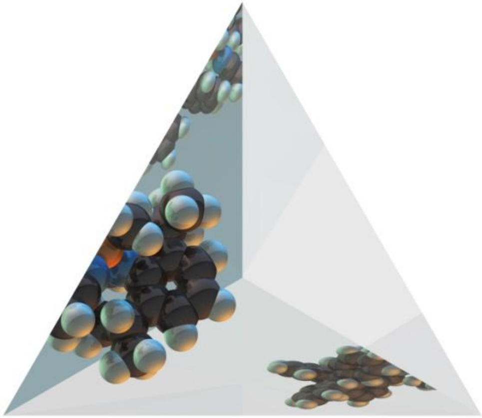


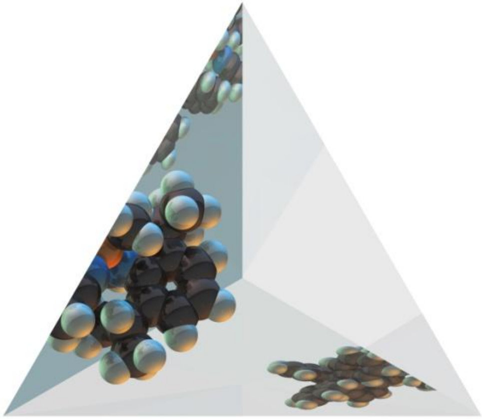
CHEMISTRY

The Central Science

8th Edition

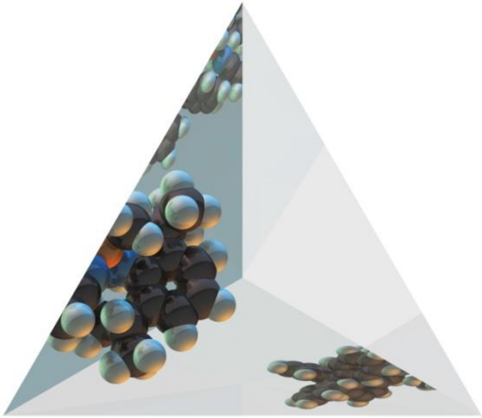
Chapter 3
Stoichiometry: Calculations with Chemical Formulas and Equations

Dr. Kozet YAPSAKLI



Objectives

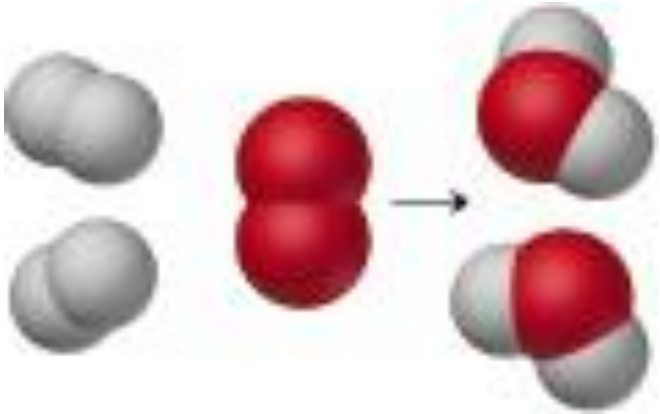
- Learn how to use chemical formulas to write chemical equations.
- Learn different type of reactions.
- Learn the relationships between masses of substances with number of moles, atoms and molecules.
- Use mole concept to determine chemical formulas.

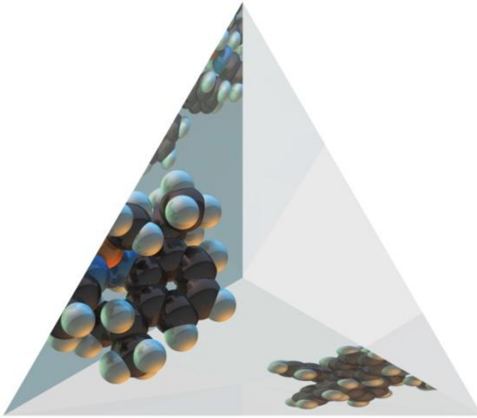


Chemical Equations

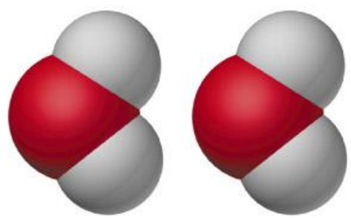
- The chemical equation for the formation of water can be visualized as two hydrogen molecules reacting with one oxygen molecule to form two water molecules:

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



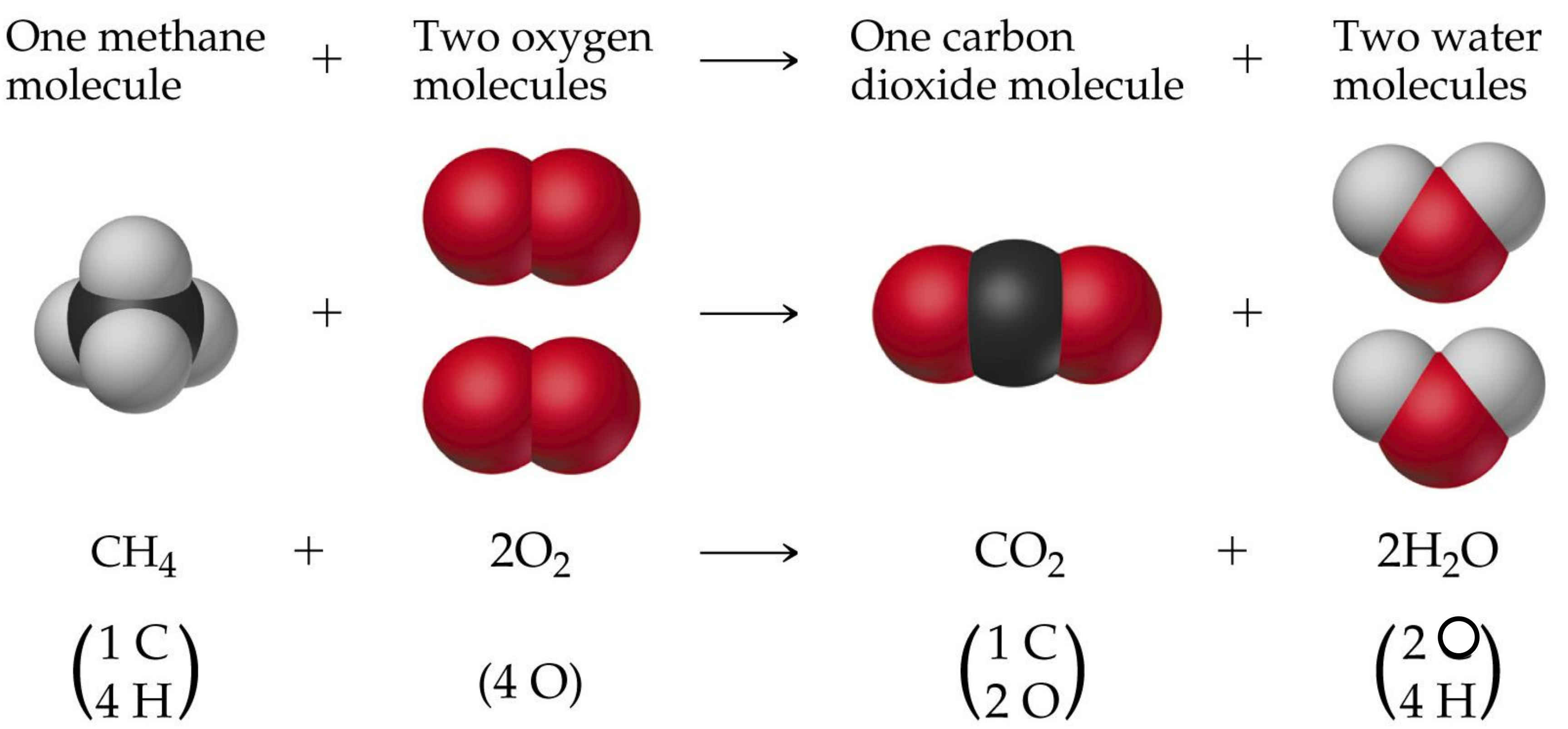


Chemical Equations

Chemical symbol	Meaning		Composition
H_2O	One molecule of water:		Two H atoms and one O atom
$2H_2O$	Two molecules of water:		Four H atoms and two O atoms
H_2O_2	One molecule of hydrogen peroxide:		Two H atoms and two O atoms

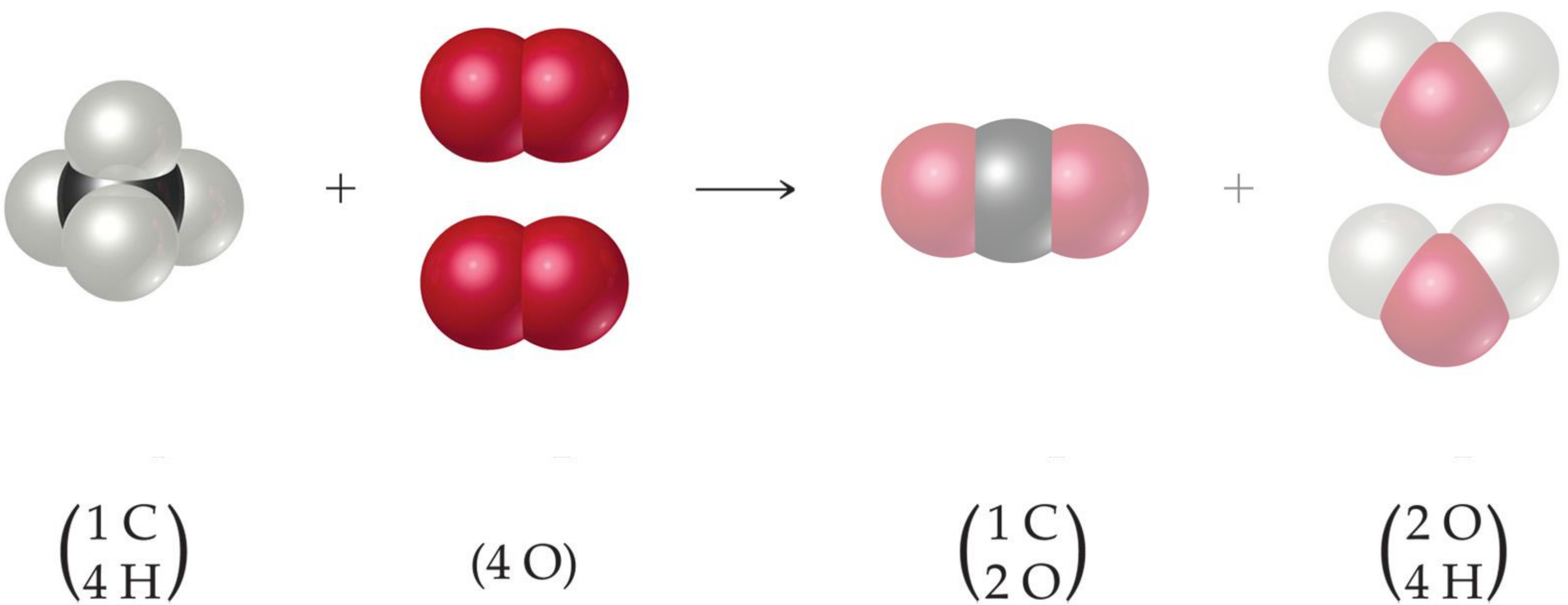
Chemical Equations

- matter cannot be lost in any chemical reactions.



