Metathesis (Double Replacement) Reactions

AX(*aq*) + BY (*aq*) → AY(*s, l, or g*) + BX(*aq*)

A metathesis reaction is one in which the cations and anions exchange partners in a solution because of the formation of a stable, new compound.

The Formation of an Insoluble Ionic Compound

AX(*aq*) + BY (*aq*) → AY(*s*) + BX(*aq*)

The AP Chem exam problems are designed so that you can deduce the ions that form the precipitate in the reaction from a simple solubility rule.

"All sodium, potassium, ammonium, and nitrate salts are soluble in water."

No sodium, potassium, ammonium, or nitrate ion will ever become a (*s*) in a metathesis reaction.

Describe the reaction for the formation of a precipitate that occurs when a barium nitrate solution is added to a potassium chromate solution.

Write the formulas of the reactants:

$$Ba(NO_3)_2(aq) + K_2CrO_4(aq)$$

Next switch the ions. This requires creating two new ionic compounds with the correct formulas to balance the charges so that the total charge of each ionic compound is zero.

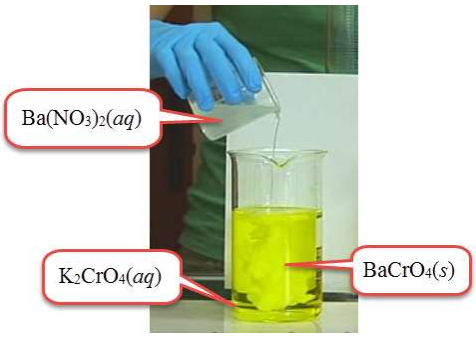
$$Ba(NO_3)_2(aq) + K_2CrO_4(aq) \rightarrow (Ba^{2+})(CrO_4^{2-}) + (K^+)(NO_3^-)$$

$$Ba(NO_3)_2(aq) + K_2CrO_4(aq) \rightarrow BaCrO_4 + KNO_3$$

Balance the reaction using coefficients:

$$Ba(NO_3)_2(aq) + K_2CrO_4(aq) \rightarrow BaCrO_4 + 2\ KNO_3$$

The final step is to determine which substance is the insoluble substance. This is usually done by elimination since the AP rules only tell you about the soluble substances. Any ionic compound with a sodium, potassium, ammonium, or nitrate ion is disqualified from forming a (*s*) and will stay behind in solution (*aq*). In this reaction the potassium nitrate will stay in solution as (*aq*)



$$Ba(NO_3)_2(aq) + K_2CrO_4(aq) \rightarrow BaCrO_4 + \mathbf{2\ KNO_3(aq)}$$

Therefore, the solid precipitate that results from mixing barium nitrate and potassium chromate solutions is barium chromate.

$$Ba(NO_3)_2(aq) + K_2CrO_4(aq) \rightarrow \mathbf{BaCrO_4(s)} + 2\ KNO_3(aq)$$

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The Formation of a Molecular Compound will also drive a metathesis reaction.

For AP Chemistry the most important molecular compound that is formed in metathesis reactions is water.

This specific type of metathesis reaction is called a neutralization reaction.
An **acid** will react with an **ionic hydroxide** salt, a base, to form water.

$$\mathbf{HX(}aq\mathbf{) + BOH (}aq\mathbf{) \rightarrow HOH + BX}$$

H^+OH^- is not an ionic compound. A covalent bond is formed, H-O-H, making the molecular compound H_2O, water.

$$\mathbf{HX(}aq\mathbf{) + BOH(}aq\mathbf{) \rightarrow H_2O(}l\mathbf{) + BX(}aq\mathbf{)}$$

Water doesn't ionize significantly. Rather than seeing a solid precipitate form as in an ionic metathesis reaction, the water that is formed in the reaction disappears into the solvent, the water. There is no visible change in a neutralization reaction unless an acid/base indicator is added to the solution.

What is the reaction when a hydrochloric acid solution is added to a potassium hydroxide solution?

First the formulas of the reactants:

$$HCl(aq) + KOH(aq)$$

Next perform the ion switch, metathesis, which requires creating new compounds with the correct ionic ratio to balance the charges.

$$HCl(aq) + KOH(aq) \rightarrow H_2O(l) + KCl(aq)$$

Weak acids have the same molecular reaction:

$$HC_2H_3O_2(aq) + KOH(aq) \rightarrow H_2O(l) + KC_2H_3O_2(aq)$$

Later in the year, there will be much more (two chapters worth) about the neutralization reaction.

