Lecture 5, The Mole

What is a mole?

Moles

Atomic mass unit and the mole

- amu definition: ^{12}C = 12 amu.
- The atomic mass unit is defined this way.
- 1 amu = 1.6605 x 10^{-24} g
- How many ^{12}C atoms weigh 12 g?
- **6.02×10^{23} ^{12}C weigh 12 g.**
- Avogadro's number
- The mole

Atomic mass unit and the mole

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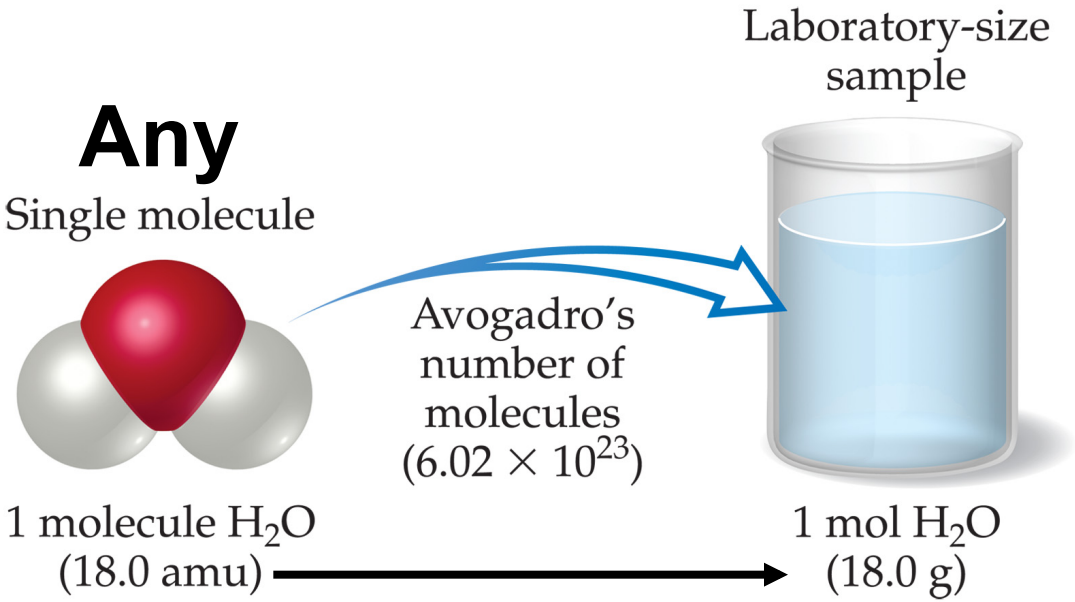
- The mole

- #atoms = (1 atom/12 amu)(1 amu/1.66x10^{-24} g)(12g)
  = **6.02x10^{23} ^{12}C weigh 12 g**

Therefore:



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

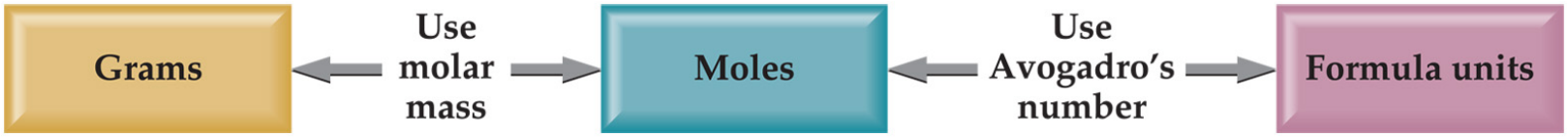
The mole

- The mole is just a number of things
- 1 dozen = 12 things
- 1 pair = 2 things
- 1 mole = 6.022141×10^{23} things

Molar Mass
The trick:

- By definition, this is 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

The number of moles correspond to the number of molecules. 1 mole of any substance has the same number of molecules.

