Chemical Reactions

Chemical changes, factors and equations

Chemical Reactions

- ***Chemical Reactions*** are what happens when new compounds are produced.
- They are represented by a ***chemical equation***.
- A chemical equations summarizes what compounds are reacting and what compounds are produced.

Reactants $\longrightarrow$ Products

Chemical Reactions

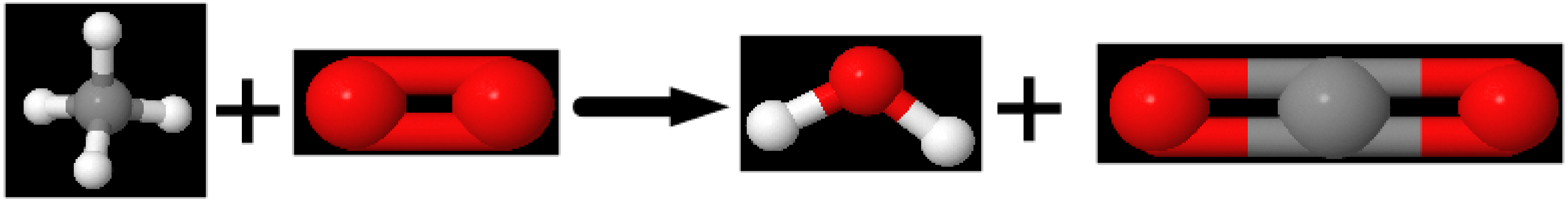
- Represented by three types of chemical equations:
  - Word Equation – uses the chemical names
  - Skeleton Equation – uses the chemical formulas
  - Balanced Equation – upholds the law of conservation of mass
- Law of Conservation of Mass
  - Atoms in a chemical reaction can not be created nor destroyed, but they can be transferred to, or exchanged, with other atoms to produce new compounds.

Law of Conservation of Mass

- In a non-nuclear chemical reaction, the total mass of the reactants is always equal to the total mass of the products.
- Atoms are not destroyed, just rearranged.

Methane + Oxygen → Water + Carbon Dioxide

$$CH_4 + O_2 \longrightarrow H_2O + CO_2$$

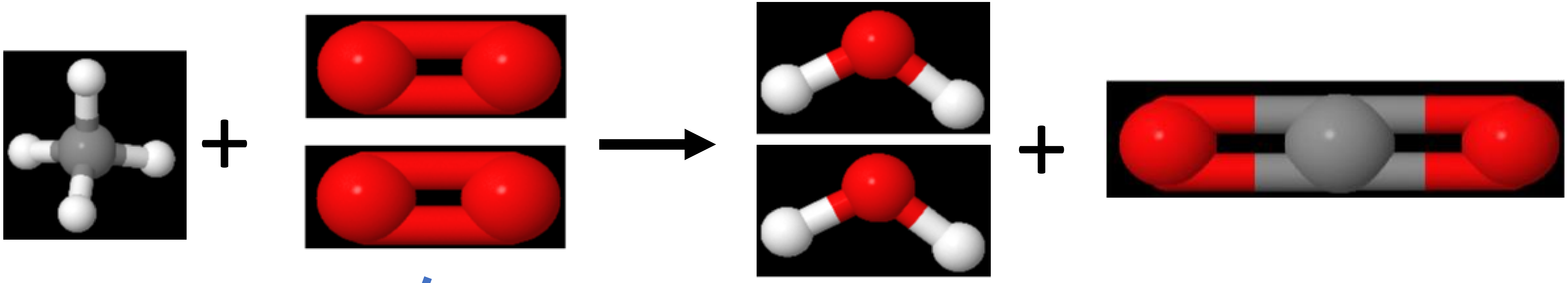


- Not possible to “lose” two hydrogen atoms and gain a third oxygen.

Law of Conservation of Mass

- To conserve mass we need more molecules!

Methane + Oxygen → Water + Carbon Dioxide



$$CH_4 + 2O_2 \longrightarrow 2H_2O + CO_2$$

This chemical equation is now *balanced*.

Balancing Chemical Equations

- Refers to the act of conserving mass.
- We use a ***skeleton equation*** to represent the reaction.
- Skeleton equations are balanced by changing the coefficients until mass is conserved.

