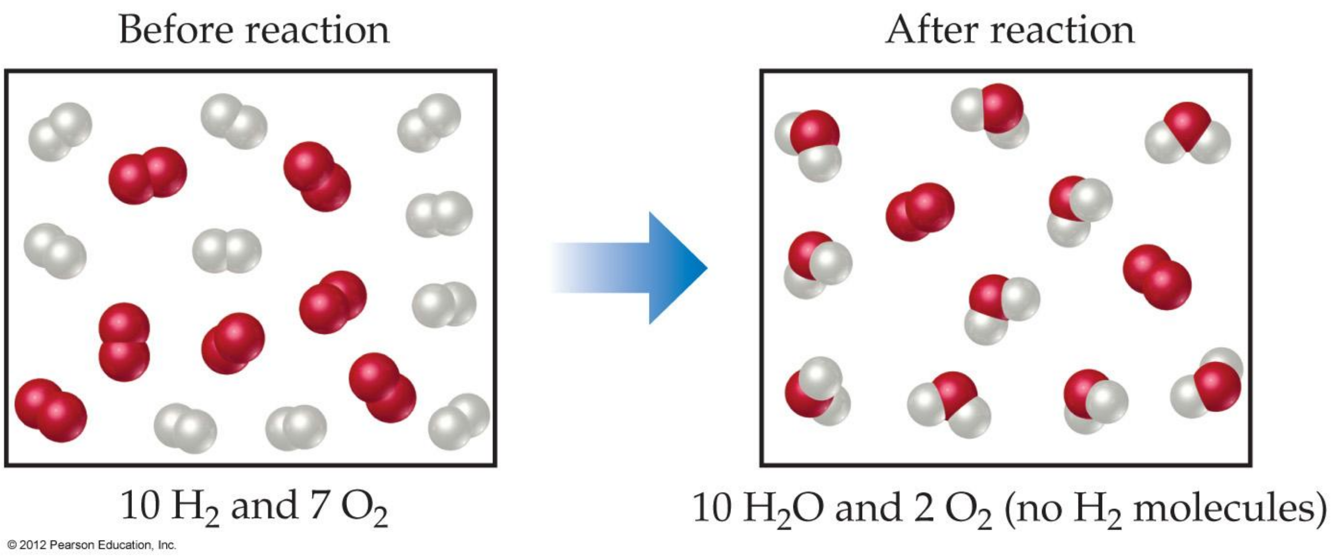
Limiting Reactants

- 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**



Sample Exercise 3.18 Calculating the Amount of Product Formed from a Limiting Reactant

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?

	$N_2(g)$	+	$3\ H_2(g)$	$\longrightarrow$	$2\ NH_3(g)$
Initial quantities:	3.0 mol		6.0 mol		0 mol
Change (reaction):	−2.0 mol		−6.0 mol		+4.0 mol
Final quantities:	1.0 mol		0 mol		4.0 mol

Theoretical Yield

- The **theoretical yield** is the maximum 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,** which is the amount one actually produces and measures

Percent yield

- One finds the **percent yield** by comparing the amount actually obtained (actual yield) to the amount it was possible to make (theoretical yield):

$$\boxed{\text{Percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%}$$

Sample Exercise 3.20 Calculating Theoretical Yield and Percent Yield

Adipic acid, $H_2C_6H_8O_4$, used to produce nylon, is made commercially by a reaction between cyclohexane (C_6H_{12}) and O_2:

$$2\ C_6H_{12}(l) + 5\ O_2(g) \longrightarrow 2\ H_2C_6H_8O_4(l) + 2\ H_2O(g)$$

(a) Assume that you carry out this reaction with 25.0 g of cyclohexane and that cyclohexane is the limiting reactant.
What is the theoretical yield of adipic acid? **(b)** If you obtain 33.5 g of adipic acid, what is the percent yield for the reaction?

Solution

Analyze We are given a chemical equation and the quantity of the limiting reactant (25.0 g of C_6H_{12}).We are asked to calculate the theoretical yield of a product $H_2C_6H_8O_4$ and the percent yield if only 33.5 g of product is obtained.

Plan

(a) The theoretical yield, which is the calculated quantity of adipic acid formed, can be calculated using the sequence of conversions shown in Figure 3.16.

