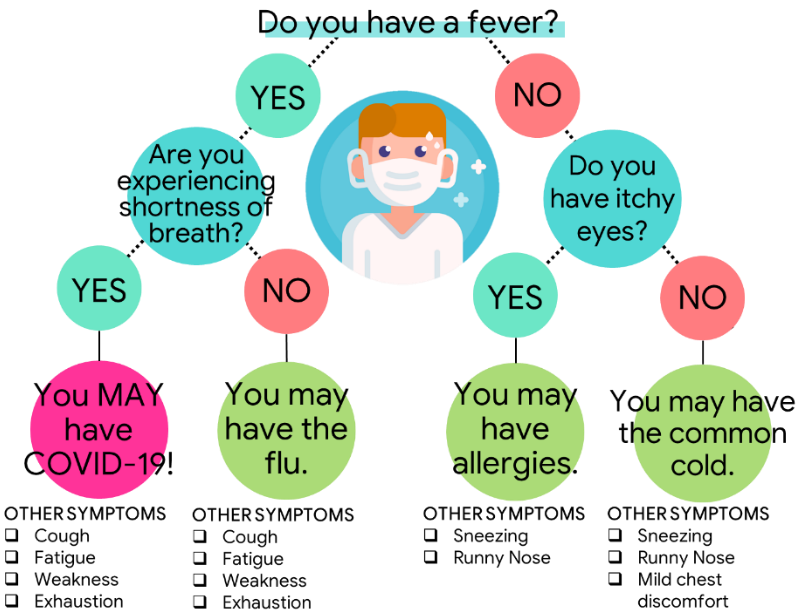
Learning Guide Module

Subject Code Chem 1 General Inorganic Chemistry
Module Code 2.0 Chemical Reactions and Stoichiometry
Lesson Code 2.2 Writing Chemical Equations and Types of Reactions
Time Limit 30 min

Components	Tasks	AT[a]	ATA[b]
Target	At the end of the chapter, the students must be able to: 1. Classify chemical reactions as combination, decomposition, single replacement or double replacement 2. Predict the products of reaction given the reactants	1 min	
Hook	**COVID-19 SYMPTOMS PROCESS MAP** People nowadays, take great delight in taking good care of their bodies by strengthening their immune systems, eating a balanced diet and doing some exercises. Some take extra caution in following health protocols at work and at home. With the threat of COVID-19 in these times, it is necessary for us to check our general physical conditions as a part of our self-love routines. Before we start with this chapter, try to answer this process map.  **Fig. 1.** COVID-19 Symptoms Process Map Take note that these are COMMON SYMPTOMS, which may vary from person to person. If you are experiencing fever, coughing, shortness of breath and exhaustion, call your physician for the proper course of actions. Behind every choice are questions. Ultimately, our results in any area of life reflect the questions we asked to get there. With the help of the process map, in a way, you were able to assess or predict your health status by answering the questions with a series of factors, in this case, your symptoms. In Chemistry, we can also predict the resulting products like the process map of COVID-19 above. In predicting the products of a chemical reaction we will consider a series of factors too. Let's learn more as we go through this module!	3 min	

Ignite

20 min

A *chemical equation* is consists of symbols and formulas representing a chemical reaction. For example, the following equation represents the reaction between zinc metal and aqueous hydrochloric acid.

$$\underbrace{Zn_{(s)} + 2HCl_{(aq)}}_{\text{reactants}} \rightarrow \underbrace{ZnCl_{2(s)} + H_{2\,(g)}}_{\text{products}}$$

In a chemical equation, the species held to react that are placed at the left side of the arrow are called *reactants*. The species produced as a result of the reaction are found at the right side of the arrow and are called *products*. The symbols used in a chemical equation are listed below (Mendoza and Religioso, 2001):

Table 1. Symbols in a Chemical Equation

Symbol	Use
+	Placed between the chemical symbols and/or formulas of reacting (reactants) and formed (products) species Left side – read as "combines with" or "reacts with" Right side – read as "and" or "plus"
→	Means "yields" or "produces"; this keeps the reactants and products apart in a chemical equation
↔ or = or $\rightleftarrows$	In place of a single-headed arrow, this is being used to indicate that the chemical reaction is reversible
(g) or ↑	Denotes that a reactant or product is in gaseous state
(s) or ↓	Denotes that a reactant or product is in solid state
(l)	Denotes that a reactant or product is in liquid state
(aq)	Denotes that the reactant or product is dissolved in water (aqueous solution)
$\xrightarrow{\Delta}$	Denotes the application of heat
$\xrightarrow{MnO_2}$	A substance seen written above the arrow denotes the presence of a catalyst. A catalyst speeds up the rate of a chemical reaction but is not consumed in the process.

