CHEMICAL REACTIONS

CHEMICAL REACTIONS ARE SHOWN AS:

\[
\text{REACTANT} \quad \overset{\text{CONDITIONS}}{\longrightarrow} \quad \text{PRODUCTS} \quad \overset{\text{CATALYSTS}}{\longrightarrow}
\]

CHEMICAL EQUATIONS AND BALANCING THEM

Write the correct formulas for reactants and products in a chemical equation. After writing the correct formulas, \textbf{NEVER CHANGE ANY SUBSCRIPTS}. You can, however, change the coefficients to balance the equation.

Example:

\[\text{AlCl}_3 + \text{AgNO}_3\]

It is very easy that one thinks of products as \text{AlNO}_3 and \text{AgCl}_3 because there are that many ions in the reactants. However, both of the above formulas of the products are wrong. To form correct formulas, one should find the charge on each element or the polyatomic ion in the formulas of reactants:

\[
\begin{align*}
3 + 1- & \quad \quad \quad 1+ 1-\\
\text{AlCl}_3 & \quad + \quad \text{AgNO}_3
\end{align*}
\]

When the products form, \text{Al} (3+) , which is the cation, bonds with the \text{NO}_3 (1-) because it is an anion. (Positive and negative charges are attracted to one another). The \text{Ag} (1+) cation then bonds with the \text{Cl} (1-) anion. The number of each element in the product is then produced by exchanging valences (without the signs). So the final answer turns out to be \text{Al(NO}_3)_3 and \text{Ag Cl} (note that both products have a total charge of zero).

\[
\text{AlCl}_3 + \text{AgNO}_3 \rightarrow \text{Al(NO}_3)_3 + \text{AgCl}
\]

Now the discrepancy in the number of the reactants and the products is corrected by balancing the equation.
1. Begin by picking the most complex molecule. This would be the one that contains the most amount of elements in the compound. (It makes no difference if it is a reactant or a product). Place the number 1 in front of this molecule. In the above example, Al(NO$_3$)$_3$ is the most complex molecule.

2. After balancing each compound, underline it so that you realize it has already been balanced and you do not need to change the coefficient anymore.

Since we now have 1 Al(NO$_3$)$_3$, there is 1 Al, and 3 (NO$_3$). Think of each polyatomic ion as a whole unit rather than splitting up every element, into 3 nitrogen ions. Now balance the other side of the equation so that you end up with the same amount of elements on each side:

$$1 \text{ Al Cl}_3 + 3 \text{ Ag NO}_3 \rightarrow 1 \text{ Al (NO}_3)_3 + 3 \text{ Ag Cl}$$

Once this has been completed, you have to balance Ag Cl. This can be done by counting each element on both sides. For instance, in this example there are 3Ag and 3Cl on the left side. On the right side there is only one of each. Balance this by placing a 3 in front of the Ag Cl. (The ones can be dropped since it is assumed that they are there). The balanced version turns out to be:

$$\text{Al Cl}_3 + 3 \text{ Ag NO}_3 \rightarrow \text{Al (NO}_3)_3 + 3 \text{ Ag Cl}$$

5. If an element exists in more than two reactants or products, balance that species last.

Example:

$$\text{C}_4\text{H}_{10} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$$

The most complex bond is C$_4$H$_{10}$. Put 1 in front of it. Now there are 4 Carbon and 10 Hydrogen. Balance this by putting 4 in front of CO$_2$, and 5 in front of H$_2$O. (Remember that there are two H’s in water, 5 x 2 = 10). The oxygen has to be balanced last because it exists in 3 parts of the equation: in O$_2$, CO$_2$, and H$_2$O. Altogether there are 13 oxygen on the right side, and 2 on the left side. This is balanced by putting 13/2 (or 7.5) in front of the oxygen on the left side. (Oxygen is diatomic and comes in “packages” of 2. 13/2 x 2 = 13).

The final answer is:

$$\text{C}_4\text{H}_{10} + 13/2 \text{ O}_2 \rightarrow 4 \text{ CO}_2 + 5 \text{ H}_2\text{O}$$

The equation is balanced!