You are expected to write and show metathesis reactions in three ways:

(1) As a "molecular" equation which you have already seen in the previous examples
(2) As an ionic equation (rarely used)
(3) As a net ionic equation (common AP Chemistry question)

(1) Molecular Equations **AX(*aq*) + BY (*aq*) → AY(*s, l, or g*) + BX(*aq*)**

The term molecular is misleading since the substances (except for water) are really ionic.
This type of equation shows the ions combined even though they are dissociated or ionized in solution.
The molecular reaction also doesn't hint at the electrical conductivity of the solution.
However, the stoichiometry is easy to see and everything in the reaction is listed.

e.g. $Ba(NO_3)_2(aq) + K_2CrO_4(aq) \rightarrow BaCrO_4(s) + 2\ KNO_3(aq)$

$HCl(aq) + KOH(aq) \rightarrow H_2O(l) + KCl(aq)$

(2) Ionic Equations **$A^+(aq) + X^-(aq) + B^+(aq) + Y^-(aq) \rightarrow AY(s, l, or\ g) + B^+(aq) + X^-(aq)$**

The complete ionic equation shows everything in the solution in its true ionic and molecular forms as reactants and products.
The ionic equation also shows the relative conductivity of reactants vs the products.
The smaller number of ion products results in lower electrical conductivity.
Complete ionic reactions are very long and it's hard to see the stoichiometry.

e.g. $Ba^{2+}(aq) + 2\ NO_3^-(aq) + 2\ K^+(aq) + CrO_4^{2-}(aq) \rightarrow BaCrO_4(s) + 2\ K^+(aq) + 2\ NO_3^-(aq)$

$H^+(aq) + Cl^-(aq) + K^+(aq) + OH^-(aq) \rightarrow H_2O(l) + K^+(aq) + Cl^-(aq)$

(3a) Net Ionic Equations of Ionic compounds **$A^+(aq) + Y^-(aq) \rightarrow AY(s, l, or\ g)$**

This is the simplest form of the metathesis reaction because only the substance that forms the precipitate, liquid, or gas is shown. It doesn't even look like a metathesis reaction since you can't tell which ions switched. This has the advantage of being simple and only shows what's changing. The net ionic reaction implies that the final reaction is not electrically conductive. This is incorrect as the spectator ions provide conductivity for the solution before and after the reaction.

e.g. $Ba^{2+}(aq) + CrO_4^{2-}(aq) \rightarrow BaCrO_4(s)$

Net ionic reactions using soluble ionic reactants are the most common type of equation question asked on AP Chemistry exams. Here is a fast method for writing net ionic reactions of ionic reactants.

Write the net ionic equation for the precipitate that forms when solutions of lead nitrate and potassium iodide are mixed.

Step 1: Cross out any soluble, spectator ions (*alkali metals, ammonium, and nitrates*)

lead ~~nitrate~~ and ~~potassium~~ iodide

Step 2: Figure out the cation – anion combination that is insoluble and write its formula as the insoluble product.

lead iodide
Pb^{2+} I^-
____ + ____ → PbI_2

Step 3: Fill in the ions that made that precipitate.

$Pb^{2+} + I^- \rightarrow PbI_2$

Step 4: Balance the reaction. (The ions must add up to a neutral charge.)

$Pb^{2+} + 2\ I^- \rightarrow PbI_2$

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(3b) Strong acids and Bases HStrong acid + SolubleOH

Since strong acids and soluble hydroxides 100% ionize, and the only product is water, the net ionic reaction will be:

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

In **strong acid strong soluble base** reactions all that happens is that water is made and spectator ions are irrelevant. All strong acid soluble base reactions net ionic equations will be the same.

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

(3c) Weak acids reacting with strong soluble bases: HWeak + SolubleOH

Weak acids do not significantly ionize.
Therefore**, weak acids must be shown as molecules** in the reactants side of a net ionic reaction and their anion (conjugate base) in the product side.

$$\mathbf{HA(}\boldsymbol{aq}\mathbf{) + OH^-(}\boldsymbol{aq}\mathbf{) \rightarrow H_2O(}\boldsymbol{l}\mathbf{) + A^-(}\boldsymbol{aq}\mathbf{)}$$

In weak acid strong soluble base reactions water is made, but the anion of the weak acid will come into play as it will prevent the final solution from being neutral and make the solution slightly basic.

Weak Acid + Base = Water + anion that reacts with water

Be on the lookout for weak acids in net ionic reactions since they are often used on the AP Chem exam.

Molecular Equation: $HC_2H_3O_2(aq) + KOH(aq) \rightarrow H_2O(l) + KC_2H_3O_2l(aq)$

Net Ionic Equation: $HC_2H_3O_2(aq) + OH^-(aq) \rightarrow H_2O(l) + C_2H_3O_2^-(aq)$

Weak molecular bases will be dealt later.

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