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

Molar mass examples

- Molecular compound
- Molar mass of water H_2O

  2H = 2*1.008 = 2.016

  1O = 16.00 = 16.00

  Molar mass = 18.016

- Ionic compound, NaCl
- Na = 22.99
- Cl = 35.45
- Molar mass = 58.44

Examples

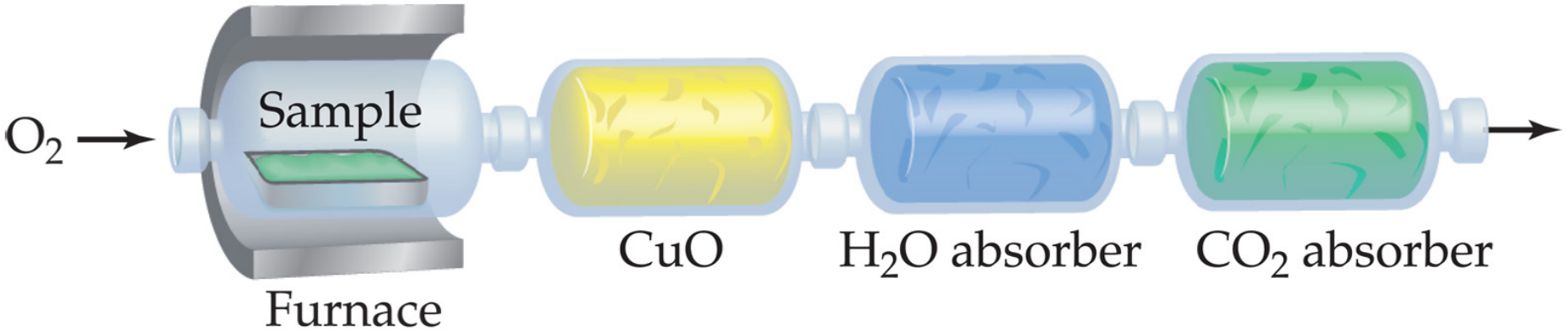
- What is the mass of 3 moles of water
- 18.016 g/mole(3 moles) = 54.048 g

- How many moles in 64 g methane CH_4?
- 4H = 1.008*4 = 4.032
- 1C = 12.01
- 16.033 g/mole
- 64 g (1mole/16.033g) = 3.991 moles

Stoichiometry the measurement of elements

Finding Empirical Formulas

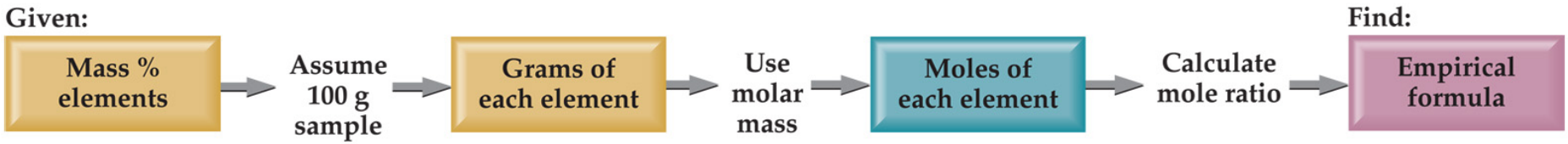
Combustion Analysis gives % composition



$$C_nH_nO_n + O_2 \longrightarrow nCO_2 + 1/2nH_2O$$

- 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

Calculating Empirical Formulas



One can calculate the empirical formula from the percent composition

Example

- An oxide of copper contains 88.82% Cu. What is the formula of the oxide?

	Cu: (88.82%)=88.82 g	O: 100-88.82=11.18% = 11.18 g
Calculate #moles	88.82 g/63.546 $gmol^{-1}$ = 1.348 mole	= 11.18 g/16.00 $gmol^{-1}$ = 0.699 mole
Get mole ratio	1.348 mol/0.699 = 2	0.699/0.699 = 1

Cu_2O copper (I) oxide

- A compound of boron and hydrogen contains 78.14% B. What is the empirical formula of the compound? If the molar mass is 27.7 $gmol^{-1}$, what is the molecular formula?

B: 78.14% = 78.14 g	H: 100-78.14 = 21.86 g
78.14 g/10.811 $gmol^{-1}$=7.228	21.86/1.008 $gmol^{-1}$=21.686
1	21.6863.00/7.228 = 3

BH_3 mass = 10.811 + 1.008*3 = 13.825 g/mol
27.77 $gmol^{-1}$/13.824 $gmol^{-1}$ = 2
Molecular weight: $(BH_3)*2=B_2H_6$

- What is the percent by mass of nitrogen in ammonium nitrate?