Anatomy of a Chemical Equation

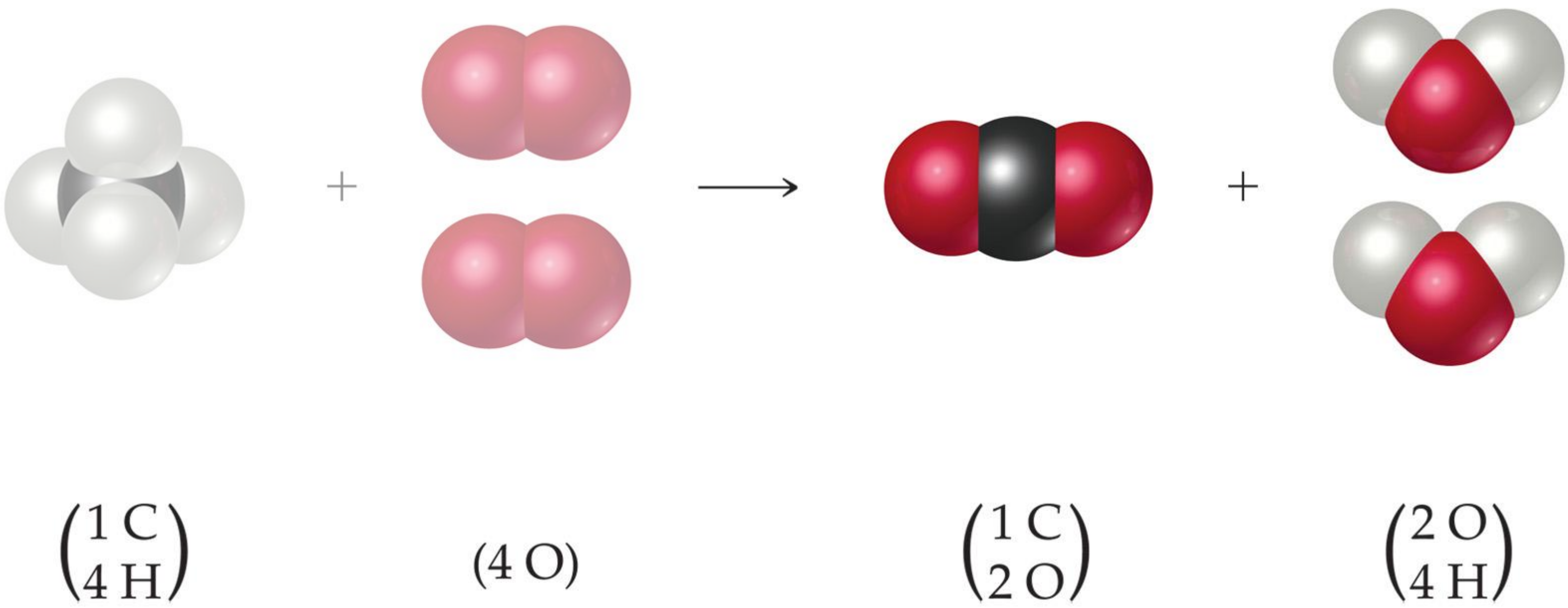
$$CH_{4\,(g)} + 2\,O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\,H_2O_{\,(g)}$$



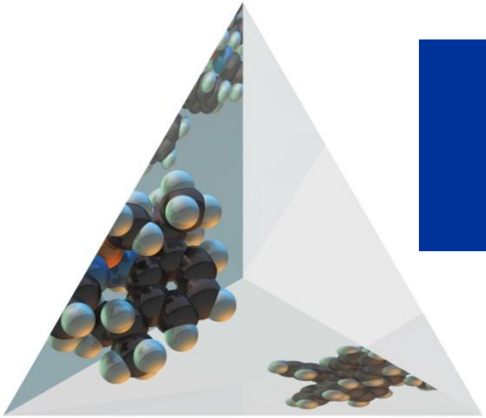
Reactants appear on the left side of the equation.

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.



Reaction Types

Combination and Decomposition Reactions

TABLE 3.1 Combination and Decomposition Reactions

Combination Reactions	
$A + B \longrightarrow C$ $C(s) + O_2(g) \longrightarrow CO_2(g)$ $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$ $CaO(s) + H_2O(l) \longrightarrow Ca(OH)_2(s)$	Two reactants combine to form a single product. Many elements react with one another in this fashion to form compounds.
Decomposition Reactions	
$C \longrightarrow A + B$ $2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$ $PbCO_3(s) \longrightarrow PbO(s) + CO_2(g)$ $Cu(OH)_2(s) \longrightarrow CuO(s) + H_2O(l)$	A single reactant breaks apart to form two or more substances. Many compounds react this way when heated.

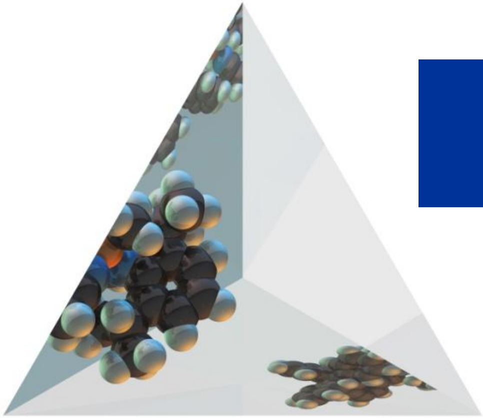
Reaction Types

Combustion in Air

Combustion is the burning of a substance in oxygen from air:

$$C_3H_8\,(g) + 5\,O_2\,(g) \longrightarrow 3\,CO_2\,(g) + 4\,H_2O\,(g)$$

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

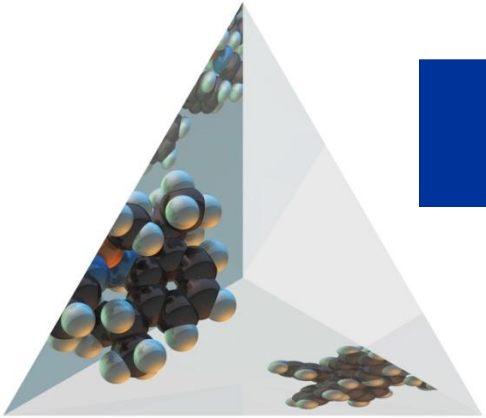


Formula Weights

Molecular Weights

- Molecular weight (MW) is the weight of the molecular formula.