To illustrate further how to indicate the physical states of the substances, consider the following examples:

When a solid carbon is burned with excess oxygen gas, carbon dioxide gas is produced.

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

An aqueous solution of sulfurous acid is formed when water in the liquid form combines with sulfur dioxide gas.

$$SO_{2(g)} + H_2O_{(l)} \rightarrow H_2SO_{3(aq)}$$

A *chemical equation* is the chemist's shorthand for describing the course of a chemical reaction. A *chemical reaction* is a process in which one set of chemical is mixed and transformed into a new set of chemicals. Here are some of the evidences that chemical reactions have taken place:

1. Change of odor (rotten eggs, food in fridge, decomposing flesh)
2. Change of color (formation of reddish-brown color on the surface of a metal when iron rusts, ripening of fruits, coral bleaching)
3. Production or loss of heat (combustion, explosion)
4. Change of composition (burned logs turned to ash)

5. Light and/or heat given off
6. Formation of gases, this is often indicated as bubbles escaping to the liquid surface (Alka-Seltzer tablet in water)
7. Formation of precipitate (insoluble particles)
8. When the reacting species cannot be brought back to its original state or composition after the reaction has taken place

TYPES OF CHEMICAL REACTIONS

I. Combination Reaction
The chemical union of two or more simpler substances to yield a more complex substance is called *combination* or *synthesis*.

The general equation for this reaction is:

$$A + B \rightarrow AB$$

CHEMISTORY:
Newt, in a teal peacock coat, met a girl who can pronounce *phenolphthalein* with extreme confidence and ease. With every syllable, his heart skipped a beat. She was Tina, a transfer student from Ilvermorny. Newt tried to initiate a close tie towards her and the two became friends immediately for they find Chemistry as a source of joy.

Fig. 2. Combination Reaction

Examples:

1. When iron filings are burned with yellow sulfur to form black iron (II) sulfide, a combination reaction occurs.
   $$Fe_{(s)} + S_{(s)} \rightarrow FeS_{(s)}$$
2. Nonmetal oxide + water → oxyacid
   $SO_{2(g)} + H_2O_{(l)} \rightarrow H_2SO_{3(aq)}$
3. Metal + oxygen → metal oxide
   $2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)}$
4. Metal oxide + water → metal hydroxide
   $CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(aq)}$
5. Nonmetal + oxygen → nonmetal oxide
   $2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)}$
6. Metal oxide + nonmetal oxide → salt
   $MgO + SO_3 \rightarrow 2MgO$

II. Decomposition Reaction
The reaction in which a compound is broken off into elements or into simpler compounds is called *decomposition* or *analysis* (Mendoza and Religioso, 2001). This is the opposite of the previously discussed combination reaction. Most of these reactions take place upon the application of heat.
The general equation for decomposition reaction is

$$AB \rightarrow A + B$$

CHEMISTORY:
During their second period, the two were caught up in a heated argument about a particular Chemistry concept. I don't know what happened after that, but Tina was seen eating alone at the cafeteria.

Fig. 3. Decomposition Reaction

Examples:

1. When an oxide is heated, generally, oxygen is given off as one of the products.

$$2HgO_{(s)} \xrightarrow{\Delta} 2Hg_{(l)} + O_{2(g)}$$

2. Some carbonates like limestone when heated decompose to yield carbon dioxide.

$$CaCO_{3(s)} \xrightarrow{\Delta} CaO_{(s)} + CO_{2(g)}$$

3. Some compounds, such as sodium hydrogen carbonate or sodium bicarbonate (baking soda), when heated break down to produce a carbonate salt, water, and carbon dioxide. Baking soda can be used to put out a flame because of the production of carbon dioxide.

$$2NaHCO_{3(s)} \xrightarrow{\Delta} Na_2CO_{3(s)} + H_2O_{(g)} + CO_{2(g)}$$

III. SINGLE REPLACEMENT REACTION
The reaction in which a free element replaces another element in a compound is called *single replacement* or *substitution* (Mendoza and Religioso, 2001).