- NH_4NO_3 2N: 14.0067*2 = 28.134
- 3O 16.00*3 = 48.00
- 4H 1.008*4 = 4.032
- 80.166 g/mole

- 28.134/80.166 = 0.3509

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,

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

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

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

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

Calculating Empirical Formulas

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

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

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

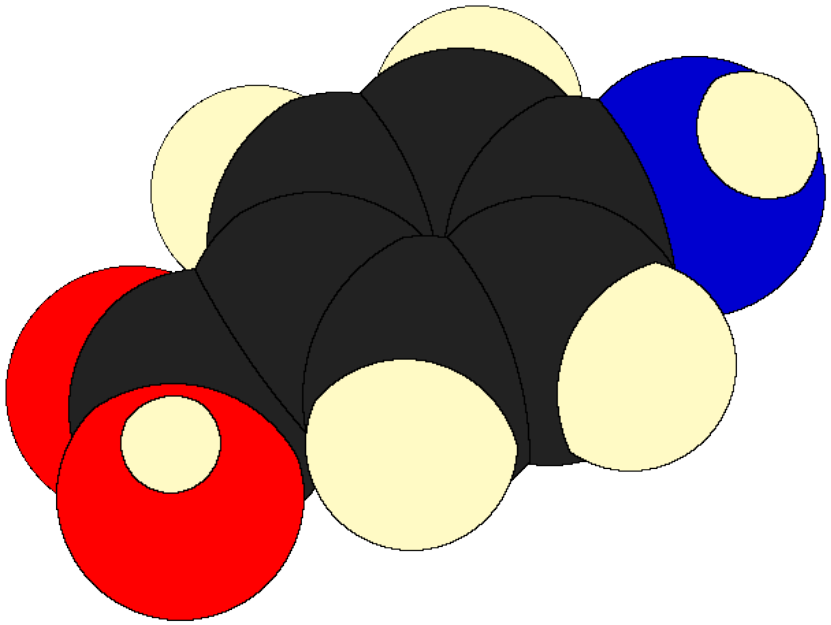
N: $\frac{0.7288\ \text{mol}}{0.7288\ \text{mol}} = 1.000$

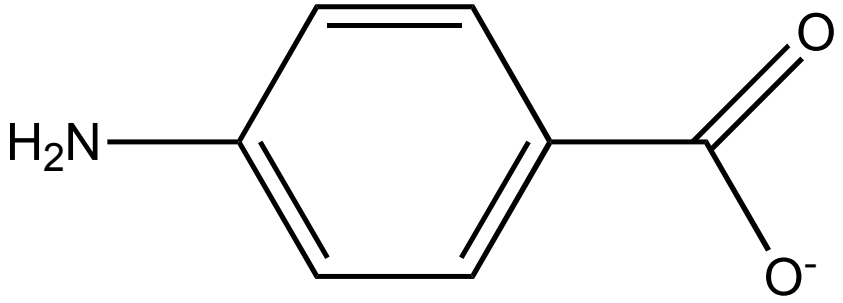
O: $\frac{1.458\ \text{mol}}{0.7288\ \text{mol}} = 2.001 \approx 2$

Calculating Empirical Formulas

These are the subscripts for the empirical formula:

$C_7H_7NO_2$





More examples for your pedagogical pleasure

What is the average mass of a single molecule of ethanol, CH_3CH_2OH (C_2H_6O)?
Mol. Mass = 2(12.01 amu/C) + 6(1.008 amu/H) + 1(16.00 amu/O) = 46.068

Does every molecule of ethanol weigh the same?

1.256 g of Sulfur reacts with excess fluorine gas (F_2) to produce 5.722 g of a substance SF_x. What is the substance?

S	+	F_2 ----→	SF_x
1.256g		5.722-1.256=4.466 g	5.722 g
(1.256 g)/32.06 $gmol^{-1}$		4.466 g/18.998 $gmol^{-1}$	
3.918 x 10^{-2} mole S		0.2351 mole F	
3.918 x 10^{-2} /3.918 x 10^{-2} =1		0.2351/3.918 x 10^{-2} = 6.00	SF_6

More examples for your pedagogical pleasure

A compound was analyzed and found to contain 53.30% carbon, 11.19% hydrogen and 35.51% oxygen by mass. The molar mass was determined to be about 90 g/mol. What is the empirical formula and what is the molecular formula of the compound?