$$MW(C_6H_{12}O_6) = 6(12.0 \text{ amu}) + 12(1.0 \text{ amu}) + 6(16.0 \text{ amu})$$

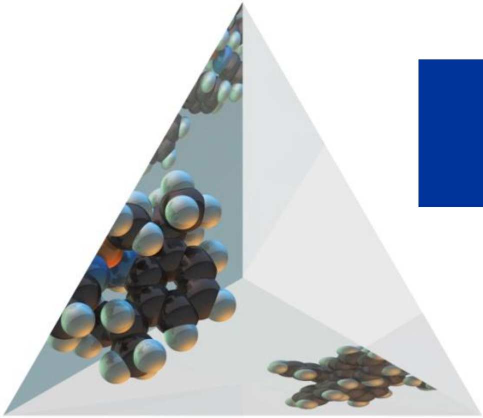


Percentage Composition

Percentage Composition

- Percent composition is the atomic weight for each element divided by the formula weight of the compound multiplied by 100:

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



Percentage Composition

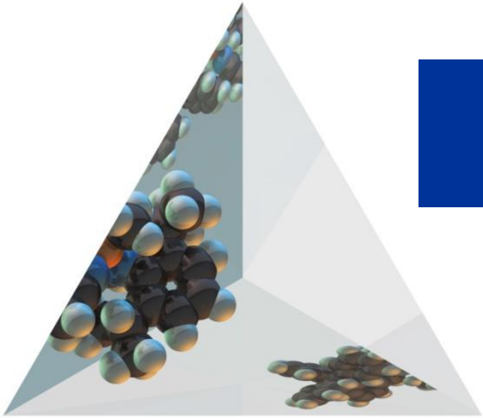
Percentage Composition

- For the molecule ethane, C_2H_6 the formula weight would be

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

So the percentage of carbon in ethane is…

$$\%C = \frac{(2)(12.0\ \text{amu})}{(30.0\ \text{amu})} \times 100 = 80.0\%$$

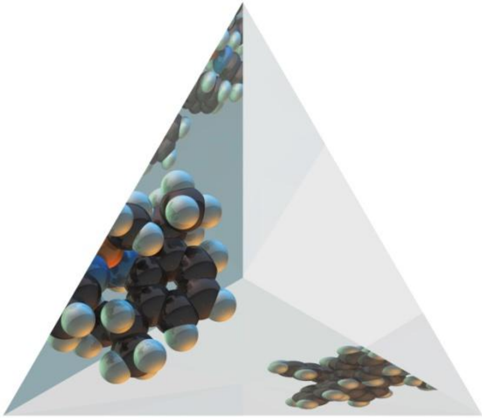


Percentage Composition

Example: What is the percent composition of N and H in ammonia (NH_3)?

$$\text{Mass Percent N in } NH_3 = \frac{\text{Mass of N in 1 mol of } NH_3}{\text{Mass of 1 mol of } NH_3} = \frac{14.01 \text{ g N}}{17.03 \text{ g } NH_3} \times 100 = 82.27\%$$

$$\text{Mass Percent H in } NH_3 = \frac{\text{Mass of H in 1 mol of } NH_3}{\text{Mass of 1 mol of } NH_3} = \frac{3(1.008) \text{ g H}}{17.03 \text{ g } NH_3} \times 100 = 17.76\%$$



The Mole

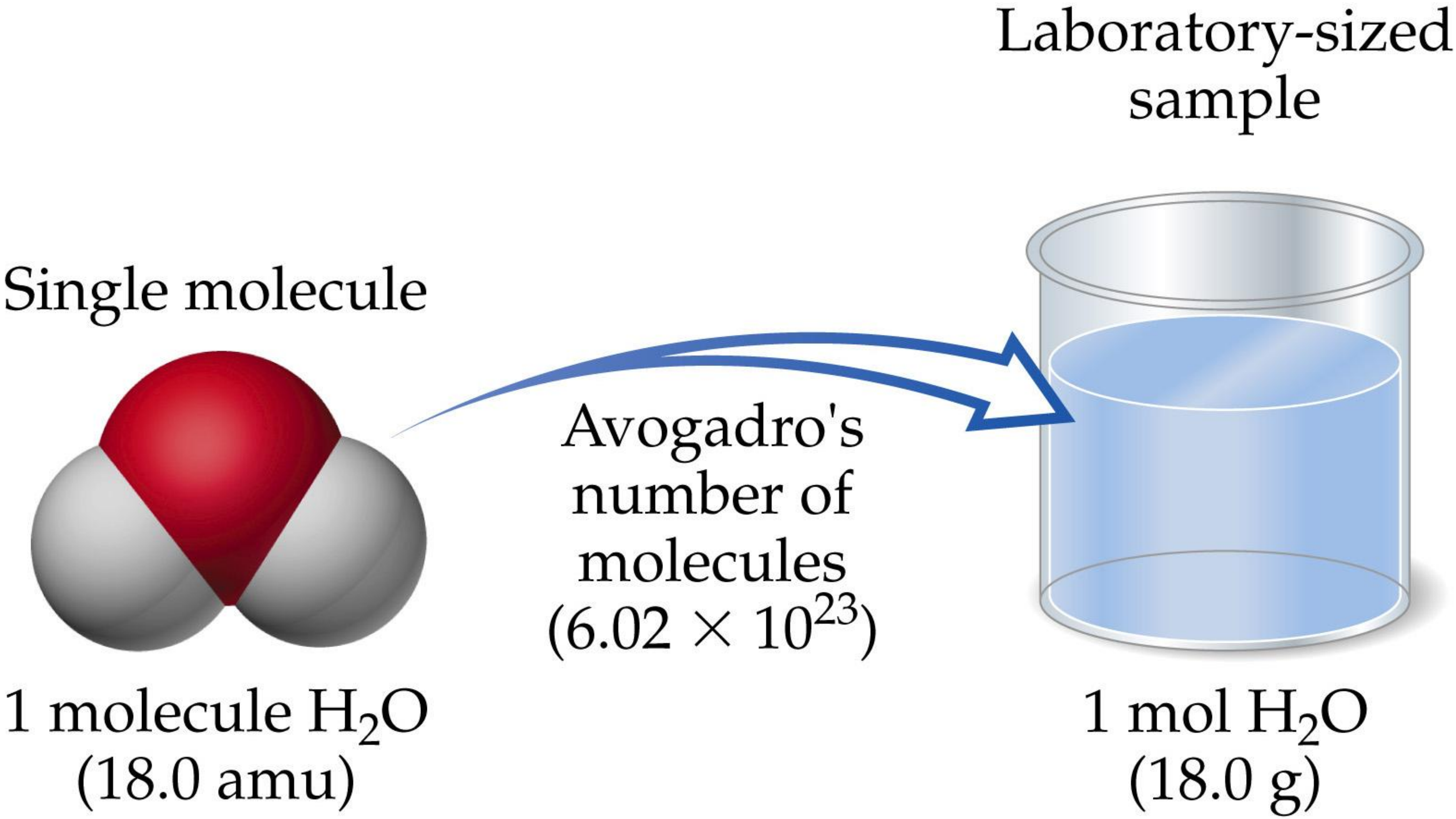
Mole: convenient measure chemical quantities.