Skeleton Equation

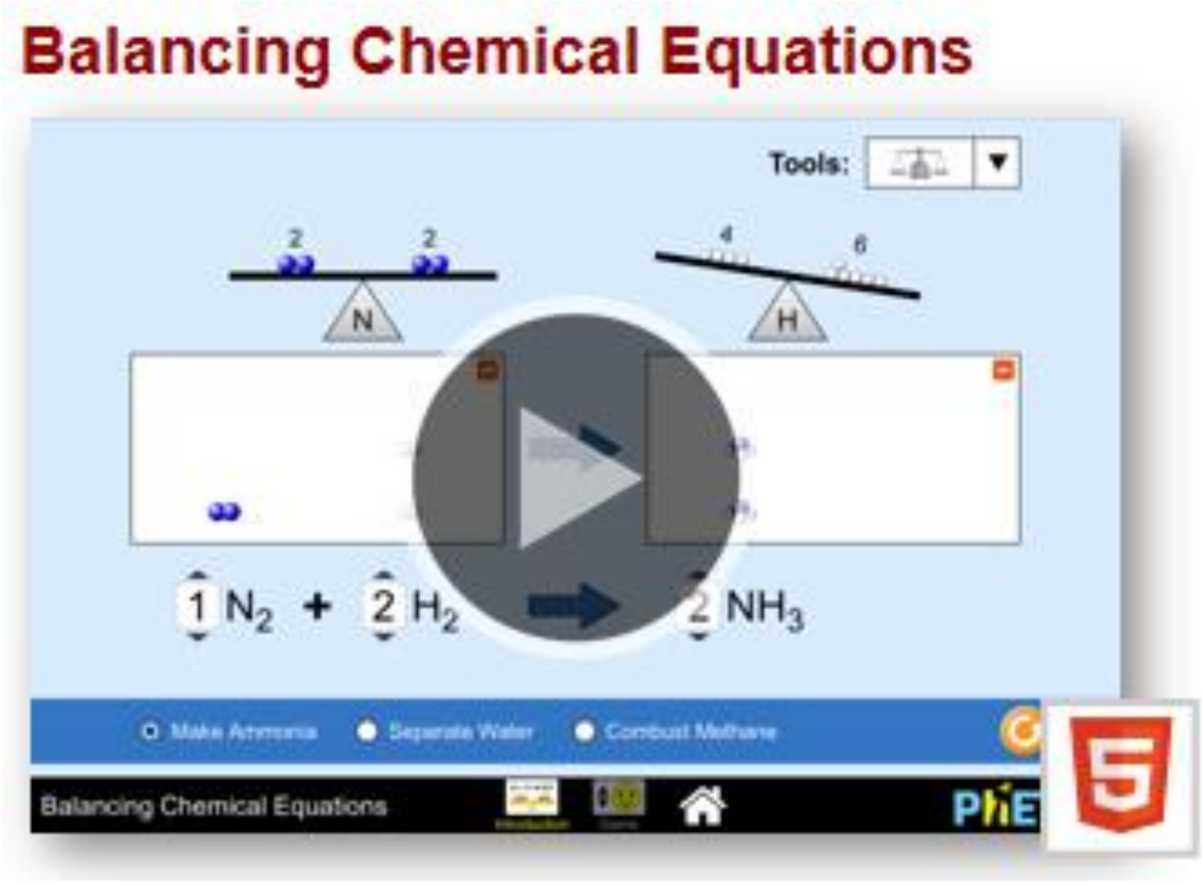
$$CH_4 + O_2 \longrightarrow H_2O + CO_2$$