Carbon	53.3 g	53.3 g/12.01 $gmol^{-1}$=4.438 mole	4.438/2.22= 2
Hydrogen	11.19 g	11.19 g/1.008 $gmol^{-1}$=11.1012 mole	11.012/2.22= 5
Oxygen	35.51 g	35.53 g/16.00 $gmol^{-1}$=2.22 moles	2.22/2.22=1

Mass of Empirical formula: 2(12.01 g/mol C) + 5(1.008 g/mol H) + 16.00 g/mol O = 45.06 g/mole Empirical formula

90 $gmol^{-1}$/45.06 $gmol^{-1}$ empirical mass = 2. So the compound is: $2(C_2H_5O)$ $C_4H_{10}O_2$

Even More examples for your pedagogical pleasure

Suppose a hydrocarbon (compound containing only C and H) is burned in air, producing CO_2 and H_2O. This is called a ***combustion reaction***. The number of moles of CO_2 produced is 1.5 times the number of moles of water produced. What is the empirical formula of the original molecule you burned? If the molecular mass of the compound is 120 $gmol^{-1}$, what is the molecular formula of the compound?

Assume 3 moles of CO_2, therefore 2 moles water.

1. Write down the reaction:

$C_NH_M + O_2 \dashrightarrow CO_2 + H_2O$

3 moles 2 mole

moles C: 3 moles H: 4 Therefore C_3H_4

Empirical mass: 3(12.01 $gmol^{-1}$ C) + 4(1.008 $gmol^{-1}$ H)= 40.0 $gmol^{-1}$

120 $gmol^{-1}$/40 $gmol^{-1}$ = 3

3(C_3H_4)=**C_9H_{12} molecular formula**

Even More examples for your pedagogical pleasure

A 15.67 g sample of a hydrate of magnesium carbonate was carefully heated in an oven to drive off the water. The mass reduced to 7.58 g. What is the formula of the hydrate?
Molar mass of $MgCO_3$ = 84.31 $gmol^{-1}$
Molar mass of H_2O = 18.016 $gmol^{-1}$

$MgCO_3 \cdot (H_2O)_n$ ----→ $MgCO_3$ + nH_2O

15.67 g 7.58 g 15.67 g – 7.58 g = 8.09 g
15.67 g 7.58 g/84.31 $gmol^{-1}$=.08990 mole 8.09 g/18.016 $gmol^{-1}$= .4490 mol

.08990/.08990=1 .4490/.08990=4.995

N=5 $MgCO_3 \cdot (H_2O)_5$

Even More examples for your pedagogical pleasure

A compound of carbon, hydrogen, and nitrogen was analyzed and found to contain 45.92% C, 12.20% H and 42.38% N. What is the empirical formula of the compound?

Assume 100g:

C: 45.42 g	45.42 g/ 12.01=3.782 mole	3.782/3.025= 1.250 mole	1.25*4=5.00
H: 12.20 g	12.20g/ 1.008gmol^{-1}=1 12.103 mole	12.103/3.025 =4.00	4*4=16
N: 42.38 N	42.38g/14.01 gmol^{-1}=3.025	3.025/3.025= 1	1*4=4