General equation:

$$AB + X \rightarrow AX + B$$

CHEMISTORY:
Newt and Tina were like two peas in a pod during their first meeting. Heads back laughing like little kids over a Chemistry pun, thoroughly pronouncing every *th* and *ph* in *phenolphthalein*, and judging the electrons of copper for setting off to its follies. Life is good until that recent argument during their Chemistry class. Now, Tina is making new friends on her own, leaving every memory that concerns Newt behind. That's Theseus in green, by the way. He's a hugger.

Fig. 4. Single Replacement Reaction

To determine which element will be displaced or substituted, you need to know the *electromotive* or *activity series*. It shows the organization of elements that dictates what metal can be put out of place from a salt or an acid in an aqueous solution. The metal at the top replaces all the metal ions below it. The second metal replaces everything below it, but its ions will be replaced only by the metal above it.

Table 1. Activity Series

increasing reactivity

Metal	Nonmetal
Rb	F
Be	Cl
K	Br
Ca	I
Na	
Mg	
Al	
Mn	
Zn	
Cr	
Fe	
Ni	
Sn	
Pb	
H	
Cu	
Hg	
Ag	
Au	

Examples:

1. $Zn_{(s)} + NiSO_{4(aq)} \rightarrow ZnSO_{4(aq)} + Ni_{(s)}$
2. $2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$
3. $Mg_{(s)} + H_2SO_4 \rightarrow MgSO_{4\ (aq)} + H_{2(g)}$

As you can see in the activity series of elements, zinc is higher than nickel, and therefore it can displace nickel. Sodium can replace a hydrogen in water and magnesium can replace one hydrogen ion from sulfuric acid. Note that hydrogen is a diatomic molecule.

Another replacement reaction involves a nonmetal displacing a nonmetal ion from its salt or acid.

4. $F_{2(g)} + 2NaCl_{(aq)} \rightarrow 2NaF_{(aq)} + Cl_{2(aq)}$

IV. Double Replacement Reaction

Two compounds are involved in double-replacement reaction or ionic reactions. The positive ions of each compound are exchanged. The reaction may also be called *metathesis* or *double-displacement reaction*.

The general equation:

$$A + B \rightarrow C + D$$

CHEMISTORY:

You can still recall how Newt and Tina meet, right? Those were the days when everything is sunshine and blue skies. Then, Theseus came with Newt's childhood friend, Lita. Newt decided to make things even with Tina.

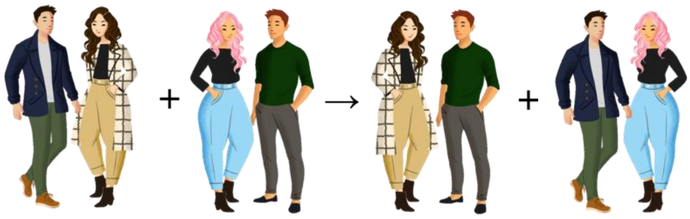


Fig. 5. Double-Replacement Method

Consider the following reactions:

1. A salt and a base
   $Ca(NO_3)_{2(aq)} + 2NaOH_{(aq)} \rightarrow 2NaNO_{3(aq)} + Ca(OH)_{2(aq)}$

2. Two salts
   $2KCl_{(aq)} + Pb(NO_3)_2 \rightarrow PbCl_{2(s)} + 2KNO_{3(aq)}$

3. A salt and an acid
   $Ba(NO_3)_{2(aq)} + H_2SO_{4(aq)} \rightarrow BaSO_{4(s)} + 2HNO_{3(aq)}$

4. Metal carbonate and an acid
   $MgCO_{3(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$
   Magnesium carbonate is one of the ingredients in antacids used in neutralizing the acid (HCl) in the stomach.

5. An acid and a base
   $2HCl_{(aq)} + Mg(OH)_{2(s)} \rightarrow MgCl_{2(aq)} + 2H_2O_{(l)}$
   Note that this reaction occurs in the stomach when milk of magnesia, $Mg(OH)_2$, is used as an antacid. This is known as a *neutralization reaction*.

PREDICTING PRODUCTS FROM CHEMICAL REACTIONS

Part of the astonishment of Chemistry is that things do not always end up the way you imagined them. If we consider the process map of COVID-19 that was presented to you earlier, many plan to do extra care not to have the virus, but sometimes, your ways of caution fail and that surprises you.

The same is true in chemical reactions. You work out a reaction, predict the possible formation of simple or complex substances and, quite often, the outcomes rendered you speechless! The exercise, then, is trying to understand what was produced, why or why not, and whether or not your observation takes you to other sweeping statements that are of use.

