Lesson 01 and 02: Introduction to Chemical Reaction Equations

01 Chemical Reactions

A chemical reaction is a process by which one or more substances may be transformed into one or more new substances...

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}
\]

The hallmark of a chemical reaction is that...

- NEW material(s) are made, and
- OLD material(s) disappear
Chemical reactions, however, do not result in new elements have been made.

In order to make new elements…
- nuclear contents must changed (protons and neutrons)
- requires nuclear reactions

For this to happen enormous amounts of energy must be added, which are not present in chemical reactions.

The alchemists, in their efforts to change lead to gold, did not understand this…
02 Chemical Reaction Equations

A **chemical equation** is a way to describe what goes on in a chemical reaction, the actual change in a material.

Chemical equations are written with…

- **symbols** of materials to include elements, ionic or covalent compounds, aqueous solutions, ions, or particles
- **arrow** pointing to the right that indicates the direction of the reaction
- materials to the left of the arrow are the **reactants**, or materials that are going to react
- materials to the right of the arrow are the **products**, or materials that have been produced by the reaction

<table>
<thead>
<tr>
<th>Example</th>
<th>Chemical Word Equation</th>
<th>Chemical Reaction Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium hydroxide and hydrochloric acid react to form sodium chloride and water.</td>
<td>NaOH + HCl → NaCl + H₂O reactants → products</td>
<td></td>
</tr>
<tr>
<td>Methane and oxygen react to form carbon dioxide and water.</td>
<td>CH₄ + 2O₂ → CO₂ + 2H₂O reactants → products</td>
<td></td>
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</table>
03 Conservation Laws and Chemical Reaction Equations

Chemical reactions have several conservation laws that we must adhered to.

The law of…
- conservation of mass/matter, and
- conservation of energy

Before explaining the two conservation laws we first need to explain some terminology…
- systems
- surroundings

The system is the part of the universe we wish to focus our attention on. In the world of chemistry, the system is the chemical reaction. The system consists of those molecules which are reacting. The surroundings are everything else, or the rest of the universe.

In chemistry there are two types of systems you need to be aware of…
- open systems
- closed systems
## Open and Closed Systems

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The law of conservation of mass/matter states that...
- matter cannot be created nor destroyed, although it may be rearranged, and therefore
- in a closed system, the mass of the reactants must equal the mass of the products

The law of conservation of energy states that the
- total amount of energy in any closed system remains constant, cannot be created nor destroyed, but can change forms

Both of these laws are fundamental in the next lesson.
01 Why Balance Chemical Equations?

Chemical reaction equations do not come already balanced… you must balance them yourselves.

Why must chemical equations be balanced? The reason is due to a fundamental physical law, the law of conservation of mass/matter…

- matter cannot be created nor destroyed, although it may be rearranged
- in a closed system, the mass of the reactants must equal the mass of the products
02 Balancing Process

Balanced chemical equations have a couple of features…

- **reactants and products** both displayed
- **subscripts** indicating the number of atoms within a molecule (never change these numbers)

\[ 2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g}) \]

- **coefficients** indicating the ratio of molecules reacting with other molecules (these numbers are for balancing purposes)

\[ 2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g}) \]

- **phases** of all species indicated (solid, liquid, gas, aqueous)

The general procedure for balancing chemical reactions is as follows…

- balance metals
- balance non-metals
- balance oxygen
- balance hydrogen
- recount all atoms
Example 01

Balance the following…

\[
\text{Ca(OH)}_2 (aq) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2 (aq) + \text{H}_2\text{O}(l)
\]

Example 02

Balance the following…

\[
\text{C}_3\text{H}_8 (g) + \text{O}_2 (g) \rightarrow \text{CO}_2 (g) + \text{H}_2\text{O}(g)
\]

Example 03

Balance the following…

\[
\text{H}_2\text{SO}_4 + \text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + \text{H}_2\text{O}
\]
Example 04

Balance the following…

<table>
<thead>
<tr>
<th>CH₄ + Cl₂ → CCl₄ + HCl</th>
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03 Balancing and Fractions

An equation is not properly balanced if the coefficients are not written in their lowest whole-number ratio…

Example 05

Balance the following…

\[ \text{NaNO}_3(s) + \text{Na}(s) \rightarrow \text{Na}_2\text{O}(s) + \text{N}_2(g) \]

- note the presence of a fraction

\[ \text{NaNO}_3(s) + 5\text{Na}(s) \rightarrow 3\text{Na}_2\text{O}(s) + \frac{1}{2}\text{N}_2(g) \]

- convert to a whole number

\[ 2\left( \text{NaNO}_3(s) + 5\text{Na}(s) \rightarrow 3\text{Na}_2\text{O}(s) + \frac{1}{2}\text{N}_2(g) \right) \]

\[ 2\text{NaNO}_3(s) + 10\text{Na}(s) \rightarrow 6\text{Na}_2\text{O}(s) + \text{N}_2(g) \]
04 Writing Word Equations

Sometimes you will be given a word equation and be asked to write out a chemical reaction equation using symbols.