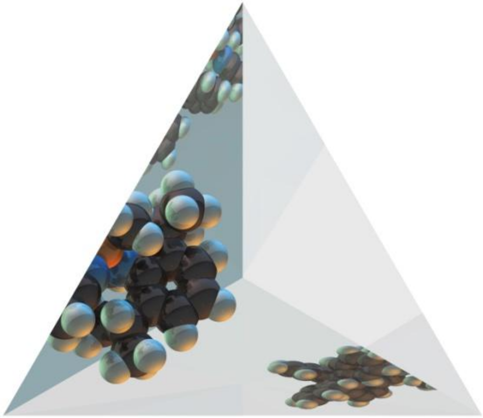
- 1 mole of something = 6.0221367×10^{23} of that thing.
- Experimentally, 1 mole of ^{12}C has a mass of 12 g.

Molar Mass

- Molar mass: mass in grams of 1 mole of substance (units g/mol, $g.mol^{-1}$).
- Mass of 1 mole of ^{12}C = 12 g.

The Mole


Laboratory-sized sample
Single molecule
Avogadro's number of molecules (6.02×10^{23})
1 molecule H_2O (18.0 amu)
1 mol H_2O (18.0 g)

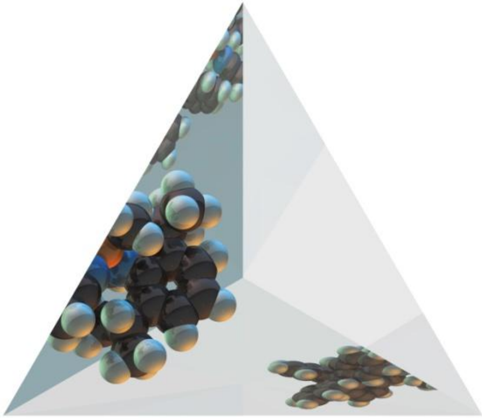


The Mole

TABLE 3.2 Mole Relationships

Name	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
				6.022×10^{23} $BaCl_2$ units
Barium chloride	$BaCl_2$	208.2	208.2	6.022×10^{23} Ba^{2+} ions
				$2(6.022 \times 10^{23})$ Cl^- ions

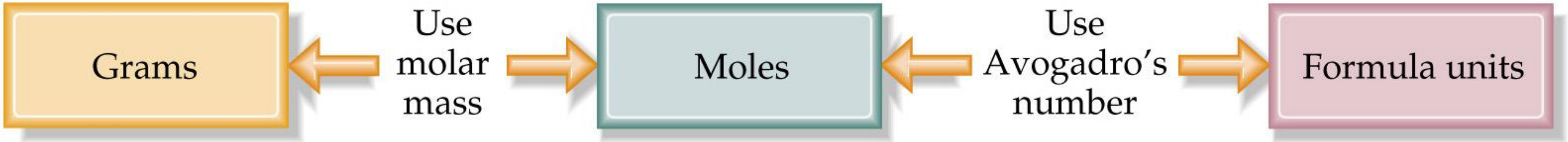
[a] Recall that the electron has negligible mass; thus, ions and atoms have essentially the same mass.

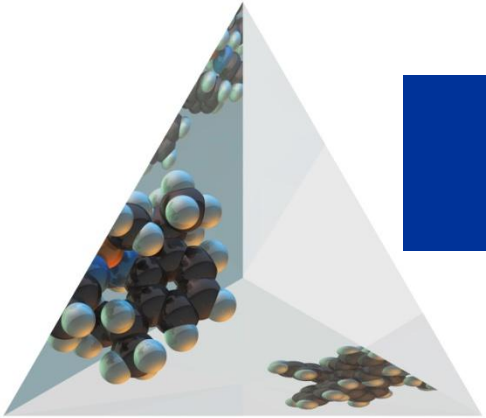


Masses and Moles

- Molar mass: sum of the molar masses of the atoms:

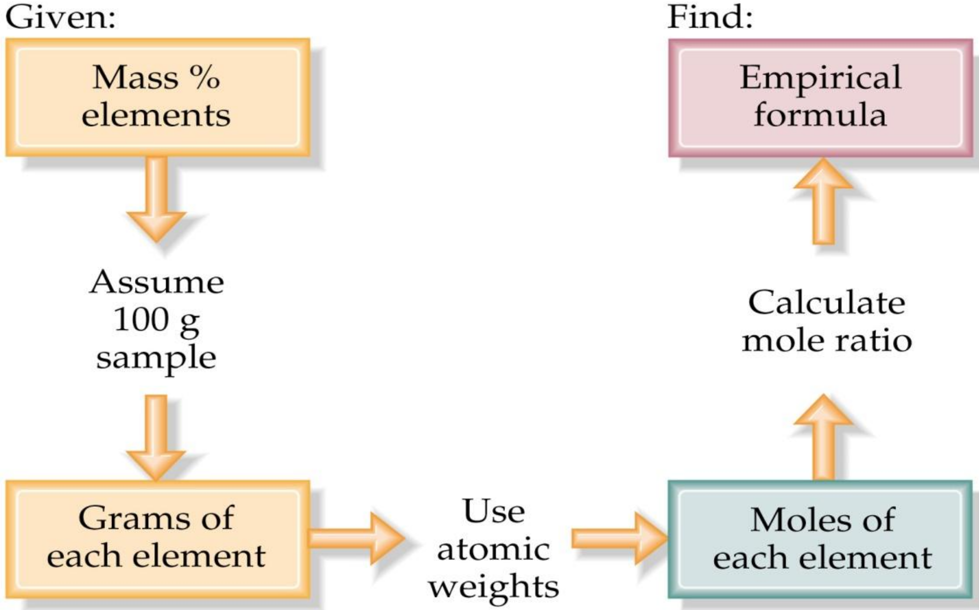
  molar mass of N_2 = 2 × (molar mass of N).
- Molar masses for elements are found on the periodic table.
- Formula weights are numerically equal to the molar mass.





Empirical Formula

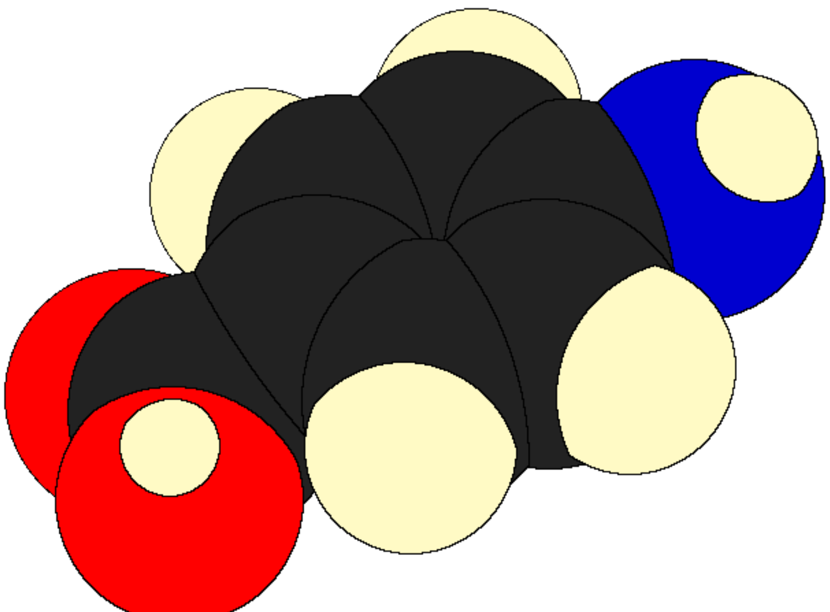
- Start with mass % of elements (i.e. empirical data) and calculate a formula, or
- Start with the formula and calculate the mass % elements.

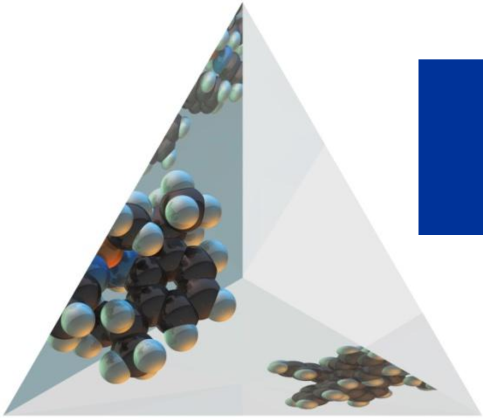


Empirical Formula

These are the subscripts for the empirical formula:

$C_7H_7NO_2$





Empirical Formula

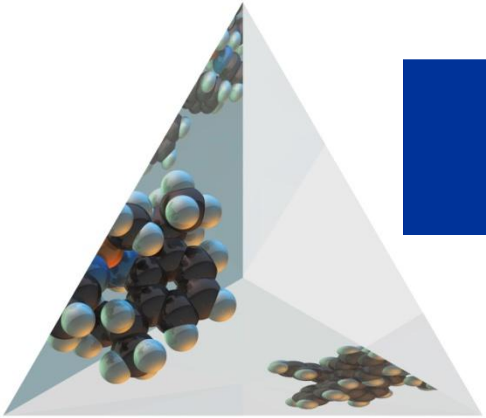
- Eugenol is the active component of oil of cloves. It has a molar mass of 164.2 g/mol and is 73.14% C and 7.37% H; the remainder is oxygen. What are empirical and molecular formulas for eugenol?

Where to start?!