Before we do the process of identifying the products in chemical reactions, diatomic molecules must be presented first. When molecules are composed of two atoms of the same or any chemical elements, we call them as *diatomic molecules*. The prefix di- meaning "two" is from Greek origin thus, when we write the formula of diatomic we write subscript 2. The following are the diatomic molecules: Hydrogen (H_2), Nitrogen (N_2), Fluorine (F_2), Oxygen (O_2), Iodine (I_2), Chlorine (Cl_2), and Bromine (Br_2). *(Memory Aid: **H**ave **N**o **F**ear **O**f **I**ce **C**old **B**eer).*

We know that the product of a simple ***synthesis reaction*** will be a simple compound containing both elements that were once the reactants. What we have here as an example is an aluminum metal reacting with chlorine gas. Remember that the charges of each element can be based on their group numbers. Aluminum is found under group III and will bear a 3+ charge. Chlorine, under group VII, will gain one electron and form chlorine ion (Cl^-). With these on hand, we can easily predict that the product to be expected would be $AlCl_3$. In fact, if aluminum metal and chlorine gas are made to react, $AlCl_3$ in solid state is the main product.

$$2Al_{(s)} + 3Cl_{2(g)} \rightarrow 2AlCl_{3(s)}$$

Solved Problem:
Find the product that forms when potassium and chlorine react.

Solution:
You can tell this is a synthesis reaction because the question asks you to find "the" product; this means there is only one product.

1. Write the formula for each reactant. Both reactants are elements, so apply the diatomic molecule rule. Chlorine forms a diatomic molecule, but potassium does not:
$$\mathbf{K + Cl_2 \rightarrow ?}$$
2. Combine K and Cl to form a compound using ionic formula writing rules:
   - Write the ion form for each substance: K^+ and Cl^-. Ignore the fact that chlorine is in diatomic form because we are considering Cl now as ion.
   - Criss-cross charges. In this case both charges are "1": **KCl**
3. Rewrite the reaction with the new compound:
$$\mathbf{K + Cl_2 \rightarrow KCl}$$

Balance the reaction: **2K + Cl2 → 2KCl** (Balancing chemical equations will be later on discussed in the next module.)

Decomposition reactions are most likely the hardest to predict, but there are some patterns that we can use for convenience. In order for you to predict the product in decomposition reaction easier, consider the different classes of decomposition reaction below:

1. Decomposition of metallic carbonate into metallic oxides and carbon dioxide. Most metal carbonates will break down upon heating to yield metal oxide and carbon dioxide.

$$\mathbf{NiCO_{3(s)} \rightarrow NiO_{(s)} + CO_{2(g)}}$$

On the other hand, metal bicarbonates decompose upon the application of heat to produce metal carbonate, water and carbon dioxide.

$$\mathbf{2NaHCO_{3(s)} \rightarrow Na_2CO_{3(s)} + H_2O_{(g)} + CO_{2(g)}}$$

2. Decomposition of metallic hydroxide (except NaOH and KOH) into metallic oxides and water when heated.

$$\mathbf{Ba(OH)_2 \rightarrow BaO + H_2O}$$

3. Decomposition of metallic chlorate into metallic chlorides and oxygen gas when heated.

$$\mathbf{2KClO_3 \rightarrow 2\ KCl + 3O_2}$$

4. Decomposition of some acids into non-metallic oxides and water when heated.

$$\mathbf{H_2CO_3 \rightarrow H_2O + CO_2}$$

5. Decomposition of organic materials into carbon dioxide and water. This reaction is also known as *combustion* reaction.

$$\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O}$$

Decomposition of metallic oxides depends on the nature of the metal but many oxygen-containing compounds will break down, upon the application of heat, to bring forth oxygen gas and "other compounds". Take a look at these examples:

$$\mathbf{H_2O_{2(aq)} \rightarrow O_{2(g)} + H_2O_{(l)}}$$
$$\mathbf{2HgO_{(s)} \rightarrow O_{2(g)} + 2Hg_{(l)}}$$
$$\mathbf{2KClO_{3(s)} \rightarrow 3O_{2(g)} + 2KCl_{(s)}}$$

For a ***single-replacement reaction***, recall that metals can replace metals and nonmetals can replace nonmetals present in a compound. For the reaction between lead (IV) chloride and fluorine gas, fluorine will displace chlorine, forming a compound of lead and fluorine and the production of diatomic chlorine. See **Table 1** for the Activity Series. Recall that the elements at the top can replace all the elements below it.

$$\mathbf{PbCl_{4(s)} + 2F_{2(g)} \rightarrow PbF_{4(s)} + 2Cl_{2(g)}}$$

Solved Problem:
Write the reaction that occurs when chlorine gas and solid sodium bromide react.