Balanced Equation

$$CH_4 + 2O_2 \longrightarrow 2H_2O + CO_2$$

coefficients

Balancing Chemical Equations



Balancing Chemical Equations: Examples

$2Fe + 3S \rightarrow Fe_2S_3$

$2MgO \rightarrow 2Mg + O_2$

$Fe_2O_3 + 3C \rightarrow 2Fe + 3CO$

Balancing Chemical Equations: Examples

Na_2CO_3 + $Ca(OH)_2$ → **2** NaOH + $CaCO_3$

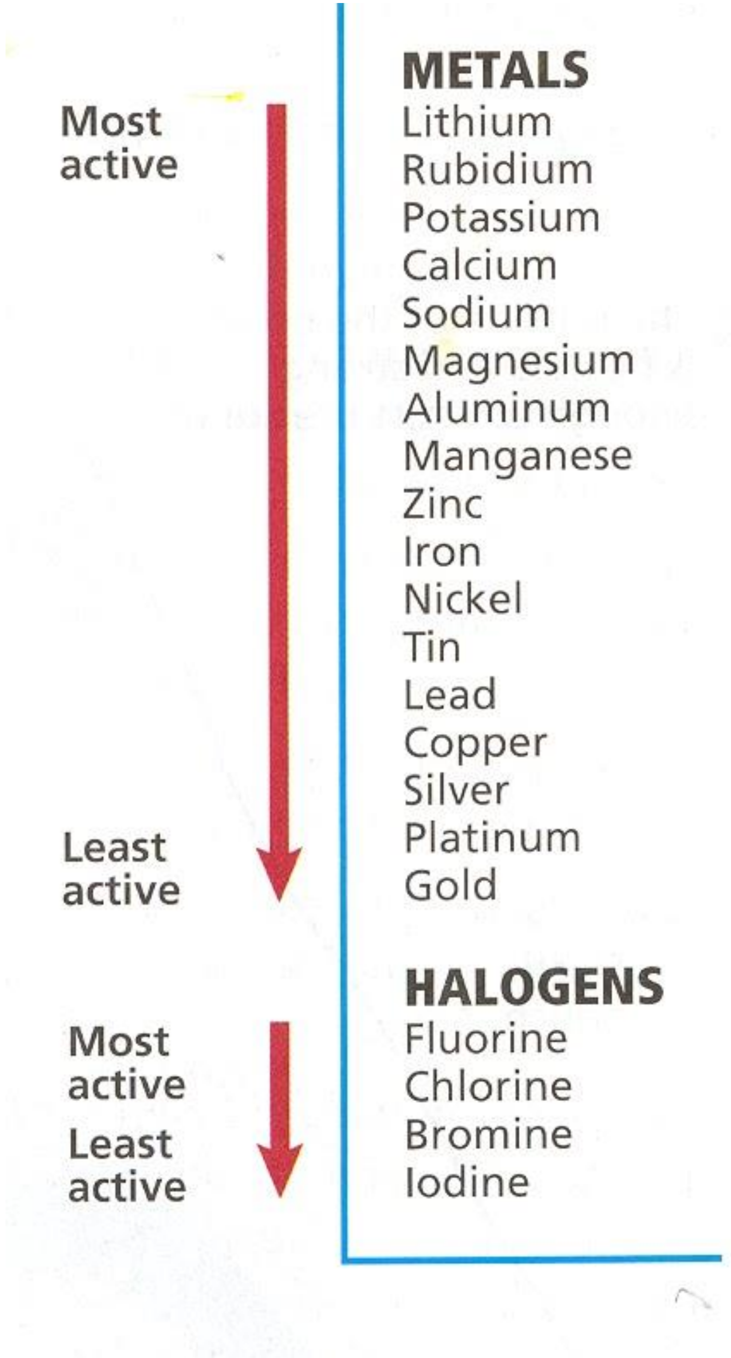
3 $BaBr_2$ + **2** Na_3PO_4 → $Ba_3(PO_4)_2$ + **6** NaBr

Types of Chemical Reactions: Combination and Decomposition

- **Combination** (synthesis): The combination of smaller atoms and/or molecules into larger molecules.
  - Two or more reactants combine to create one product.
- Example: $2H_2 + O_2 \rightarrow 2H_2O$
- **Decomposition**: Splitting a large molecule into elements or smaller compounds.
  - One reactant produces two or more products.
  - $NH_4NO_3 \rightarrow N_2O + 2H_2O$

Types of Chemical Reactions: Single Replacement

- **Single Replacement**: One element replaces another element in a compound.
  - Below, lithium replaces calcium.
- Example: $Ca(OH)_2 + 2Li \rightarrow 2LiOH + Ca$
- Such reactions will only occur if the single element is more reactive than what is would replace.