The whole equation could be multiplied by 2 to get rid of the fraction.

$$2 \text{ C}_4\text{H}_{10} + 13 \text{ O}_2 \rightarrow 8 \text{ CO}_2 + 10 \text{ H}_2\text{O}$$
Predicting the outcome

There are six general types of reactions considered here and each can be divided further:

1) COMBINATION, SYNTHESIS OR ADDITION:

When 2 or more reactants produce one product, the reaction is combination.

\[ A + B \rightarrow C \]

a) Any element may react with another to produce a binary compound (metals do not react with metals). If the reaction is between two nonmetals, the product is covalent. The possibility of products is vast but, in some case, the formula of the product can be deduced by exchanging the charge. After writing the correct formulas of reactants and products, the equation should be balanced.

\[ S + H_2 \rightarrow H_2S \]

Remember that hydrogen, oxygen, nitrogen and halogens are diatomic.

\[ N_2 + 3H_2 \rightarrow 2NH_3 \]

It is wrong to write:

\[ N + 3H \rightarrow NH_3. \]

On the other hand, if the reaction is between a metal and a nonmetal, the product will be ionic and the formula can be deduced by exchanging the charges, in most cases.

\[ 3Ba + 2P \rightarrow Ba_3P_2 \]

Generally, in the above reactions, heat should be applied for the reaction to start going.

b) Formation of metallic oxides:

This is a special case of the previous section where a metal reacts with oxygen.

\[ Zn + 1/2O_2 \rightarrow ZnO \]

c) Formation of nonmetallic oxide:

This is also a special case of section (a) where a nonmetal reacts with oxygen.

\[ Cl_2 + 7/2O_2 \rightarrow Cl_2O_7 \]

d) Formation of a base by reaction of a metallic oxide with water:
Bases are simply compounds which produce hydroxide ion (OH\(^{-}\)) in water. Metallic oxides react with water to produce bases:

\[
\text{ZnO} + \text{H}_2\text{O} \rightarrow \text{Zn(OH)}_2
\]
\[
\text{Al}_2\text{O}_3 + 3\text{H}_2\text{O} \rightarrow 2\text{Al(OH)}_3
\]

*Remember that the charge on hydroxide is -1 so you exchange the charge on hydroxide with the metal ion to make the formula of hydroxide.*

e) Formation of an acid from the reaction of a nonmetallic oxide with water:

An acid is a compound which produces hydrogen ions or protons (H\(^{+}\)) in water. A nonmetallic oxide generally produces an acid upon reacting with water. Sometimes, these equations are too complicated. Some simpler ones are:

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3
\]
\[
\text{Cl}_2\text{O}_7 + \text{H}_2\text{O} \rightarrow 2\text{HClO}_4
\]

2) DEGRADATION OR DECOMPOSITION:

This reaction is the reverse of combination reaction is the reverse of combination reactions when one reactant produces two or more products.

\[
\text{ZnO} \rightarrow \text{Zn} + 1/2 \text{O}_2
\]
\[
\text{CO}_2 \rightarrow \text{C} + \text{O}_2
\]
\[
\text{H}_2\text{CO}_3 \rightarrow \text{H}_2\text{O} + \text{CO}_2
\]

Certain salts, upon heating, release a gas and a solid salt behind.

\[
\text{KClO}_3 (s) \rightarrow \text{KCl} (s) + 3/2\text{O}_2 (g)
\]
\[
\text{NH}_4\text{Cl} (s) \rightarrow \text{NH}_3(g) + \text{HCl} (g)
\]
3. DOUBLE DISPLACEMENT REACTIONS:

IT IS AS IF A COUPLE EXCHANGES PARTNERS WITH ANOTHER COUPLE:

$$\text{NaCl(aq)} + \text{AgNO}_3(\text{aq}) \rightarrow \text{AgCl(g)} + \text{NaNO}_3(\text{aq})$$

DOUBLE DISPLACEMENT REACTION CAN BE DIVIDED INTO SEVERAL CATEGORIES:

A. PRECIPITATE FORMATION: ABOVE REACTION IN WHICH AgCl IS A PRECIPITATE:

$$\text{Na}_2\text{CO}_3 + 2\text{HCl} \rightarrow \text{H}_2\text{O} + \text{CO}_2(\text{g}) + \text{NaCl}$$

Formation of the acids H$_2$SO$_3$ and H$_2$CO$_3$ results in decomposition of those acids and production of SO$_2$ and CO$_2$ respectively.