Solution:
1. Translate reactants to formulas.
   - Apply the diatomic molecule rule to the element chlorine: $\mathbf{Cl_2}$.
   - Write the formula for sodium bromide.
     1. Write ions: Sodium = $\mathbf{Na^+}$ and bromide = $\mathbf{Br^-}$
     2. Criss-cross charges: Sodium bromide = **NaBr**
2. Start writing the reaction; include states of matter:
$$\mathbf{Cl_{2(g)} + NaBr_{(s)} \rightarrow ?}$$
3. Determine the products based on chlorine's charge as an ion.
   - Ignore the diatomic nature of chlorine and write it as an ion: $\mathbf{Cl^-}$.
   - Chlorine is negative so it will replace the negative part of **NaBr**.

When Cl replaces Br, Br will be on its own: Br_2. Cl^- combines with Na^+. Write the positive ion first and criss-cross charges to get the compound: **NaCl**.

4. Write the complete reaction:

$$\mathbf{Cl_{2(g)} + NaBr_{(s)} \rightarrow NaCl_{(s)} + Br_{2(g)}}$$

Balance the reaction: $\mathbf{Cl_{2(g)} + 2NaBr_{(s)} \rightarrow 2NaCl_{(s)} + Br_{2(g)}}$

The prediction of probable products in ***double-replacement reactions*** is pretty straightforward for the cations and anions are simply interchanged. Keep in mind, one of the products must form an insoluble substance (precipitate), or else a chemical reaction did not take place. For the reaction between lead (II) nitrate and potassium iodide, it is predicted that the products would be lead (II) iodide and potassium nitrate.

$$\mathbf{Pb(NO_3)_{2(aq)} + 2KI_{(aq)} \rightarrow PbI_{2(s)} + 2KNO_{3(aq)}}$$

Solved Problem:

Write the equation for the reaction of lead (II) nitrate with potassium sulfide.

Solution:

1. Write the ions and criss-cross charges to determine reactant formulas:
   - Ions in lead(II) nitrate: $\mathbf{Pb^{2+}}$ and $\mathbf{NO_3^-}$
     - -Formula after criss-cross: $\mathbf{Pb(NO_3)_2}$
   - Ions in potassium sulfide: $\mathbf{K^+}$ and $\mathbf{S^{2-}}$
     - -Formula after criss-cross: $\mathbf{K_2S}$
2. Start writing the reaction:

$$\mathbf{Pb(NO_3)_2 + K_2S \rightarrow ? + ?}$$

3. Write new formulas for each cation; pair it with a new anion.
   - For lead (II):
     1. Write ions that will combine: $\mathbf{Pb^{2+}}$ and $\mathbf{S^{2-}}$
     2. Criss-cross charges; in this case both charges cancel: **PbS**
   - For potassium:
     1. Write ions that will combine: $\mathbf{K^+}$ and $\mathbf{NO_3^-}$
     2. Criss-cross charges: $\mathbf{KNO_3}$
4. Write the reaction: $\mathbf{Pb(NO_3)_2 + K_2S \rightarrow PbS + KNO_3}$

Balance the reaction: $\mathbf{Pb(NO_3)_2 + K_2S \rightarrow PbS + 2KNO_3}$

Navigate

CHEM-MUST-TRY!

I. Classify the following reactions as combination (C), decomposition (D), single replacement (SR), or double replacement (DR) reactions. Write the abbreviations only.