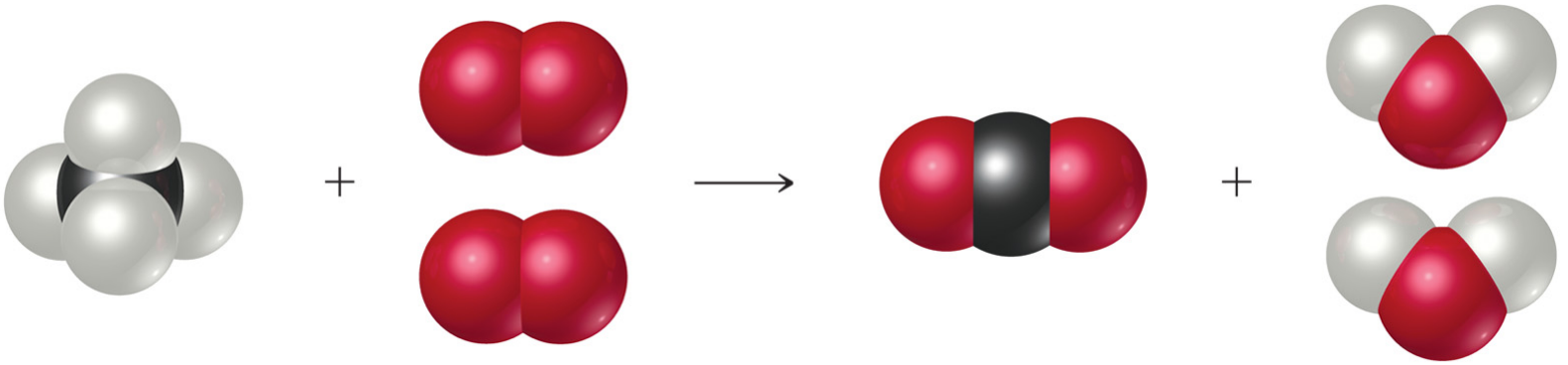
$C_5H_{16}N_4$

Stoichiometry:

Calculations with Chemical Formulas and Equations

Anatomy of a Chemical Equation

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



$\begin{pmatrix} 1\,C \\ 4\,H \end{pmatrix}$ $(4\,O)$ $\begin{pmatrix} 1\,C \\ 2\,O \end{pmatrix}$ $\begin{pmatrix} 2\,O \\ 4\,H \end{pmatrix}$

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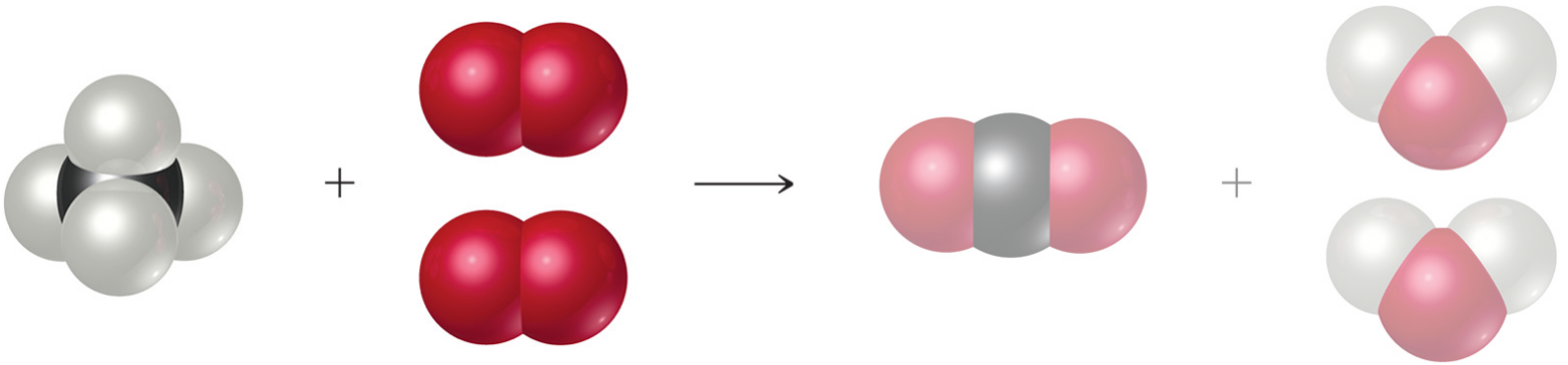
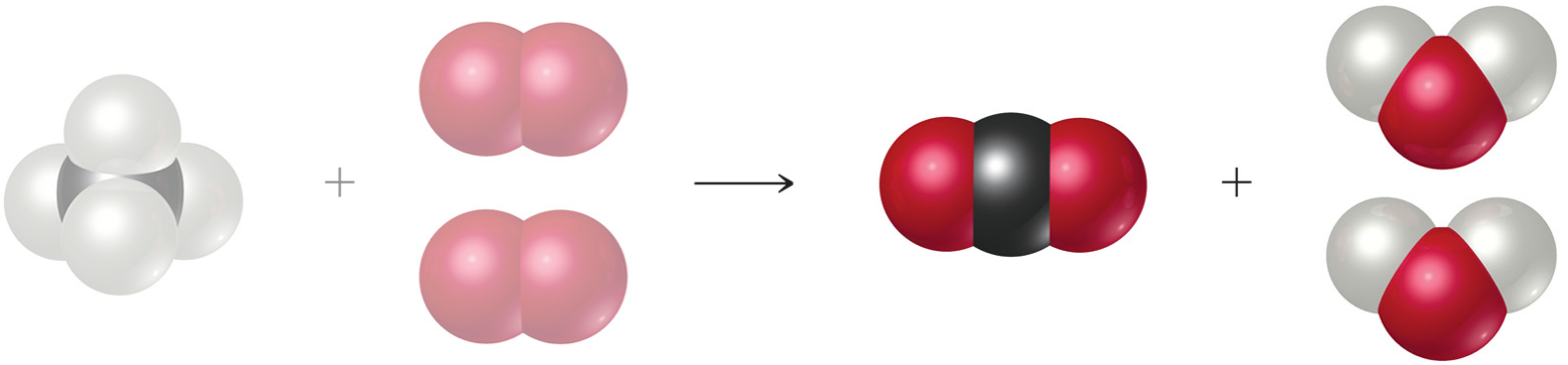