Always remember to balance all chemical reaction equations, including these.

Example 06

Aqueous hydrochloric acid reacts with calcium carbonate crystals, producing aqueous calcium chloride, gaseous carbon dioxide and liquid water. Write the balanced chemical reaction equation.

\[ \text{HCl(aq)} + \text{CaCO}_3(\text{s}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O(l)} \]
Lesson 05: Chemical Reaction Types

There are six basic types of chemical reactions…

- synthesis or combination
- decomposition
- dissociation
- single replacement reactions
- double replacement reactions
- combustion

When determining a balanced chemical reaction from only reactants, follow the steps below…

- FIRST: determine what type of reaction is present
- SECOND: determine the products that will be produced
- THIRD: determine the final balanced reaction
01 Synthesis or Combination Reactions

Synthesis reactions involve the reaction between a…
• compound containing one type of element, and another compound containing one type of element

\[ A + B_2 \rightarrow AB_2 \]
\[ A_2 + B_2 \rightarrow 2AB \]

Example 01: Synthesis

Determine the following (1) type of reaction, (3) products produced, and the (2) balanced reaction.

• \( \text{Zn}(s) + \text{S}_8(s) \rightarrow \)

02 Decomposition Reactions

Decomposition reactions result when a…
• compound is broken down into simpler compounds, usually through a process called electrolysis

\[ 2AB \rightarrow A_2 + B_2 \]

Decomposition is the opposite of synthesis.
03 Dissociation Reactions

Dissociation is commonly mistaken as decomposition, but there is a difference.

When the compound undergoes dissociation, it is…

- broken down into ions (rather than atoms) so there will be a charge or charges on the product side of the equation

\[ AB \rightarrow A^+ + B^- \]

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**Example 02: Decomposition**

Determine the following (1) type of reaction, (3) products produced, and the (2) balanced reaction.

- ICl(s) →
- NO₂(g) →
04 Single Replacement Reactions

Single replacement reactions involve the reaction between an...
- element, and a compound

In a single replacement reaction, there is a rule that is always followed...
- metals replace metals, or
- non-metals replaces non-metals

\[ A + BC \rightarrow AC + B \]

**Example 03 Single Replacement**

Determine the following (1) type of reaction, (3) products produced, and the (2) balanced reaction.

- \( Cl_2(g) + CaBr_2(s) \rightarrow \)
- \( Pb(s) + H_3PO_4(aq) \rightarrow \)
05 Double Replacement Reactions

Single replacement reactions involve the reaction between an…

- compound, and a
- compound

In a double replacement reaction, this rule is always followed…

- metals replace a metals, and
- non-metals replace a non-metals

\[ AB + CD \rightarrow AC + BD \]

**Example 04: Double Replacement**

Determine the following (1) type of reaction, (3) products produced, and the (2) balanced reaction.

- \( \text{NaBr(aq)} + \text{Ca(OH)}_2 \text{(aq)} \rightarrow \)
- \( \text{Li}_3\text{N(aq)} + \text{NH}_4\text{NO}_3\text{(aq)} \rightarrow \)
- \( \text{ZnSO}_4\text{(aq)} + \text{SrCl}_2\text{(aq)} \rightarrow \)
A special type of double replacement reaction is the neutralization reaction which involves…

- an acid (contains a H), and
- a base (contains an \( \text{OH}^- \))

\[
\text{HA} + \text{BOH} \rightarrow \text{AB} + \text{H}_2\text{O}
\]

This reaction always produces two compounds…

- a salt, and
- water

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**Example 05: Double Replacement / Neutralization**

Determine the following (1) type of reaction, (3) products produced, and the (2) balanced reaction.