Reaction	Classification
1. $Mg_{(s)} + N_2 \rightarrow Mg_3N_{2(s)}$	
2. $CuCO_{3(s)} \rightarrow CuO_{(s)} + CO_{2(g)}$	
3. $Zn_{(s)} + H_2SO_{4(aq)} \rightarrow ZnSO_{4(s)} + H_{2(g)}$	
4. $Mg_3N_{2(s)} + H_2O_{(l)} \rightarrow NH_{3(g)} + Mg(OH)_{2(aq)}$	
5. $3MnO_{2(s)} + 4Al_{(s)} \rightarrow 2Al_2O_{3(s)} + 3Mn_{(s)}$	
6. $AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} + NaNO_3$	
7. $HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$	
8. $2HNO_{3(aq)} + Ca(OH)_{2(aq)} \rightarrow Ca(NO_3)_{(aq)} + H_2O_{(l)}$	
9. $CuSO_4 \cdot 5H_2O \xrightarrow{\Delta} CuSO_{4(s)} + 5H_2O_{(g)}$	
10. $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	

5 min

II. Predict the products of the following chemical reactions. Classify each using the abbreviations in Test I. Balanced chemical equations are not required.

1. $Mg + Br_2 \rightarrow$
   Type of reaction:
   Chemical equation:

2. $Al + O_2 \rightarrow$
   Type of reaction:
   Chemical equation:

3. $AgCl \rightarrow$
   Type of reaction:
   Chemical equation:

4. $K + H_2O \rightarrow$
   Type of reaction:
   Chemical equation:

5. $MnCl_2 + (NH_4)_2CO_3 \rightarrow$
   Type of reaction:
   Chemical equation:

Additional Assessment:

Directions: Examine the unfinished chemical equations carefully. Predict the products and determine the type of chemical reaction in the following items. ***(Note:** You don't have to balance the chemical equations for this will be discussed on the next learning guide module.)*

1. $Mg + I_2 \rightarrow$

2. $NaOH + HClO_4 \rightarrow$

3. $HCl + Zn \rightarrow$

4. $NaCl + AgNO_3 \rightarrow$

5. $Na + MgCl_2 \rightarrow$

6. $CaCl_2 + K_2CO_3 \rightarrow$

7. $K + Cl_2 \rightarrow$

	8. $HgO \rightarrow$ 9. $Li + N_2 \rightarrow$ 10. $BaCl_2 + K_3PO_4 \rightarrow$		
Knot	• A chemical equation is consists of symbols, formulas, and other abbreviations representing a chemical reaction, including the chemical species involved as reactants and products, their respective physical states, and the number of moles of each compound in the reaction. The reaction is said to be balanced when proper coefficients are placed before the compounds making the total number of every element equal on both sides of the equation. *(This will be discussed in the next module.)* • Memory aid for diatomic molecules: **H**ave (Hydrogen) **N**o (Nitrogen) **F**ear (Fluorine) **O**f (Oxygen) **I**ce (Iodine) **C**o**l**d (Chlorine) **Be**e**r** (Bromine) • There are four different types of reactions that can be represented by equations. They are illustrated below with letters representing elements, compounds, or ions. Combination reaction: $A + B \rightarrow AB$ Decomposition reaction: $AB \rightarrow A + B$ Single Replacement Reaction $AB + C \rightarrow AC + B$ The activity series can show the ability of metals to substitute other metal ions in a chemical reaction. Hydrogen, even though not a metal, is generally counted in the series. Double Replacement Reaction $AB + CD \rightarrow AC + BD$	1 min	

[a] suggested time allocation set by the teacher
[b] actual time spent by the student (for information purposes only)

References:

Albarico, J. (PSHS-CBRZ). (n.d.). THINK Framework. Based on Science Links by E.G. Ramos and N. Apolinario, Quezon City. Rex Bookstore.

Bayquen, A. (2012). *Chemistry, Exploring Life Through Science*. (G. Bernas PhD, Coordinator.) 2nd Edition. Quezon City, Philippines: Phoenix Publishing House.

Chemical Reactions [PowerPoint Presentation]. (n.d.). Retrieved July 10, 2020 from Essential Chemistry, PASCO Education.

Mendoza, E., Religioso T. (2001). *You and the Natural World Series, Third Year Chemistry Textbook*. (M. Deauna, Coordinator.) 2nd Edition. Quezon City, Philippines: Phoenix Publishing House.

Silberberg M. (2015). *Chemistry: The Molecular Nature of Matter and Change*. 7th Edition. New York, USA: McGraw-Hill Education.

Teacher Yael (n.d.). *Cream and Brown Illustration Social Science Class Education Presentation* [PowerPoint Presentation]. Retrieved July 11, 2020 from Canva.

Types of Reactions [Word Document]. (n.d.). Retrieved July 10, 2020 from Essential Chemistry, PASCO Education.

Young, Paul (2019). *Predicting Products from Chemical Reactions*. Retrieved July 12, 2020 from Chemistry LibreTexts.

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