B. GAS FORMATION:

$$\text{HI} + \text{KOH} \rightarrow \text{KI} + \text{H}_2\text{O}$$

C. ACID-BASE REACTIONS:

4. SINGLE DISPLACEMENT REACTION:

IT IS AS IF A SINGLE TAKES AWAY A PARTNER OF A COUPLE:

$$\text{Na} + \text{HOH} \rightarrow \text{NaOH} + 1/2\text{H}_2$$

$$\text{Ca} + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{H}_2(\text{g})$$

Single displacement equations can be divided into the following categories:

1. Reaction of metals with acids,

$$2\text{Al} + 3\text{H}_2\text{SO}_4 \rightarrow \text{Al}_2(\text{SO}_4)_3 + 3\text{H}_2(\text{g})$$

*Hydrogen gas should be written as H$_2$ (diatomic).*
2. Reactions of metals with water,

\[ \text{Na} + \text{HOH} \rightarrow \text{NaOH} + \frac{1}{2} \text{H}_2 \]

In these reactions, water is considered an acid and it is better to write H'OH' as H' is replaced by the metal.

3. Reactions of metals with salts,

\[ 3\text{Zn} + \text{Cu}_3(\text{PO}_4)_2 \rightarrow \text{Zn}_3(\text{PO}_4)_2 + 3\text{Cu} \]

How we decide which metal can replace another metal or hydrogen is determined by how much the metal has a tendency to turn into a cation. This is called the activity of metals and is shown in the table below for common metals.

<table>
<thead>
<tr>
<th>Greatest tendency to become ionic</th>
<th>Potassium</th>
<th>React violently with water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreasing tendency to become ionic</td>
<td>Sodium</td>
<td>Reacts slowly with water</td>
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<tr>
<td></td>
<td>Calcium</td>
<td>React very slowly with water</td>
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<td></td>
<td>Magnesium</td>
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<td></td>
<td>Lead</td>
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<tr>
<td></td>
<td>HYDROGEN</td>
<td>Do not react with hydrogen ions</td>
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<tr>
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<td>Copper</td>
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<td>Sliver</td>
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<td></td>
<td>Platinum</td>
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<tr>
<td></td>
<td>Gold</td>
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</tbody>
</table>

Least tendency to become ionic
Ionic and Net Ionic Equations:

To write ionic equations, one ionizes any dissociating compound such as NaCl (Na\(^+\) + Cl\(^-\)), HCl (H\(^+\) + Cl\(^-\)), etc. for the reactants and products.

To understand which compound dissociates and which one does not, consider the expression “the majority rules.”

If a compound exists as an ion (more than 50%), it is considered ionized, if less, it is written as an unionized molecule noting its state, aqueous, solid, liquid, or gas.

For example water, H\(_2\)O, could dissociate into H\(^+\) and OH\(^-\) ions so, it is possible to find these ions in a million unionized water molecule. Therefore water is never written in its unionized form H\(_2\)O(l).

Likewise, an insoluble salt such as silver chloride (AgCl) will dissociate into Ag\(^+\) and Cl\(^-\) ions in the order of about one in a million. It is written as AgCl(s) not its dissociated form.

In the net ionic equation all the ions which are the same from both sides of the ionic equation (spectator ions) are cancelled just like an algebraic equation. This results in an equation with no spectator ions present.

Generally the soluble salts, strong acids and strong bases are ionized. A salt such as (NH\(_4\))\(_2\)SO\(_4\) is ionized into 2NH\(_4\)^+ and SO\(_4\)^- ions, and K\(_3\)PO\(_4\) into 3K\(^+\) and PO\(_4\)^3-.

Note: it is a common mistake to write (NH\(_4\))\(_2\) or K\(_3\). Moreover, when there is a coefficient in front of a compound such as 2Ca(NO\(_3\))\(_2\), the 2 is multiplied by both ions as 2Ca\(^{2+}\) + 4NO\(_3\)^-.

There are four possibilities in the formation of ionic and net ionic equations:

a) No net ionic equation:

$$\text{NaCl(aq) + KBr(aq)} \rightarrow \text{NaBr(aq) + KCl(aq)}$$

$$\text{Na}^+ + \text{Cl}^- + \text{K}^+ + \text{Br}^- \rightarrow \text{Na}^+ + \text{Br}^- + \text{K}^+ + \text{Cl}^-$$

Observe, all the spectator ions are cancelled out. There is no net ionic equation. Actually we are mixing two solutions of NaCl and KBr. Nothing happens except for the process of mixing.

b) Neutralization Process

$$\text{H}_2\text{SO}_4 (aq) + 2\text{NaOH (aq)} \rightarrow \text{Na}_2\text{SO}_4(aq) + 2\text{H}_2\text{O (l)}$$

$$\text{H}^+ + \text{HSO}_4^- + 2\text{OH}^- \rightarrow 2\text{Na}^+ + \text{SO}_4^{2-} + 2\text{H}_2\text{O (l)}$$