$\begin{pmatrix} 1\,C \\ 4\,H \end{pmatrix}$ $(4\,O)$ $\begin{pmatrix} 1\,C \\ 2\,O \end{pmatrix}$ $\begin{pmatrix} 2\,O \\ 4\,H \end{pmatrix}$

Reactants appear on the left side of the equation.

Anatomy of a Chemical Equation

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

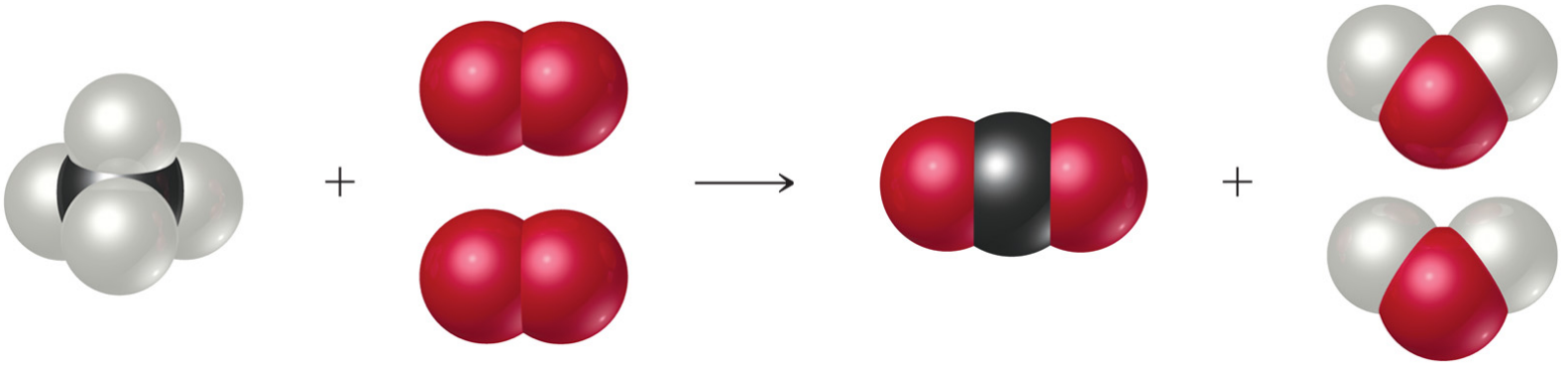


$\begin{pmatrix} 1\,C \\ 4\,H \end{pmatrix}$ $(4\,O)$ $\begin{pmatrix} 1\,C \\ 2\,O \end{pmatrix}$ $\begin{pmatrix} 2\,O \\ 4\,H \end{pmatrix}$

Products appear on the right side of the equation.