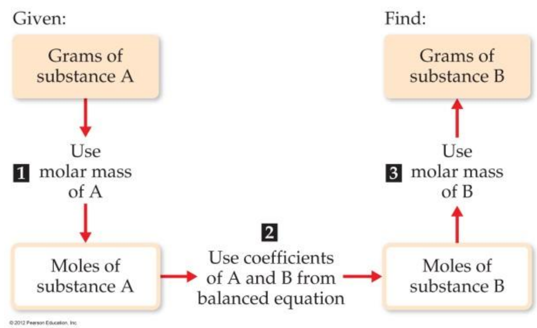


FIGURE 3.16 Procedure for calculating amounts of reactants consumed or products formed in a reaction. The number of grams of a reactant consumed or product formed can be calculated in three steps, starting with the number of grams of any reactant or product. Notice how molar masses and the coefficients in the balanced equation are used.

Sample Exercise 3.20 Calculating Theoretical Yield and Percent Yield

Continued

(b) The percent yield is calculated by using Equation 3.14 to compare the given actual yield (33.5 g) with the theoretical yield.

Solve

(a) The theoretical yield is

$$\text{Grams } H_2C_6H_8O_4 = (25.0\ \cancel{\text{g } C_6H_{12}})\left(\frac{1\ \cancel{\text{mol } C_6H_{12}}}{84.0\ \cancel{\text{g } C_6H_{12}}}\right)\left(\frac{2\ \cancel{\text{mol } H_2C_6H_8O_4}}{2\ \cancel{\text{mol } C_6H_{12}}}\right)\left(\frac{146.0\text{ g } H_2C_6H_8O_4}{1\ \cancel{\text{mol } H_2C_6H_8O_4}}\right)$$

$$= 43.5\text{ g } H_2C_6H_8O_4$$

$$\textbf{(b)}\ \text{Percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\% = \frac{33.5\text{ g}}{43.5\text{ g}} \times 100\% = 77.0\%$$

Check We can check our answer in **(a)** by doing a ballpark calculation. From the balanced equation we know that each mole of cyclohexane gives 1 mol adipic acid. We have 25/84 $\approx$25/75= 0.3 mol hexane, so we expect 0.3 mol adipic acid, which equals about 0.3 $\times$ 150 = 45g, about the same magnitude as the 43.5 g obtained in the more detailed calculation given previously. In addition, our answer has the appropriate units and significant figures. In **(b)** the answer is less than 100%, as it must be from the definition of percent yield.

Key items

- Chemical Equations
- Types of Chemical Reactions
- Formula Weights
- Avogadro's Number and the Mole
- * Empirical Formulas from Analysis
- Quantitative Information from Balanced Equations
- *Limiting Reactants

For the reaction X → Y,
X is referred to as the

a. yield.
b. reactant. 反应物
c. product.
d. coefficient.

For the reaction X $\rightarrow$ Y, X is referred to as the

a. yield.
b. reactant.
c. product.
d. coefficient.

Hydrocarbons burn to form

a. H_2O and CO_2.
b. charcoal.
c. methane.
d. O_2 and H_2O.

Hydrocarbons burn to form

a. H_2O and CO_2.
b. charcoal.
c. methane.
d. O_2 and H_2O.

$C_6H_6 + O_2 \rightarrow CO_2 + H_2O$

When this equation is correctly balanced, the coefficients are

a. 1, 7 → 6, 3.
b. 1, 8 → 6, 3.
c. 2, 15 → 12, 6.
d. 2, 16 → 12, 6.

$C_6H_6 + O_2 \rightarrow CO_2 + H_2O$

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a. 1, 7 → 6, 3.
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c. 2, 15 → 12, 6.
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$2\ NaN_3 \rightarrow 2\ Na + 3\ N_2$

This is an example of a ________ reaction.

a. decomposition
b. combination
c. combustion
d. replacement

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This is an example of a ________ reaction.

a. decomposition
b. combination
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The formula weight of any substance is also known as

a. Avogadro’s number.
b. atomic weight.
c. density.
d. molar mass.

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a. Avogadro's number.
b. atomic weight.
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d. molar mass.

The formula weight of Na_3PO_4 is _________ grams per mole.

a. 70
b. 164
c. 265
d. 116

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a. 70
b. 164
c. 265
d. 116

The percentage by mass of phosphorus in Na_3PO_4 is

a. 44.0.
b. 11.7.
c. 26.7.
d. 18.9.

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$$\boxed{\frac{31}{3x(23) + (31) + 4x(16)} \text{ x100\%}}$$

One millionth of one mole of a noble gas = ________ atoms.

a. 6.02×10^{17}
b. 6.02×10^{20}
c. 6.02×10^{14}
d. Atoms are too small to count.

One millionth (百万份之一) of one mole of a noble gas = _________ atoms.

a. 6.02×10^{17}

b. 6.02×10^{20}

c. 6.02×10^{14}

d. Atoms are too small to count.