Types of Chemical Reactions: Double Replacement

- **Double Replacement**: The exchange of positive ions between two ionic compounds.
- $Na_2S + Cd(NO_3)_2 \rightarrow CdS + 2NaNO_3$

Combustion Reactions

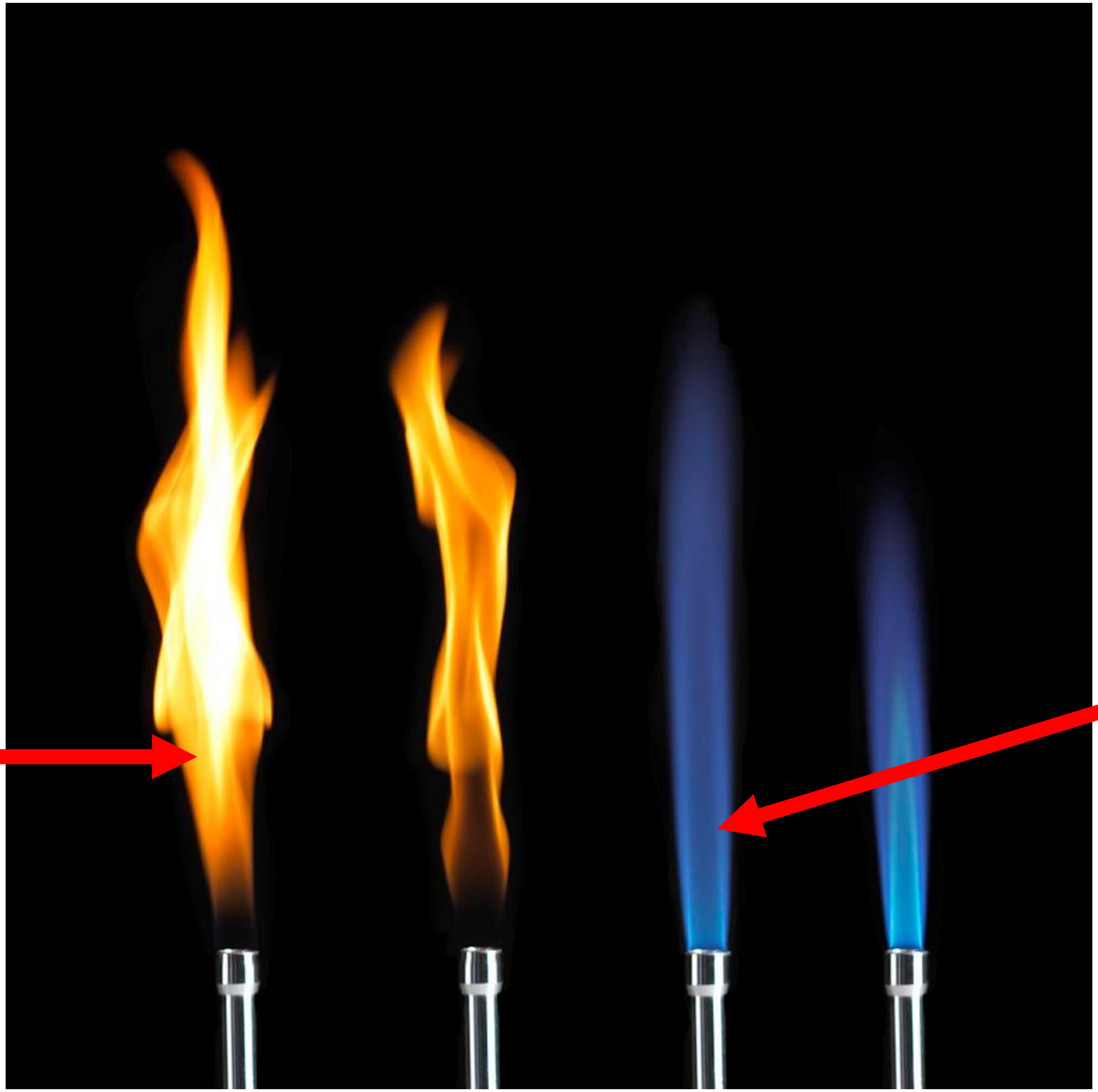
- The very rapid reaction of a substance with oxygen that produces oxides and heat.
  - Many substances do this, but we will focus on the combustion of ***hydrocarbons***.
- Hydrocarbons are compounds of carbon and hydrogen and sometimes oxygen. For example:
  - Butane: C_4H_{10}, Butanol: C_4H_9OH
  - Propane: C_3H_8, Propanol: C_3H_7OH
  - Methane: CH_4, Methanol: CH_3OH
  - Glucose: $C_6H_{12}O_6$, Sucrose: $C_{12}H_{22}O_{11}$