1. What is the % of oxygen?
   - 100% - (73.14% + 7.37%) = 19.49%
2. How many grams of C, H, and O?
   - Assume you have 100 g of the compound therefore your percentages are the number of grams of C, H, and O.
     - 73.14 g of C
     - 7.37 g of H
     - 19.49 g of O

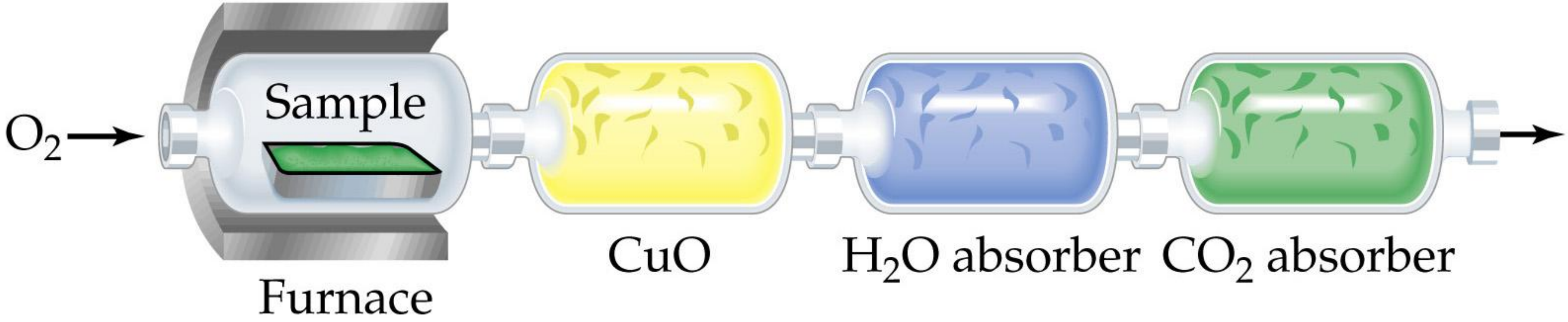
Empirical Formula

3. Change the grams into moles.
   - 73.14 g of C × 1 mole of C / 12.011g of C = 6.09 mols of C
   - 7.37 g of H × 1 mole of H / 1.0079 g of H = 7.31 mols of H
   - 19.49 g of O × 1 mole of O / 15.9994 g of O = 1.22 mols of O
4. Find the mole ratios (divide the large amount(s) of moles by the smallest amount of moles).
   - 6.09 mols of C / 1.22 mols of O = 5 mols of C to 1 mol of O
   - 7.37 mols of H / 1.22 mols of O = 6 mols of H to 1 mol of O
5. So what does this mean?
   - C_5H_6O is the empirical formula
6. How to get the molecular formula?
   - Molecular weight of the empirical formula.
     - 82 g/mol
   - Divide the molecular weight of eugenol by the molecular weight empirical formula.
     - 164.2 g/mol / 82 g/mol = 2
   - So there are 2 units of the empirical formula.
     - $(C_5H_6O)_2 = C_{10}H_{12}O_2$



Combustion Analysis

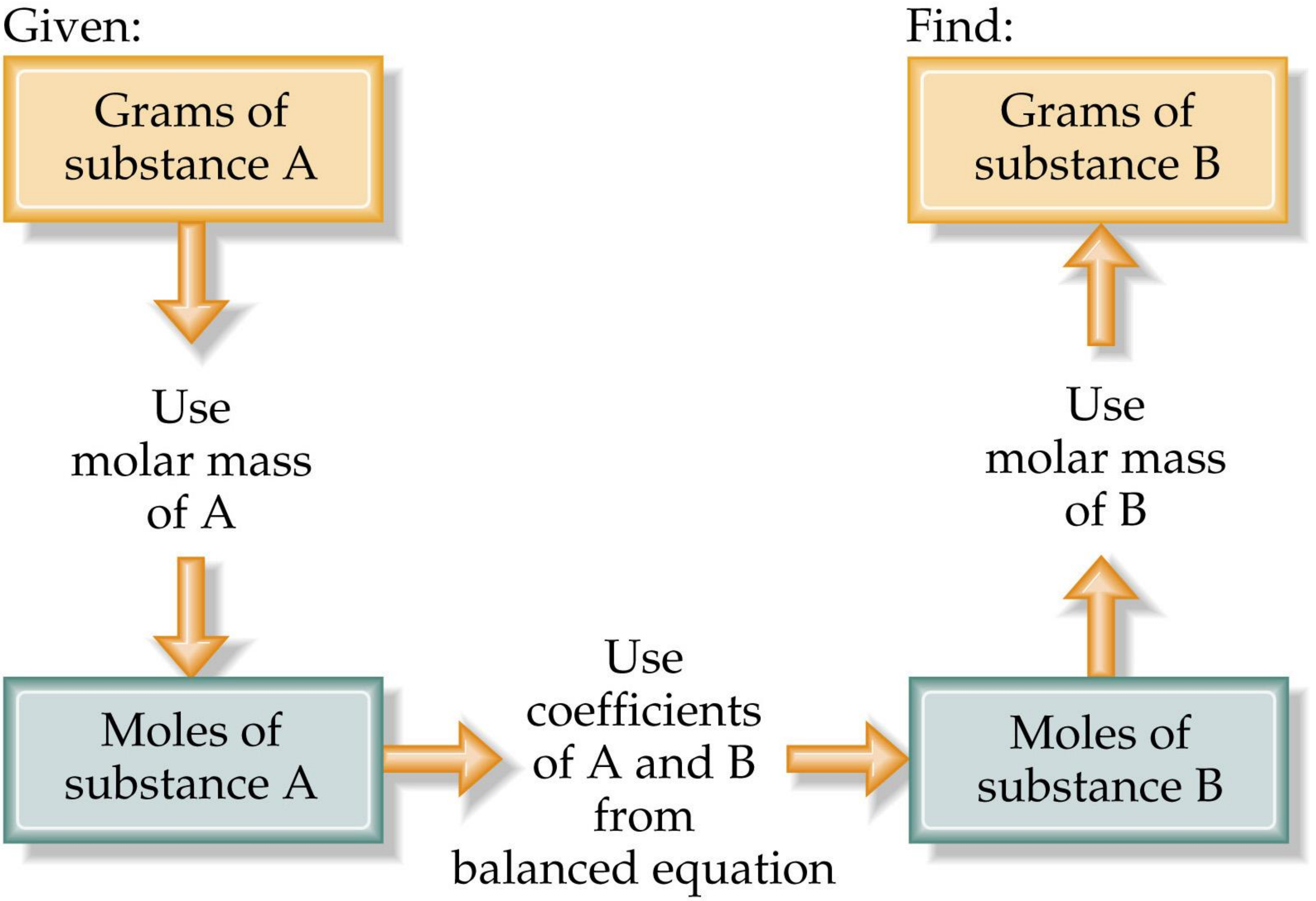
- Empirical formulas are determined by combustion analysis:



C is determined from the mass of CO_2 produced

H is determined from the mass of H_2O produced

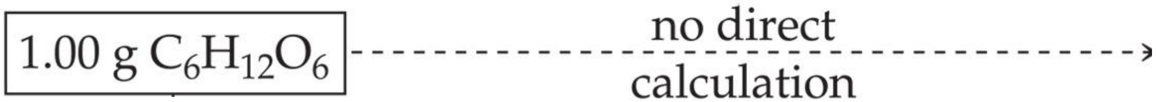
O is determined by difference after the C and H have been determined



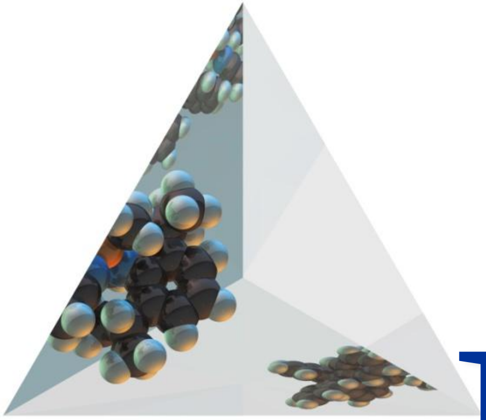
From the mass of Substance A you can use the ratio of the coefficients of A and B to calculate the mass of Substance B formed.

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



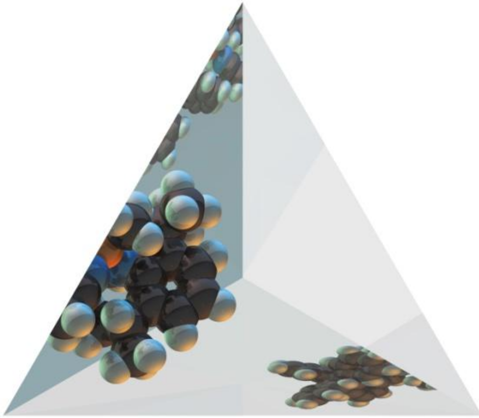
Limiting Reactants

How Many Cakes Can I Make?

- You can make cakes until you run out of one of the ingredients
- Once this family runs out of sugar, they will stop making cakes

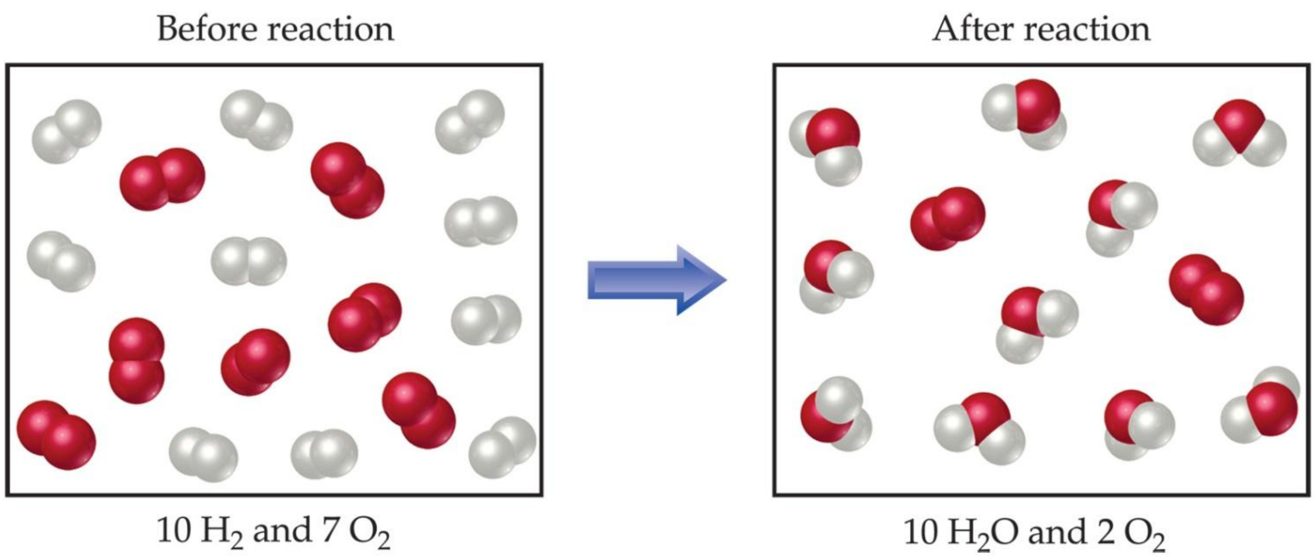
How Many Cakes Can I Make?

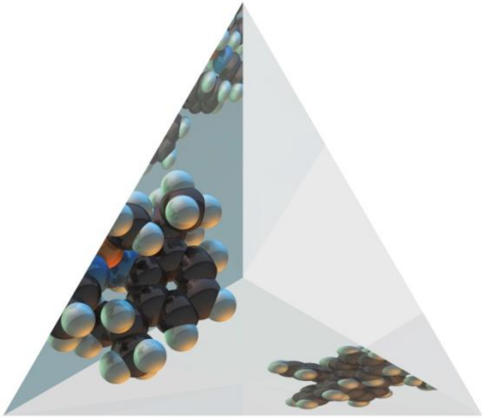
- In this example the sugar would be the limiting reactant, because it will limit the amount of cakes you can make



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)... O_2 would be the excess reagent...





Limiting Reactants

Theoretical Yields

- The quantity of product that is calculated to form when all of the limiting reactant is consumed in a reaction is called the **theoretical yield**.
- The amount of product actually obtained is called the ***actual yield.***

Actual yield < Theoretical yield

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