Chemical Equations

This section will review three main concepts:

1. what a chemical equation is and what it represents
2. how to balance a chemical equation, and why balancing is necessary
3. the five types of chemical reactions and their equations to the point where you will be writing and balancing equations like an expert

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Chemical equations - are a shorthand representation of the events that occur in a real chemical reaction.

For example:

Nitrogen gas reacts with hydrogen gas to form ammonia gas.

- using formulae we can write that

$N_{2\,(g)}$ + $H_{2(g)}$ ----------> $NH_{3\,(g)}$

reactants react to form products

However, the statement above is **not** an equation. It is merely a statement of reactants and products in a chemical reaction. If this statement is to be an equation it must reflect abeyance to all the laws of nature that real chemical reactions must obey. What are these laws? Well, there are three.

1. **Law of conservation of atoms** - atoms of reactants are rearranged into new and different compounds, but during that process, the atoms are neither created nor destroyed. If you compare the number of nitrogen atoms on the reactant side with the number on the product side, you see we seem to have destroyed one. Likewise, if you compare the number of hydrogen atoms on the reactant side to the number on the product side, we seem to have created one.
2. **Law of Conservation of mass** - Mass can neither be created nor destroyed is what this law contends, however, if we compare the total relative masses of the products with the total masses of the reactants, we seem to have destroyed 13 units of mass.
3. **Law of Conservation of Energy** - This states that energy can neither be created nor destroyed.

So the statement above does not show compliance or agreement with these natural laws and hence is not yet an equation. In order to turn this statement into an equation, it must be balanced, and this is the first important procedure that must be learned.

Balancing Chemical Equations

This is a two-step process. Your knowledge of chemical nomenclature is crucial to your success here. Given the name of a compound, you must be able to write the correct formula showing the physical state the compound would be in at room temperature, using the following symbols:

If the substance is a gas - use the subscripted symbol **(g)**
e.g. $O_{2(g)}$, $HCl_{(g)}$, $H_{2(g)}$ etc.

If the substance is in aqueous solution - use the subscript symbol **(aq)**
e.g. $NaOH_{(aq)}$, $KCl_{(aq)}$, $Al_2(SO_4)_{3(aq)}$ etc.

If the substance is a solid - use the subscript symbol **(s)**
e.g. $C_{(s)}$, $At_{2(s)}$, $KBr_{(s)}$, $Fe_{(s)}$ etc.

If the substance is a liquid - use the subscript symbol **(l)**
e.g. $H_2O_{(l)}$, $CCl_{4(l)}$, $CH_3OH_{(l)}$ etc.

Step 1 - Write the correct chemical formulas for reactants and products.

Example 1. Magnesium reacts with oxygen in the air to form magnesium oxide

You first write: ____$Mg_{(s)}$ + ____$O_{2(g)}$ -------> ____$MgO_{(s)}$

Note - In this first step do not worry about the fact that the oxygen atoms are not yet balanced. Look at each chemical formula separately, and make sure each formula is correct.

Step 2 - Now... Balance the atoms

You balance by using coefficients (numbers in front of formulas) to indicate the number of formula units or molecules of each reactant and product required.

NEVER try to balance equations by changing or introducing subscript numbers to the formulas of the reactants and products!

Generally, you start by balancing the atom of which there is a greater number. So first:
_____$Mg_{(s)}$ + ____$O_{2(g)}$ ---------> **2**$MgO_{(s)}$ (Oxygen atoms balance)

Then continue progressively to balance the rest of the atoms:

2$Mg_{(s)}$ + $O_{2(g)}$ -------> **2**$MgO_{(s)}$ (Magnesium atoms balance)

Example 2. Copper metal reacts with silver nitrate solution to form silver and aqueous Copper(II) nitrate.

Step one - Write the correct formulas for everything.
Step two - Do your best to balance the atoms using coefficients.

Solution: Step one - Write the correct formulas for everything.