Anatomy of a Chemical Equation

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

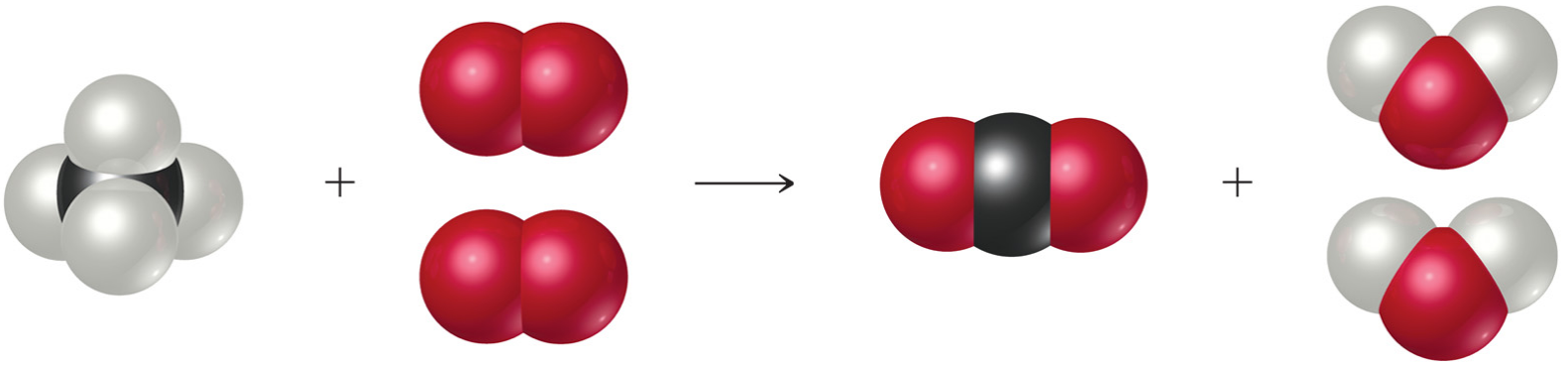


$\begin{pmatrix} 1\,C \\ 4\,H \end{pmatrix}$ $(4\,O)$ $\begin{pmatrix} 1\,C \\ 2\,O \end{pmatrix}$ $\begin{pmatrix} 2\,O \\ 4\,H \end{pmatrix}$

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

Anatomy of a Chemical Equation

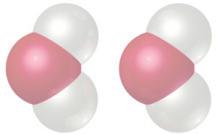
$$CH_{4\,(g)} + 2\,O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2\,H_2O_{\,(g)}$$



$\begin{pmatrix} 1\,C \\ 4\,H \end{pmatrix}$ $(4\,O)$ $\begin{pmatrix} 1\,C \\ 2\,O \end{pmatrix}$ $\begin{pmatrix} 2\,O \\ 4\,H \end{pmatrix}$

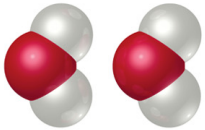
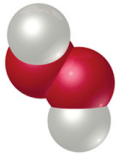
Coefficients are inserted to **balance** the equation.

Subscripts and Coefficients Give Different Information

Chemical symbol	Meaning		Composition
H_2O	One molecule of water:		Two H atoms and one O atom
$2\ H_2O$	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

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

Subscripts and Coefficients Give Different Information

Chemical symbol	Meaning		Composition
H_2O	One molecule of water:		Two H atoms and one O atom
$2\ H_2O$	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

- Subscripts tell the number of atoms of each element in a molecule
- Coefficients tell the number of molecules (compounds).

Stoichiometry of Chemical Reactions
Balancing an equation

1. Write the correct formula for all the participants
2. Select the most complicated formula and balance those atoms first
3. Start with those atoms that occur in only one formula on each side
4. Leave simple molecules such as H_2 and O_2 until the end.

Examples:

$Al_4C_3 + H_2O \longrightarrow Al(OH)_3 + CH_4$

$NH_3 + O_2 \longrightarrow NO + H_2O$

$C_3H_8 + O_2 \longrightarrow CO_2 + H_2O$

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Examples:

$Al_4C_3 + 12H_2O \longrightarrow 4Al(OH)_3 + 3CH_4$

$2NH_3 + 5/2O_2 \longrightarrow 2NO + 3H_2O$

$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$

$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

Stoichiometry of Chemical Reactions

When doing stoichiometric calculations you must always work in moles?
Because moles tell you how many molecules/atoms you have.

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

1 mole of propane requires _____ moles of O_2
1 mole of propane produces _____ moles of CO_2

What mass of carbon dioxide is produced from 110 g of propane?
How many moles of water are produced?
What mass of oxygen is required?
What happens if there is not enough oxygen?

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

110 g

110/44=2.5 mole

2.5*3=7.5 mole

7.5*(44gmol^{-1})=330g

2.5(4)=10 moles

What happens if there is not enough oxygen?

The reaction goes, but not all of the 110 g of propane can react, so some is left over
This is the case of the *limiting reactant.*