Combustion Reactions

- **Complete Combustion:**
  - hydrocarbon + oxygen → carbon dioxide + water
  - $CH_4 + O_2 \rightarrow CO_2 + H_2O$
- **Incomplete Combustion (low O_2 levels or cold) – 2 Types:**
  - hydrocarbon + oxygen → carbon monoxide + water
  - $CH_4 + O_2 \rightarrow CO + H_2O$
  - hydrocarbon + oxygen → carbon + water
  - $CH_4 + O_2 \rightarrow C + H_2O$

Incomplete vs Complete Combustion: Butane

Incomplete:
- Orange flame
- Releases CO or C.
- Releases less heat



Complete:
- Blue flame
- Releases CO_2
- Releases more heat

Balancing Combustion Reactions

- These can be tricky as there are a high number of atoms. One strategy is to balance the O_2 term last by using a fraction coefficient (if necessary), then multiplying to remove the fraction.

Complete Combustion of Propane:

$C_3H_8 + \mathbf{5}O_2 \rightarrow \mathbf{3}CO_2 + \mathbf{4}H_2O$

Balancing Combustion Equations

- Complete Combustion of Ethane:

$$\left\{ C_2H_6 + \frac{7}{2}O_2 \rightarrow 2CO_2 + 3H_2O \right\} \times 2$$

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

Balancing Combustion Reactions

- Incomplete combustions of methane: Same Strategy
  - Carbon atoms
  - Hydrogen atoms
  - Oxygen atoms

$$CH_4 + \frac{3}{2}O_2 \rightarrow CO + 2H_2O$$

Double Every Coefficient!

$$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$$

Stoichiometric Calculations

- In a balanced chemical equation, the coefficients are the minimum number of atoms/molecules necessary.
- Chemistry calculates in moles, so the coefficients are the number of moles of each reactant and product.
- This gives ***mole ratios*** between all chemicals in the reaction.
- Mole ratios are used to calculate the amount of any chemical knowing how much of another is used.

Mole Ratios

- Take the complete combustion of ethane, for example:

$$\mathbf{2}C_2H_6 + \mathbf{7}O_2 \rightarrow \mathbf{4}CO_2 + \mathbf{6}H_2O$$

- In the above, there exists six unique mole ratios between all the chemicals being used.
- When solving a problem, use the ratio involving the chemicals in the question. (examples on next slide)

Stoichiometric Calculations

$$\mathbf{2}C_2H_6 + \mathbf{7}O_2 \rightarrow \mathbf{4}CO_2 + \mathbf{6}H_2O$$

- Calculate the number of moles of water if 3.5 moles of ethane react with an excess of oxygen.
- Calculate the number of moles of oxygen required to react with 8.35 moles of ethane.

Stoichiometric Calculations: Mass of a Product

$$\mathbf{2}C_2H_6 + \mathbf{7}O_2 \rightarrow \mathbf{4}CO_2 + \mathbf{6}H_2O$$

- Calculate the mass of (a) carbon dioxide and (b) water produced by burning 785 g of ethane in excess oxygen.
- Calculate the mass of oxygen used up in the reaction.

- It is possible to measure other quantities, such as # of particles or volume, using mole ratios.

Calculating # Molecules & Volume

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

- Calculate the number water molecules when 321 g of ethane are completely combusted.
- Calculate the volume of carbon dioxide produced if 143 L of oxygen gas is burned when reacting with ethane at STP.

Limiting Reagent

- Limiting Reagent: Determines the amount of product that can be formed by a reaction.
- Excess Reagent: The reactant not completely used up in a reaction.
  - We will again use the ethane combustion as an example.

$$\mathbf{2}C_2H_6 + \mathbf{7}O_2 \rightarrow \mathbf{4}CO_2 + \mathbf{6}H_2O$$

Determining Limiting Reagents

$$\mathbf{2}C_2H_6 + \mathbf{7}O_2 \rightarrow \mathbf{4}CO_2 + \mathbf{6}H_2O$$

- Suppose you have **835 g** of ethane and **3250 g** of oxygen. Determine the limiting reagent.
  - Convert each mass into moles.
  - Determine how many moles of oxygen are required to react with the number of moles of ethane (stoichiometric calculation).
  - If # moles required is less than we have, then it is the excess reagent and ethane is the limiting reagent and vice-versa.