$Cu_{(s)}$ +$AgNO_{3(aq)}$ ------> $Cu(NO_3)_{2(aq)}$ + $Ag_{(s)}$

Step two - Do your best to balance the atoms using **coefficients.**

$Cu_{(s)}$ + 2$AgNO_{3(aq)}$ ------> $Cu(NO_3)_{2(aq)}$ + 2$Ag_{(s)}$

Example 3. lead II nitrate + potassium iodide ----> lead II iodide + potassium nitrate

Step one - Write the correct formulas for everything.
Step two - Do your best to balance the atoms using coefficients

Solution: Step one - Write the correct formulas for everything

$Pb(NO_3)_{2(aq)}$ + $KI_{(aq)}$ ------> $PbI_{2(s)}$ + $KNO_{3(aq)}$

Step two - Do your best to balance the atoms using **coefficients.**

$Pb(NO_3)_{2(aq)}$ + 2$KI_{(aq)}$ ------> $PbI_{2(s)}$ + 2$KNO_{3(aq)}$

Practice

1. Natural gas (mostly methane) is burned in air to form carbon dioxide gas and water vapor.

2. _____$H_{2(g)}$ + _____$Cl_{2(g)}$ ----------> _____$HCl_{(g)}$

3. _____$N_{2(g)}$ + _____$H_{2(g)}$ ----------> _____$NH_{3(g)}$

4. Ammonia gas dissolves in water to form ammonium hydroxide.

5. _____$H_2O_{2(l)}$ ----------> _____$H_2O_{(l)}$ + $O_{2(g)}$

(Solutions: 1. Natural gas (mostly methane) is burned in air to form carbon dioxide gas and water vapor.

$CH_{4(g)}$ + $2O_{2(g)}$ ------> $CO_{2(g)}$ + $2H_2O_{(g)}$

2. **$H_{2(g)}$ + $Cl_{2(g)}$ ----------> $2HCl_{(g)}$**

3. **$N_{2(g)}$ + $3H_{2(g)}$ ----------> $2NH_{3(g)}$**

4. Ammonia gas dissolves in water to form ammonium hydroxide.

$NH_{3(g)}$ + $H_2O_{(l)}$ ------> $NH_4OH_{(aq)}$

5. **$2H_2O_{2(l)}$ ----------> $2H_2O_{(l)}$ + $O_{2(g)}$)**

Reaction Types

There are six types of chemical reaction that you will have to learn to recognize, write correctly and balance. They are as follows:

1. **Simple Composition -** Element + Element ------> Compound
2. **Simple Decomposition** - Compound ------> Element + Element
3. **Single Replacement** - Element + Compound ------> Element + Compound
4. **Double Replacement -** Compound + Compound ----> Compound + Compound
5. **Hydrocarbon Combustion -** Hydrocarbon + Oxygen ----> Carbon dioxide + water
6. **Other** - Anything that does not fit into one of the above categories.

Simple Composition and Simple Decomposition Reactions

The steps are as before:

1. **Write** the correct chemical formulas for the reactants and products.
2. Indicate the **physical state** that each substance is in.
3. Use the simplest whole number coefficients to **balance** the chemical equations.

Simple Composition

Element + Element ----------> Compound

$2Mg_{(s)} + O_{2(g)}$ ----------> $2MgO_{(s)}$

Simple Decomposition

Compound ----------> Element + Element

$8HgS_{(s)}$ ----------> $8Hg_{(l)} + S_{8(s)}$

Now try these examples:

1. $S_{8(s)} + O_{2(g)}$ ----------> $SO_{2(g)}$
2. $HgO_{(s)}$ ----------> $Hg_{(l)} + O_{2(g)}$
3. Lithium metal reacts with nitrogen gas from the air.
4. Molten sodium hydroxide is decomposed into its elements.

(Solutions:

1. **$S_{8(s)} + 8O_{2(g)}$ ----------> $8SO_{2(g)}$**
2. **$2HgO_{(s)}$ ----------> $2Hg_{(l)} + O_{2(g)}$**
3. Lithium metal reacts with nitrogen gas from the air.

   $6Li_{(s)} + N_{2(g)}$ ------> $2Li_3N_{(s)}$
4. Molten sodium hydroxide is decomposed into its elements.