One millionth = $1/10^{6} = 10^{-6}$

Ethanol contains 52.2% carbon, 13.0% hydrogen, and 34.8% oxygen by mass. The empirical formula of ethanol is

a. $C_2H_5O_2$
b. C_2H_6O
c. $C_2H_6O_2$
d. $C_3H_4O_2$

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(C) 52.2/12 = 4.35
(H) 13/1 = 13
(O) 34.8/16 = 2.175

(C) 4.35/2.175 = 2
(H) 13/2.175 = 5.977 ≈ 6
(O) 2.175/2.175 = 1

Ribose (核醣) has a molecular weight of 150 grams per mole and the empirical formula CH_2O. The molecular formula of ribose is

a. $C_4H_8O_4$.
b. $C_5H_{10}O_5$.
c. $C_6H_{14}O_4$.
d. $C_6H_{12}O_6$.

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a. $C_4H_8O_4$.
b. $C_5H_{10}O_5$.
c. $C_6H_{14}O_4$.
d. $C_6H_{12}O_6$.

Molecular formula = $(CH_2O)n$
Molecular weight = 150 g/mole
n(30) g/mole = 150 g/mole
n = 5

When 3.14 g of Compound X is completely combusted, 6.91 g of CO_2 and 2.26 g of H_2O form. The molecular formula of Compound X is

a. C_7H_{16}.

b. $C_6H_{12}O$.

c. $C_5H_8O_2$.

d. $C_4H_4O_3$.

When 3.14 g of Compound X is completely combusted, 6.91 g of CO_2 and 2.26 g of H_2O form. The molecular formula of Compound X is

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$C_6H_6 + 2\ Br_2 \rightarrow C_6H_4Br_2 + 2\ HBr$

When 10.0 g of C_6H_6 and 30.0 g of Br_2 react as shown above, the limiting reactant is

(C: 12; H: 1; Br: 79.9)

a. Br_2.
b. C_6H_6.
c. HBr.
d. $C_6H_4Br_2$.

$C_6H_6 + 2\ Br_2 \rightarrow C_6H_4Br_2 + 2\ HBr$

When 10.0 g of C_6H_6 and 30.0 g of Br_2 react as shown above, the limiting reactant is

(C: 12; H: 1; Br: 79.9)

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b. C_6H_6.
c. HBr.
d. $C_6H_4Br_2$.

10.0g C_6H_6 = 10/(6x12+6)
= 0.128 mole C_6H_6

30.0g Br_2 = 30/(2x79.9)
= 0.188 mole Br_2

0.128 mole C_6H_6 requires
0.256 mole Br_2

$2\ Fe + 3\ Cl_2 \rightarrow 2\ FeCl_3$

When 10.0 g of iron and 20.0 g of chlorine react as shown, the theoretical yield of $FeCl_3$ is

Fe: 55.85; Cl:35.45)

a. 10.0 g.
b. 20.0 g.
c. 29.0 g.
d. 30.0 g.

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Fe: 55.85; Cl:35.45)

a. 10.0 g.
b. 20.0 g.
c. 29.0 g.
d. 30.0 g.

10.0g Fe = 0.179 mole Fe

20.0g Cl_2 = 20/(2x35.45)
0.282 mole Cl_2

0.179 mole $FeCl_3$ will be formed
0.179x(55.85+3x35.45) = 29.0g

The percentage yield of a reaction is 100% x (Z), where Z is

a. theoretical yield / actual yield.
b. calculated yield / actual yield.
c. calculated yield / theoretical yield.
d. actual yield / theoretical yield.

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$C_3H_4O_4 + 2\ C_2H_6O \rightarrow$

$C_7H_{12}O_4 + 2\ H_2O$

When 15.0 g of each reactant was mixed, 15.0 g of $C_7H_{12}O_2$ formed. The percentage yield of this product is

$C_3H_4O_4$: 104; C_2H_6O: 46; $C_7H_{12}O_2$: 160

a. 100%.
b. 75%.
c. 65%.
d. 50%.

$C_3H_4O_4 + 2\ C_2H_6O \rightarrow$

$C_7H_{12}O_4 + 2\ H_2O$

When 15.0 g of each reactant was mixed, 15.0 g of $C_7H_{12}O_2$ formed. The percentage yield of this product is

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a. 100%.

b. 75%.

c. 65%.

d. 50%.

➢ Law of Conservation of Mass

"We may lay it down as an incontestable (无可争辩) axiom (原则) 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