Note that H\(_2\)SO\(_4\) dissociates into H\(^+\) and HSO\(_4\)^- ions not 2H\(^+\) and SO\(_4\)^2-.
Sulfuric acid is a strong acid only on the 1\(^{st}\) proton not the second.

$$\text{H}^+ + \text{HSO}_4^- + 2\text{OH}^- \rightarrow \text{SO}_4^{2-} + 2\text{H}_2\text{O (l)}$$
Whenever $\text{H}_2\text{CO}_3$ (carbonic acid) and $\text{H}_2\text{SO}_3$ (sulfurous acid) are formed in an equation, the acids are decomposed into water and a gas (respectively $\text{CO}_2$ and $\text{SO}_2$).

\[
\begin{align*}
\text{NaHCO}_3 \text{ (aq)} + \text{HBr} \text{ (aq)} & \rightarrow \text{H}_2\text{O} \text{ (l)} + \text{CO}_2 \text{ (g)} + \text{NaBr} \text{ (aq)} \\
\text{Na}^+ + \text{HCO}_3^- + \text{H}^+ + \text{Br}^- & \rightarrow \text{H}_2\text{O} \text{ (l)} + \text{CO}_2 \text{ (g)} + \text{Na}^+ + \text{Br}^- \\
\text{HCO}_3^- + \text{H}^+ & \rightarrow \text{H}_2\text{O} \text{ (l)} + \text{CO}_2 \text{ (g)}
\end{align*}
\]

d) Precipitate formation

\[
\begin{align*}
3\text{AgNO}_3 \text{ (aq)} + \text{H}_3\text{PO}_4 \text{ (aq)} & \rightarrow \text{Ag}_3\text{PO}_4(s) + 3\text{HNO}_3 \text{ (aq)} \\
3\text{Ag}^+ + 3\text{NO}_3^- + \text{H}_3\text{PO}_4 \text{ (aq)} & \rightarrow \text{Ag}_3\text{PO}_4(s) + 3\text{H}^+ + 3\text{NO}_3^- \\
3\text{Ag}^+ + \text{H}_3\text{PO}_4 \text{ (aq)} & \rightarrow \text{Ag}_3\text{PO}_4(s) + 3\text{H}^+
\end{align*}
\]

The last point is if one uses a reactant in its pure form such as solid sodium chloride or hydrogen chloride gas, they are not written in the dissociated form.

\[
\begin{align*}
\text{NaCl(s)} + \text{HBr} \text{ (aq)} & \rightarrow \text{NaBr(aq)} + \text{HCL} \text{ (aq)} \\
\text{NaCl(s)} + \text{H}^+ + \text{Br}^- & \rightarrow \text{Na}^+ \text{ Br}^- + \text{H}^+ + \text{Cl}^- \\
\text{NaCl(s)} & \rightarrow \text{Na}^+ + \text{Cl}^-
\end{align*}
\]

Stepwise acid dissociation and salt formation

e) Weak acid formation
\[
\text{NaF} + \text{HCl} \rightarrow \text{HF} + \text{NaCl}
\]

f) Complex ion formation
\[
\begin{align*}
\text{Al(OH)}_3 \text{ (s)} + \text{NaOH} & \rightarrow \text{Na}^+ \text{ Al(OH)}_4^- \\
\text{Al(OH)}_3 \text{ (s)} + \text{Na}^+ + \text{OH}^- & \rightarrow \text{Na}^+ + \text{Al(OH)}_4^-
\end{align*}
\]

\[
\begin{align*}
\text{H}_3\text{PO}_4 + \text{NaOH} & \rightarrow \text{Na}_2\text{HPO}_4 + \text{H}_2\text{O} \\
\text{Na}_2\text{HPO}_4 + \text{NaOH} & \rightarrow \text{Na}_3\text{PO}_4 + \text{H}_2\text{O} \\
\text{Na}_3\text{PO}_4 + \text{NaOH} & \rightarrow \text{Na}_3\text{PO}_4 + \text{H}_2\text{O} \\
\text{H}_3\text{PO}_4 + 3\text{NaOH} & \rightarrow \text{Na}_3\text{PO}_4 + 3\text{H}_2\text{O}
\end{align*}
\]

\[
\begin{align*}
\text{H}_4\text{SO}_4 + \text{NH}_3 & \rightarrow \text{NH}_4\text{HSO}_4 \quad \text{2} \\
\text{NH}_4\text{HSO}_4 + \text{NH}_3 & \rightarrow \text{NH}_4\text{H}_2\text{SO}_4
\end{align*}
\]