   $2NaOH_{(l)}$ ------> $2Na_{(l)} + O_{2(g)} + H_{2(g)}$)

Single Replacement Reactions

element + compound ------> element + compound

$Cl_{2(g)} + 2NaI_{(aq)}$ ------> $I_{2(aq)} + 2NaCl_{(aq)}$

Double Replacement Reactions

compound + compound ------> compound + compound

$Pb(NO_3)_{2(aq)} + 2KI_{(aq)}$ ------> $PbI_{2(s)} + 2KNO_{3(aq)}$

Now try these examples:

1. Sodium metal reacts vigorously with water.
2. ____$NaCl_{(aq)}$ + ____$H_2SO_{4(aq)}$ ----> ____$HCl_{(aq)}$ + ____$Na_2SO_{4(aq)}$
3. ____ $Al_{(s)}$ + ____$Fe_2O_{3(s)}$-----> ____$Fe_{(l)}$ + ____$Al_2O_{3(s)}$

4. ____$K_{(s)}$ + ____$AlCl_{3(s)}$ ------> _____$Al_{(s)}$ + ____$KCl_{(s)}$
5. ____$H_2SO_{4(aq)}$ + ____ $Ca_3(PO_4)_{2(aq)}$ ------>
6. Hydrogen sulfide gas from a natural gas well reacts with the lead II chromate pigment in house paint.
7. ____$H_2S_{(g)}$ + ____$Ag_{(s)}$ ------>
8. ____ $Ca(OH)_{2(aq)}$ + ____$Mg(HCO_3)_{2(aq)}$ --> ____$Mg(OH)_{2(s)}$ + ___$Ca(HCO_3)_{2(aq)}$

(Solutions:

1. Sodium metal reacts vigorously with water.

$2Na_{(s)} + 2H_2O_{(l)}$ ------> $2NaOH_{(aq)} + H_{2(g)}$

2. **$2NaCl_{(aq)} + H_2SO_{4(aq)}$ ----> $2HCl_{(aq)} + Na_2SO_{4(aq)}$**

3. **$2Al_{(s)} + Fe_2O_{3(s)}$ -----> $2Fe_{(l)} + Al_2O_{3(s)}$**

4. **$3K_{(s)} + AlCl_{3(s)}$ ------> $Al_{(s)} + 3KCl_{(s)}$**

5. **$3H_2SO_{4(aq)} + Ca_3(PO_4)_{2(g)}$ ------> $3CaSO_{4(s)} + 2H_3PO_{4(aq)}$**

6. Hydrogen sulfide gas from a natural gas well reacts with the lead II chromate pigment in house paint.

$H_2S_{(g)} + PbCrO_{4(aq)}$ ------> $PbS_{(s)} + H_2CrO_{4(aq)}$

7. **$H_2S_{(g)} + 2Ag_{(s)}$ ------> $Ag_2S_{(s)} + H_{2(g)}$**

8. **$Ca(OH)_{2(aq)} + Mg(HCO_3)_{2(aq)}$ ------> $Mg(OH)_{2(s)} + Ca(HCO_3)_{2(aq)}$)**

Hydrocarbon Combustion and other Reactions

Hydrocarbon + oxygen ------> carbon dioxide + water

e.g. $CH_{4(g)} + 2O_{2(g)}$ ------> $CO_{2(g)} + 2H_2O_{(g)}$

This is one the the few reactions where we can actually tell you in which order to balance the equation. First, you balance the carbon, then the hydrogen, and then the oxygen .

Try these

1. $C_8H_{18(g)}$ + ____$O_{2(g)}$ --------> ?
2. Propane gas (C_3H_8) is burned in air to produce carbon and water vapor.
3. Paraffin ($C_{25}H_{52(s)}$) burns in the presence of oxygen.

OTHER

Describes any reaction that does not fit into any one of the categories above.

____$CaCO_{3(s)}$ + ____$HCl_{(aq)}$ ---> ___$CaCl_{2(aq)}$ + ____$H_2O_{(g)}$ + ____ $CO_{2(g)}$

(Solutions: 1. **$C_8H_{18(g)}$ + 25/2 $O_{2(g)}$ --------> 8$CO_{2(g)}$ + 9$H_2O_{(g)}$ or,**
2$C_8H_{18(g)}$ + 25 $O_{2(g)}$ --------> 16$CO_{2(g)}$ + 18$H_2O_{(g)}$

2. Propane gas (C_3H_8) is burned in air to produce carbon and water vapor.

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

3. Paraffin ($C_{25}H_{52(s)}$) burns in the presence of oxygen.

$C_{25}H_{52(s)}$ + 38 $O_{2(g)}$ ------> 25 $CO_{2(g)}$ + 26 $H_2O_{(g)}$

OTHER -Describes any reaction that does not fit into any one of the categories above.

$CaCO_{3(s)}$ + 2$HCl_{(aq)}$ ---> $CaCl_{2(aq)}$ + $H_2O_{(g)}$ + $CO_{2(g)}$)