- \( \text{HNO}_3(aq) + \text{Sr(OH)}_2(aq) \rightarrow \)
- \( \text{HBr}(g) + \text{Al(OH)}_3(aq) \rightarrow \)
06 Combustion Reactions

A combustion reaction is when a...
- carbon containing compound (organic substances) is combined with oxygen
- which then produces carbon dioxide and water

\[ C_xH_y + O_2 \rightarrow CO_2 + H_2O \]

Combustion is commonly called burning. It is an *exothermic* reaction, which means heat is produced.

Combustion occurs predominantly in...
- automobiles
- homes
- factories

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**Example 06 Combustion**

Determine the following (1) type of reaction, (3) products produced, and the (2) balanced reaction.

- \( C_5H_9O(g) + O_2(g) \rightarrow \)
Lesson 06: Enthalpy Changes in Chemical Reactions

01 Introduction

The basis for all chemical reactions is the breaking of old bonds and the formation of new bonds…

- breaking of bonds requires energy
- formation bonds releases energy

Sometimes we want to know how much energy is left after all old bonds are broken and all new bonds are formed. Do we have more energy or less energy after a chemical reaction takes place?
Two terms are important in the discussion of energy changes during chemical reactions…

- system
- surroundings

The system is the part of the universe we wish to focus our attention on. In chemistry, the system is the chemical reaction and the surroundings are everything else, or the rest of the universe.

There are two kinds of systems that are possible…

- open systems
- closed systems
### Open and Closed Systems

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Important Terms: Kinetic Energy and Potential Energy

Over the next several lessons two different terms are used to describe the energy changes that take place during chemical reactions…

- **kinetic energy** is the energy caused by movement.
- **potential energy** is the energy available due to the attractive and repulsive forces within and among molecules.

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04 Enthalpy

Heat

During chemical reactions, energy is exchanged with the surroundings. Energy in the form of heat is either…

- obtained from the surroundings causing the surroundings to get cooler: endothermic reactions
- given to the surroundings causing the surroundings to get warmer: exothermic reactions

Changes in Heat Content

The total energy of a chemical system is referred to as its heat content, or enthalpy (H). As a chemical reaction takes place, old bonds break and new bonds form, and as a result, enthalpy changes (ΔH). The change in enthalpy is calculated by taking the difference in the enthalpy of reactants and the enthalpy of products. Individual reactant and product enthalpies are never determined, only the change in enthalpy (ΔH) is.
Note Regarding Heat

Heat has a very different scientific meaning than its meaning in general usage…

- **general definition**: heat usually refers to what we feel - our perception of molecular kinetic energy only
- **scientific definition**: heat is the kinetic energy transferred from one body to another because of a difference in temperature
05 Exothermic and Endothermic Reactions and Enthalpy

Exothermic Reactions

An exothermic reaction transforms chemical potential (stored) energy into kinetic (not storable) energy.

Endothermic Reactions

An endothermic reaction is just the reverse of an exothermic reaction. An endothermic reaction transforms kinetic (not storable) energy into chemical potential (stored) energy.
Example: Extremely Exothermic Thermite Reaction

\[
\text{Fe}_2\text{O}_3 + 2\text{Al} \rightarrow 2\text{Fe} + \text{Al}_2\text{O}_3 + \text{heat}
\]
Example: Endothermic Barium Hydroxide and Ammonium Thiocyanate Reaction
We experimentally determine $\Delta H$ by performing the reaction in a calorimeter. A calorimeter is an apparatus designed to hold in and hold out heat energy.

Within the calorimeter, the reaction vessel is immersed in a pure liquid, usually water. The conditions are regulated so that all of the energy produced (exothermic) or consumed (endothermic) by the reaction is transferred to or reabsorbed from this surrounding liquid. The liquid's change in
temperature allows us to calculate the energy released or absorbed by the reaction.

An Everyday Calorimeter

What you probably call a **Thermos** is in fact so common a calorimeter that its manufacturer's name has become synonymous with the product.
The gain of heat energy or loss of heat energy by a chemical system can be expressed…

- within the chemical equation as a reactant or a product or
- separately from the equation

See the following two examples…

- exothermic reactions

\[ 2H_2(g) + O_2(g) \rightarrow 2H_2O(g) + 483.6kJ \]


2H₂(g) + O₂(g) → 2H₂O(g), ΔH = −483.6kJ

• endothermic reactions

2CO₂(g) + 566kJ → 2CO(g) + O₂(g)

or…

2CO₂(g) → 2CO(g) + O₂(g), ΔH = +566kJ